A PERFORMANCE-BASED TECHNOLOGY ASSESSMENT METHODOLOGY TO SUPPORT DOD ACQUISITION

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Many weapon system failures are attributed to premature transfer of technology to operational systems. Insufficient measures of assessing technology readiness are major contributors to such failures. This paper presents a methodology to measure the performance risk of technology in order to determine its transition readiness. This methodology is referred to as Technology Performance Risk Index (TPRI). The TPRI can track technology readiness through a life cycle, or it can be used at a specific time to support a particular system milestone decision. The TPRI is computed using the performance requirements, the Degree of Difficulty (DD), and the unmet performance. These components are combined in a closed-loop feedback manner to analytically calculate the performance risk. TPRI is illustrated by an example using published system requirements data.

Since World War II, the United States Armed Forces have maintained a technological advantage over adversaries. Today, the military is facing continued threats that require an accelerated pace of technology development amid global proliferation of military technologies (Lukens, 2003). The Department of Defense

(DoD) has estimated a need for $50 billion dollars for missile defense research and development over years 2004–2009 (General Accounting Office [GAO], 2003); however, this requirement must be balanced with other funded programs. The demands to support additional operational tempos, higher maintenance costs for aging weapon systems, and higher system acquisition costs, limit the available funding for new technology development. These increasing demands compete for the same money used for research and development of technology, and often the technology budget is further reduced. Additionally, the impact of company buyouts has reduced the military industrial research base in the United States from 21 companies in 1993 to 5 companies in 2002 (Linster, Slate, & Waller, 2002). Consequently, this has resulted in substantial reduction in Independent Research and Development (IR&D) activities. In today's DoD environment, it is important that investments in technology are successfully transitioned to operational military systems.

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Changing to a capability-based acquisition strategy is another indicator of the significance of technology. Mr. Pete Aldridge identified in a memo (Aldridge, 2002) to the Secretary of Defense his intent to accelerate the flow of technology to the warfighter. Later, Mr. Aldridge (2003) announced his goal to initiate high-leverage technologies to create the warfighting capabilities and strategies of the future. Therefore, it is imperative that the technology meets maturity and performance requirements, prior to being transitioned to the acquisition system. Furthermore, a capability-based acquisition strategy will allow acquisition programs to pull advanced technology into systems faster, thus fielding systems with advanced technologies to the warfighter faster. The capability-based acquisition cycle also means that requirements will evolve faster, which mandates close monitoring of systems' requirements and the technologies we use to meet these requirements.

THE PROBLEM

Development of new defense technologies within the DoD is a multi-dimensional problem. First, DoD must resolve issues that result from immature technologies transition. The General Accounting Office (GAO) has stated that immature technology transition is the leading cause of weapon system problems (GAO, 1999). An important factor in the success of a new weapon system is ensuring that technologies are mature prior to being integrated (GAO, 1999). Second, the creation of parallel paths for the development of technology and the development of an acquisition weapon system has diluted the link between technology and system performance requirements. The technologist has responsibility for managing the development of the technology, while the weapon system acquisitionist has responsibility for the development of the weapon system. Unfortunately, the technologist has different goals, environments, and perspectives than the system acquisitionist (McGrath, 2003). The original reasoning behind this deliberate separation is that it allows the acquisitionist to focus on meeting requirements for the system development, while providing the technologist an environment to explore capabilities of the technology. An unforeseen result of this separation is that two conflicting drives of motivation are generated.

The technologist is motivated to transition technologies into weapon systems. Thus, technologists are optimistic on the maturity assessment of their technology. The acquisitionist is motivated to meet system requirements, and often uses a risk adverse approach for the design process. Consequently, the acquisitionist is more likely to underestimate the maturity of new technologies. This forces the technologist to focus on risk mitigation. These conflicting motivations justify the need for an objective methodology to assess a technologies fit with system performance requirements. As a technology's maturity increases, the criticality for decision support tools to determine transition readiness is also increased. Hence, a common understanding, between the technologist and the acquisitionist, is needed.

PROPOSED METHODOLOGY

One approach to develop a common understanding of technology readiness is to utilize a modified version of Garvey's system performance risk index (Garvey & Cho, 2003). The threshold value of a Technical Performance Measure (TPM) divides performance into acceptable and unacceptable risk regions. In this manner, it is the goal of a system developer to reach the acceptable performance risk region. To get into the acceptable performance risk region, the technology must meet or exceed the identified TPM threshold. Garvey provided guidelines for calculating the achieved performance.

The proposed methodology to assess technology readiness proposed in this paper is referred to as the Technology Performance Risk Index (TPRI). The index is based on the system's performance requirements and the ability of the technology to achieve that performance. The achieved performance is normalized so multiple requirements can be assessed simultaneously. A condensed solution for the two cases of the required performance behaviors is then calculated. In the first case, perfomance must decrease to meet the established TPM threshold. The achieved performance is computed as the inverse of the percentage of the TPM threshold that the measured performance represents. The achieved performance, A_{ij}, at time i, for TPM j is calculated by:

$$A_{ij} = \min\left\{\frac{threshold}{m_{ij}},1\right\} \qquad \text{Equation 1}$$

where m_{ij} is the measured performance. Examples of this type of required performance behavior are weight constraints or mean time to repair TPMs. In the second case, performance must increase to meet the threshold and A_{ij}, at time i, for the jth TPM is computed using:

$$A_{ij} = \min\left\{\frac{m_{ij}}{threshold},1\right\} \qquad \text{Equation 2}$$

Again, m_{ij} is the measured performance. In the increasing performance behavior, the achieved performance is equivalent to the percentage that the measured performance represents of the TPM threshold. Two examples of increase perfomance behavior TPMs would include number of units available or mean-time-between-failures.

Garvey defines the system performance risk index as the amount of the remaining unmet performance relative to meeting a set of identified TPMs. Emphasis is placed on the unmet performance as issues for management to focus and resolve with priorities and allocation of resources. Although Garvey's method provides a quantitative measure of meeting a set of established requirements, it inherently lacks the inclusion of a true risk measure. More specifically, in Garvey's approach, unmet performance does not indicate what it will take to reach the acceptable risk region. It merely provides a measure of progress achieved at a certain time.

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This article presents a research effort to address the linkage between technologies, system performance requirements and risks in the DoD environment. This methodology is used to measure risk associated with satisfying an identified set of TPMs for a given system. The TPRI provides information regarding performance risk associated with a technology to support the decisions of whether or not a certain technology is ready to be transitioned to an acquisition system. The TPRI offers a measure of the actual performance risk of a technology by providing an assessment of a given technologies ability to achieve performance requirements.

Thus, a common understanding of performance risks between technologist and acquisitionist is accomplished. The impact of the TPRI can be described using the following analogy: a thermostat measures actual outside temperature, yet to a human, the wind chill factor is of more concern. In this same manner, the TPRI is like the wind chill factor, as it affords valuable information that allows insight into the technology that would not be obtained from individual metrics.

Performance-based requirements criteria are typically established by an acquisitionist. Typically, these criteria and the basis for measurement are identified in an agreement with the technologist. This serves as a basis consisting of the individual requirements and associated threshold values against which technologies will be evaluated. This information is utilized to compare against the measured level of performance achieved.

The TPRI extends Garvey's methodology to include a measure of performance risk so that acquisitionists can have access to information that will assist in setting priorities and allocating resources (Garvey & Cho, 2003). For this purpose, the Degree of Difficulty (DD) is the metric utilized by TPRI. The DD metric (Mankins, 1998 & 2002) provides a measure of anticipated risk, ranging from low level risk to high level risk, and can be considered as a probability of failure in regards to the technology achieving the objectives.

In TPRI, the DD metric is modified to assign a numerical value to each of Mankins' defined levels. This provides a quantitative means to combine risks across various requirements. In this context, the DD metric is bounded by zero and one. Table 1 provides a summary of each of the DD levels with anticipated risk, and the numerical value, as well as the theoretical boundary levels. The lower boundary with a DD of zero indicates there is no risk involved in meeting the objectives and is guaranteed success. The DD at level 1 has a very low risk and is assigned a 0.1 value; a DD at level 2 has an anticipated moderate risk and has an assigned value of 0.3, while the DD at level 3 has a high risk, with

TABLE 1. DEGREE OF DIFFICULTY (DD) LEVELS WITH RISKS AND ASSIGNED NUMERICAL VALUES

Degree of Difficulty	Risk Level	DD Value
Level 0 (Theoretical Lower Bound)	No Risk; Guaranteed Success	0.0
Level 1	Very Low Risk	0.1
Level 2	Moderate	0.3
Level 3	High	0.5
Level 4	Very High	0.7
Level 5	Extremely High Risk, Requiring a Fundamental Breakthrough	0.9
Level 6 (Theoretical Upper Bound)	Guaranteed Failure	1.0

a 0.5 value. A technology with very high risk is identified as DD level 4 and has a 0.7 value. In the case that a technology has a high expectation of failure, requiring a fundamental breakthrough, is assigned a DD level 5 with a 0.9 numerical value. In addition, the theoretical upper bound of the DD metric indicates the highest level of risk with no anticipated success (guaranteed failure), and is assigned a value of 1.

A major attribute of TPRI is that it accounts for unmet performance and associated risk to quantify effects upon the achieved performance. Risk is defined as a measure of the probability and the severity of adverse effects (Haimes, 1998). The TPRI is applicable to the technical risk form; referred to as performance risk. The TPMs provide a gauge of technical progress measured against satisfying an identified set of thresholds pertaining to performance requirements. The TPRI correlates the performance risk associated with a technology not meeting the threshold value of a TPM.

TPRI METHODOLOGY

To formulate the TPRI model, the unmet performance and DD are combined to adjust the achieved performance. The TPRI is expressed mathematically as:

$$TPRI = 1 - \frac{A}{1+(1-A)*DD} \qquad \text{Equation 3}$$

The unmet performance, $1-A$, is a measure of the severity component of risk, while DD signifies the probability component of risk. These two components are combined to formulate a measure of performance risk of the unmet performance-based on a closed loop feedback mechanism. This index provides a measure of performance risks to meet the TPM threshold in an effort to reach the acceptable performance risk region goal.

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The behavior of the TRPI model is depicted in Figure 1. The TPRI is plotted versus the performance achieved using DD as a parameter. The TPRI has a value of zero when all the performance measures have been achieved. The DD values that are between the theoretical bounds of zero and one indicate the perceived level of difficulty

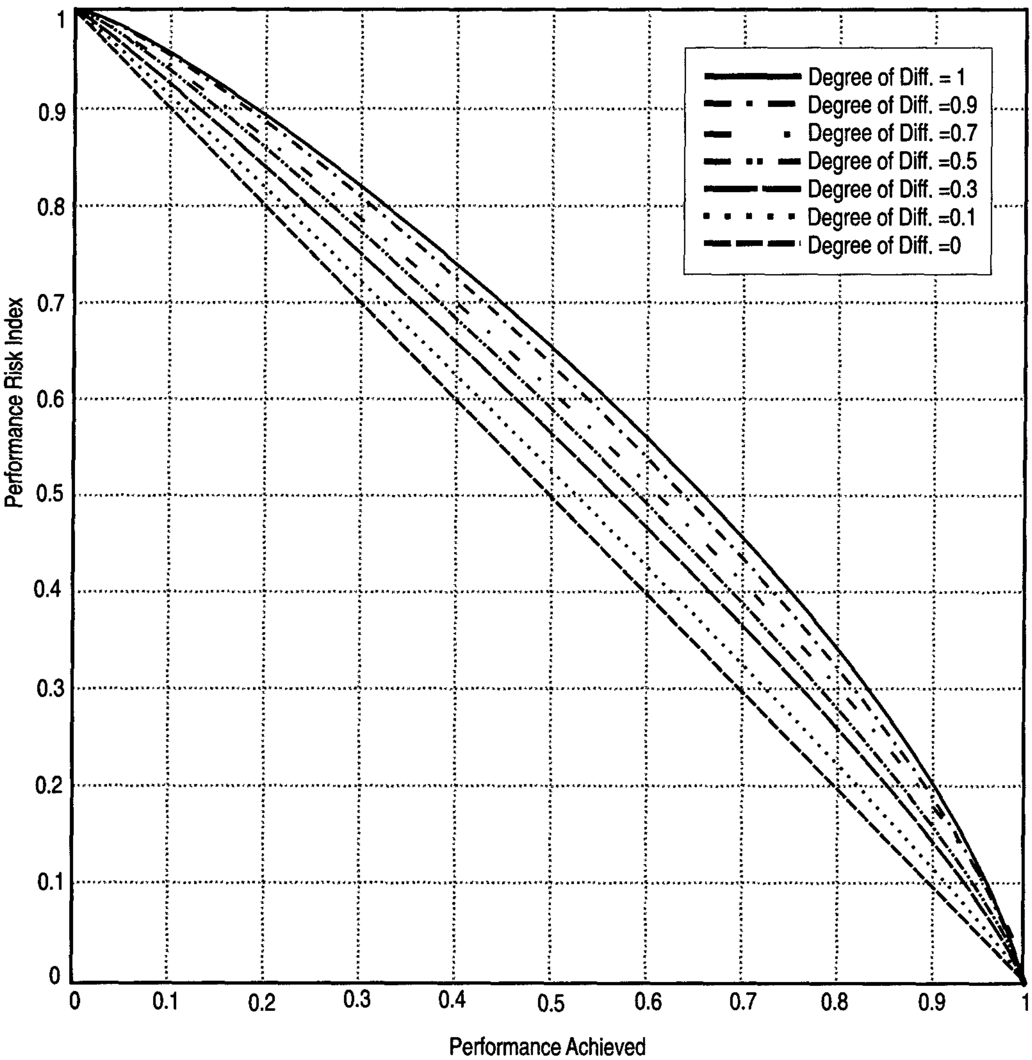

FIGURE 1. TPRI PER ACHIEVED PERFORMANCE WITH DEGREE OF DIFFICULTY AS A PARAMETER

in developing the technology to meet the required system performance requirements.

The theoretical lower boundary of TPRI is identified at DD=0, and corresponds to the line with the lowest TPRI value. This boundary indicates that there is no perceived performance risk with guaranteed success, and it is equivalent to Garvey's approach of unmet performance as the measure of system performance risk. As the DD increases, the TPRI also increases. As expected, non-zero DD yields a non-linear behavior between the achieved performance and the corresponding TPRI value. The DD=1.0 provides the theoretical upper bound, indicating a guaranteed failure. There is a maximum TPRI difference of 0.18 between the two theoretical bounded cases. The TPRI provides a realistic measure

TABLE 2. MEASURED PERFORMANCE OF TPMS PER TIME PERIOD

Technical Performance Measures	Measured Performance. m						
	Threshold	t=1	t=2	t=3	t=4	t=5	t=6
A1 - Average Processing Delay (msec)	1	3	2.86	1.18	1.09	1.03	0.98
A2 - Mean Time to Repair (minutes)	10	50	43	43	27	12	9
A3 - Payload Weight (lbs)	950	2112	1764	1328	1189	1008	948
A4 - Engagement Coordination (sec)	0.01	0.1	0.04	0.032	0.02	0.01	0.01
A5 - Interceptors Available (# of units)	150	67	128	134	139	142	159
A6 - Mean Time Between Failure (hrs)	500	100	189	223	348	379	521
A7 - Single Shot Success Probability (%)	0.95	0.87	0.89	0.91	0.934	0.94	0.99
A8 - Damage Assessment Accuracy (%)	0.995	0.6	0.878	0.94	.0945	0.999	1
A9 - Software Coding (# coded modules)	763	578	643	687	698	723	763

of performance risk associated with the technology to meet, or exceed, the established threshold. Thus, the TPRI yields valuable information to support the acquisitionist and the technologist in making sound decisions regarding the performance risk as a component of the transition readiness of a technology.

ANALYSIS

The TPRI is applied to existing published data (Garvey & Cho, 2003) as shown in Table 2. This data consists of a set of nine TPMs, corresponding threshold values, and the measured performance over the six various points of time. An assessment of the levels of measured performance across each of the TPMs during the time periods is presented. For example, the average processing delay increases in performance by decreasing the average processing delay, measured in milliseconds, from 3 msec at t=1, to 1.03 msec at t=5, to exceeding the TPM threshold (of 1 msec) with a measured performance of 0.98 msec at the sixth time period. The measured performance data contained in Table 2 indicates each of the nine TPM thresholds are either met or exceeded at the sixth time period.

Examples of this decreasing performance behavior would include the following four TPMs: average processing delays, mean time to repair, payload weight, and engagement coordination.

The achieved performances for TPMs with decreasing performance behavior are calculated using Equation 1. Examples of this decreasing performance behavior would

TABLE 3. ACHIEVED PERFORMANCE (PERCENTAGE) OF TPMS PER TIME PERIOD

		Achieved Performance, A					
Technical Performance Measures	Threshold	t=1	t=2	t=3	t=4	t=5	t=6
A1 - Average Processing Delay (msec)	1	0.33	0.35	0.85	0.92	0.97	1
A2 - Mean Time to Repair (minutes)	10	0.20	0.23	0.23	0.37	0.83	1
A3 - Payload Weight (lbs)	950	0.45	0.54	0.72	0.80	0.94	1
A4 - Engagement Coordination (sec)	0.01	0.10	0.25	0.31	0.50	1.00	1
A5 - Interceptors Available (# of units)	150	0.45	0.85	0.89	0.93	0.95	1
A6 - Mean Time Between Failure (hrs)	500	0.20	0.38	0.45	0.70	0.76	1
A7 - Single Shot Success Probability (%)	0.95	0.92	0.94	0.96	0.98	0.99	1
A8 - Damage Assessment Accuracy (%)	0.995	0.60	0.88	0.94	0.95	1.00	1
A9 - Software Coding (# coded modules)	763	0.76	0.84	0.90	0.91	0.95	1

include the following four TPMs: average processing delays, mean time to repair, payload weight, and engagement coordination. In order to meet the TPM threshold, the performance behavior is to be minimized.

In a similar manner, Equation 2 is applied to calculate the achieved performances for TPMs with increasing performance behavior. Examples of this performance behavior would include: number of interceptors available, mean time between failure, single shot success probability, damage assessment accuracy, and number of software modules written. The performance behavior of these TPMs must be maximized to meet or exceed the TPM threshold.

The resulting achieved performance data for each of the nine TPMs and each time measurement are tabulated in Table 3. The achieved performance measure is bounded by 0 and 1. The larger number value of achieved performance indicates that the technology performance is approaching the TPM threshold. An achieved performance of 1 indicates that the technology has either met or exceeded the TPM threshold and has accomplished the goal of entering the acceptable risk region.

Table 4 provides the listing of the nine TPMs and the associated achieved performance. The Degree of Difficulties are arbitrarily selected (for demonstration purposes) for each TPM per each of the six time periods. The TPRI was computed for each individual TPM requirement for each time period. For example, at time period t=1, the average processing delay TPM has a TPRI of 0.75, 0.74 at t=2, 0.19 at t=3, and continues to improve until t=6, when the computed TPRI is zero, indicating that the TPM was met or exceeded.

The total system level TPRI is also calculated for the technology for each of the six time periods. The aggregate TPRI for the technology is computed by averaging the TPRI values of the nine individual TPM requirements, and is identified in Table 4. As the technology advances in improved performance, the TPRI value decreases, indicating lower system performance risks. For example, the aggregate TPRI for the technology is 0.64 for the first time period, 0.49 for the second time period, and continues to improve (decrease) through the sixth time period, when the aggregate TPRI is zero.

Figure 2 depicts the aggregate technology-level TPRI value for each time period. Observation of this figure indicates the areas of significant risk and helps

TABLE 4A. TPMS AND ASSOCIATED ACHIEVED PERFORMANCE

Technical Performance Measures	Achieved Performance t1	Degree of Difficulty	TPRI per Requirement
A1 - Average Processing Delay (msec)	0.33	0.5	0.75
A2 - Mean Time to Repair (minutes)	0.20	0.9	0.88
A3 - Payload Weight (lbs)	0.45	0.5	0.65
A4 - Engagement Coordination (sec)	0.10	0.7	0.94
A5 - Interceptors Available (# of units)	0.45	0.5	0.65
A6 - Mean Time Between Failure (hrs)	0.20	0.9	0.88
A7 - Single Shot Success Probability (%)	0.92	0.3	0.11
A8 - Damage Assessment Accuracy (%)	0.60	0.7	0.53
A9 - Software Coding (# coded modules)	0.76	0.7	0.35

Total TPRI, at t1 = 0.64

Technical Performance Measures	Achieved Performance t2	Degree of Difficulty	TPRI per Requirement
A1 - Average Processing Delay (msec)	0.35	0.5	0.74
A2 - Mean Time to Repair (minutes)	0.23	0.9	0.86
A3 - Payload Weight (lbs)	0.54	0.5	0.56
A4 - Engagement Coordination (sec)	0.25	0.5	0.82
A5 - Interceptors Available (# of units)	0.85	0.3	0.18
A6 - Mean Time Between Failure (hrs)	0.38	0.9	0.76
A7 - Single Shot Success Probability (%)	0.94	0.3	0.08
A8 - Damage Assessment Accuracy (%)	0.88	0.5	0.17
A9 - Software Coding (# coded modules)	0.84	0.5	0.22

Total TPRI, at t2 = 0.49

Technical Performance Measures	Achieved Performance t3	Degree of Difficulty	TPRI per Requirement
A1 - Average Processing Delay (msec)	0.85	0.3	0.19
A2 - Mean Time to Repair (minutes)	0.23	0.9	0.86
A3 - Payload Weight (lbs)	0.72	0.3	0.34
A4 - Engagement Coordination (sec)	0.31	0.5	0.77
A5 - Interceptors Available (# of units)	0.89	0.3	0.13
A6 - Mean Time Between Failure (hrs)	0.45	1.9	0.70
A7 - Single Shot Success Probability (%)	0.96	1.3	0.05
A8 - Damage Assessment Accuracy (%)	0.94	0.3	0.07
A9 - Software Coding (# coded modules)	0.90	0.3	0.13

Total TPRI, at t3 = 0.36

TABLE 4B. TPMS AND ASSOCIATED ACHIEVED PERFORMANCE (cont)

Technical Performance Measures	Achieved Performance	Degree of Difficulty	TPRI per Requirement
	t4		
A1 - Average Processing Delay (msec)	0.92	0.1	0.09
A2 - Mean Time to Repair (minutes)	0.37	0.7	0.74
A3 - Payload Weight (lbs)	0.80	0.3	0.25
A4 - Engagement Coordination (sec)	0.50	0.5	0.60
A5 - Interceptors Available (# of units)	0.93	0.1	0.08
A6 - Mean Time Between Failure (hrs)	0.70	0.9	0.45
A7 - Single Shot Success Probability (%)	0.98	0.3	0.02
A8 - Damage Assessment Accuracy (%)	0.95	0.1	0.05
A9 - Software Coding (# coded modules)	0.91	0.3	0.11
	Total TPRI, at t4 = 0.27		
Technical Performance Measures	**Achieved Performance**	**Degree of Difficulty**	**TPRI per Requirement**
	t5		
A1 - Average Processing Delay (msec)	0.97	0.1	0.03
A2 - Mean Time to Repair (minutes)	0.83	0.7	0.25
A3 - Payload Weight (lbs)	0.94	0.3	0.07
A4 - Engagement Coordination (sec)	1.00	0	0.00
A5 - Interceptors Available (# of units)	0.95	0.1	0.06
A6 - Mean Time Between Failure (hrs)	0.76	0.9	0.38
A7 - Single Shot Success Probability (%)	0.99	0.1	0.01
A8 - Damage Assessment Accuracy (%)	1.00	0	0.00
A9 - Software Coding (# coded modules)	0.95	0.3	0.07
	Total TPRI, at t5 = 0.10		
Technical Performance Measures	**Achieved Performance**	**Degree of Difficulty**	**TPRI per Requirement**
	t6		
A1 - Average Processing Delay (msec)	1	0	0.00
A2 - Mean Time to Repair (minutes)	1	0	0.00
A3 - Payload Weight (lbs)	1	0	0.00
A4 - Engagement Coordination (sec)	1	0	0.00
A5 - Interceptors Available (# of units)	1	0	0.00
A6 - Mean Time Between Failure (hrs)	1	0	0.00
A7 - Single Shot Success Probability (%)	1	0	0.00
A8 - Damage Assessment Accuracy (%)	1	0	0.00
A9 - Software Coding (# coded modules)	1	0	0.00
	Total TPRI, at t6 = 0.0		

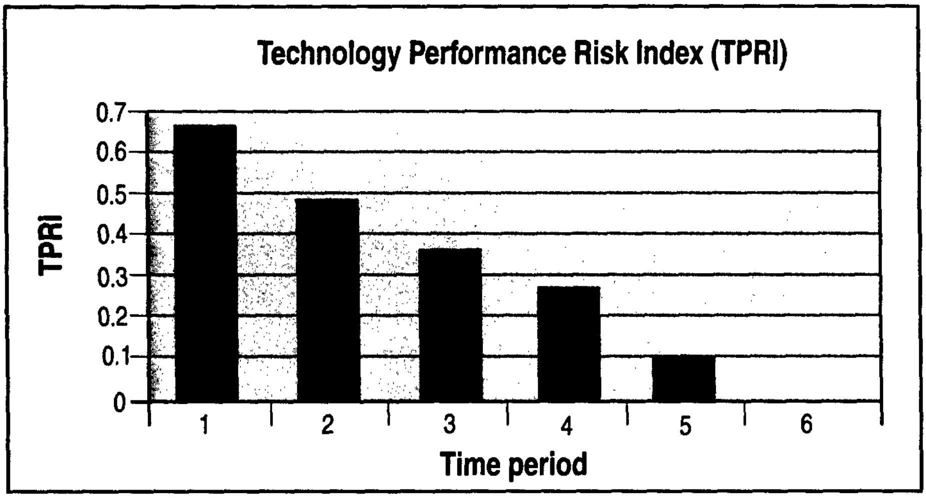

FIGURE 2. SYSTEM-LEVEL TECHNOLOGY PERFORMANCE RISK INDEX PER TIME PERIOD

decision makers with providing additional information pertaining to the performance risk involved with a technology to meet the threshold values associated with TPMs. At the sixth time period, the technology has achieved the acceptable risk region and has a zero-valued TPRI.

TPRI BENEFITS

The TPRI provides a realistic performance risk assessment based on performance requirements, Degree of Difficulty, and unmet performance. These components are combined in a closed-loop feedback manner to calculate the technology performance risk. This decision support tool provides insight to the risk involved in the unmet performance to meet TPM thresholds, and the level of activity required to meet or exceed the threshold. TPRI applies performance risks associated with an unmet requirement as correction/feedback to the achieved performance. Since TPRI is based on meeting TPM thresholds and identifying associated risks with unmet requirement, it provides common ground between technologist and acquisitionist. As a result, an improved understanding of the technology's capabilities to support the acquisition system is gained.

CONCLUSION

This research has focused on the development and demonstration of a quantitative methodology to evaluate and monitor technology to determine transition readiness. The TPRI provides a means to assess potential technologies and assist the decision maker in where to apply resources to address unmet requirements. The TPRI supports monitoring of performance of a technology against threshold limits. It integrates the technology degree of difficulty along with the system unmet requirements in a closed loop to gain additional information regarding a technology's performance risk over time. Additionally, it reduces the probability associated with immature technology being transitioned to a weapon system prematurely. This approach is anticipated to contribute toward level of success pertaining to the integration of technology into system(s) of the aerospace and defense domains.

NEXT STEPS

Future efforts will include examining methods to combine this quantitative Technology Performance Risk Index (TPRI) with a technology maturity metric, such as the widely utilized Technology Readiness Level (TRL). Various ranking and weighting schemes are planned to be examined for potential applicability in the TPRI calculation. There are plans to apply the TPRI as a decision support tool to assist a decision maker with evaluating and selecting the best of identified multiple technologies across same set of TPMs.

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