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RELIABILITY, MAINTAINABILITY, & SUPPORTABILITY

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John Leavitt & Miklós Szidarovszky

Reliability Through Customizable Monte Carlo Simulation

A customizable and computerized Monte Carlo analysis uses thousands of simulations to estimate the reliability of a given system. This technology allows a user to perform a user-friendly flowchart simulation, which may also be used for optimization, risk, financial, probability, and event tree analyses. In this article, we will use ReliaSoft's RENO software to perform a simple reliability and risk analysis for an anesthesia machine and its safety components. This software is used to build complex models for simulations.

An anesthesia machine is frequently used during dental and medical procedures. The machine mixes oxygen (O_2), nitrous oxide (N_2O), and sterilized air into a vapor that is then used to sedate the patient. Component reliability is crucial for anesthesia machines, as failures have the potential to result in damages to the machine and, in extreme cases, death of the patient. To avoid and prepare for potential failures, the design and operation of the machine requires preventive engineering, detection controls and a trained anesthetist who is capable of responding to failures.

In this example, we will demonstrate how to use RENO to estimate the probability of failure and perform a simple sensitivity analysis given thousands of Monte Carlo simulations. Such an analysis may be used by reliability engineers to simulate the reliability of detection controls given the simulated reliability of specific components.

PROCESS

Suppose an anesthetic machine follows the process diagrammed below in Figure 1. Please note that this diagram and the machine operations are for example purposes only and may not represent an actual machine.

A gas cylinder containing oxygen-enriched breathable air supplies high pressurized gas though a pressure relief device (PRD) to a vaporizer. The PRD regulates air pressure to prevent high pressure damage to the vaporizer. An electronic pressure detection sensor is located on the other side of the PRD to inform the anesthesiologist if the PRD fails.

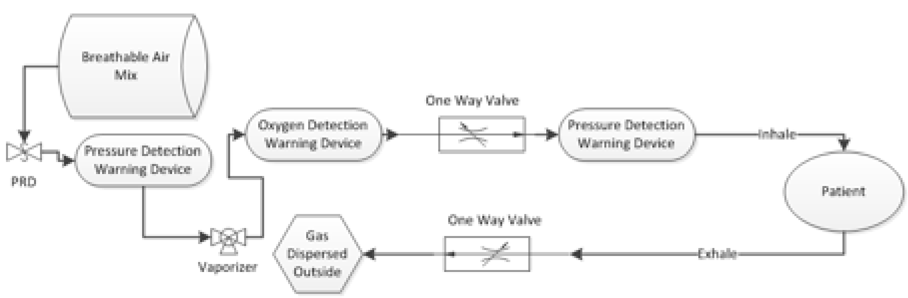

FIGURE 1

Russell A. Vacante, Ph.D.

The Value of Receiving a Higher Education in the -illities and Related Engineering Disciplines

With the ever-increasing cost of higher education and waning opportunities to realize a lucrative technological career, many students, especially those who are U.S native born, are steering their higher education sights away from a career in engineering. Among those students who do pursue a formal education, few are actively seeking out courses of study in reliability, maintainability, supportability, logistics and systems engineering. The reasons are many, however, they all boil down to "there's little perceived return on investment."

Newspaper articles and television news programs frequently report on the

continued on page 7

The oxygen-enriched air is then mixed with nitrous oxide within the vaporizer until the mix is safe for sedation. An electronic oxygen detection device ensures that the vaporizer mix maintains safe oxygen-to-nitrous-oxide ratios. If oxygen levels don't appear to normalize, the sensor alerts the anesthesiologist.

Next, the air mix travels through a one-way valve to the patient. Before reaching the patient, a final sensor checks incoming air pressure to be sure that the air is getting to the patient. If there is a perceived loss of air pressure, an alert is sent to the anesthesiologist.

Finally, the patient exhales waste air that is sent though a one-way valve and dispersed to an outside environment.

In operating an anesthetic machine, it's important to avoid Type II errors, where we think the system is reliable even though it's not, because they may lead to damage of the machine or harm the patient. Detecting effects that are not present, a Type I error, is frustrating, but it is preferred when compared to the alternative.

Assumptions

Please note that the following assumptions are for example purposes only and may not reflect an action failure distribution for an anesthetic machine.

1) The pressure relief device follows a 2-parameter Weibull distribution with a beta of 1.5 and an eta of 1,400 hours. A failure would be a leak that allows over pressurized air to reach and potentially damage the vaporizer.
2) The vaporizer reliability follows a 2-parameter Weibull distribution with a beta of 2 and an eta of 600 hours. A failure would occur if the vaporizer did not produce the correct air to nitrous oxide mixture ratio.
3) The unidirectional inhalation valve reliability follows a 2-parameter Weibull distribution with a beta of 1.5 and an eta of 2,000 hours. A failure could be an air leak on the way to the patient or a valve that allows exhaled air from the patient.
4) The PRD high pressure sensor will detect dangerous pressures 99% of the time, given that the PRD is not working correctly.
5) The low oxygen detector, located after the vaporizer, will detect low oxygen levels 94% of the time, given an incorrect vaporization mixture.
6) The unidirectional inhalation pressure sensor will detect losses in air pressure 97% of the time.
7) Machine components are inspected and refurbished like new after every 400 hours of use. If a failure is detected, the machine is repaired before its next operation.

Model Type	Model Name	Distribution Or Equation/Value	Model Category	Parameter1	Parameter2
Model	PRD	2P-Weibull	Reliability	1.5	1400
Model	Vaporizer	2P-Weibull	Reliability	2	1200
Model	Valve	2P-Weibull	Reliability	1.5	2000
Static	StaticPRD	rvm(PRD)			
Static	StaticVaporizer	rvm(Vaporizer)			
Static	StaticValve	rvm(Valve)			
Variable	PM_Cycle_Time	400			
Variable	Improvement	1			

Figure 2

Objective

A failure of the failure detection systems for the PRD, vaporizer, or unidirectional valve is not acceptable. Find the expected percent of times safety controls fail given that there is a failure.

Solution

RENO can be used to simulate the process of a flowchart with assumptions imbedded into it as Resources. Resources are called upon by the flowchart during a simulation. In this solution we will use three different types of Resources; Models, Static Functions and Variables.

The solution must include reliability Models within RENO for pressure relief devices, the vaporizer and the valve. We defined RENO Static functions to generate a random failure time from each model that remains constant throughout each simulation analysis. Lastly, we defined two variables for the sensitivity analysis that were used to keep track of the number of preventive maintenance cycles and reliability improvements for the components. A summary of all resources are shown in Figure 2, above.

After inputting the assumptions into the software, a flowchart can be created that follows the logic in the process. This solution is only one of many logical flowcharts that can be used to simulate the reliability of the machine. This flowchart

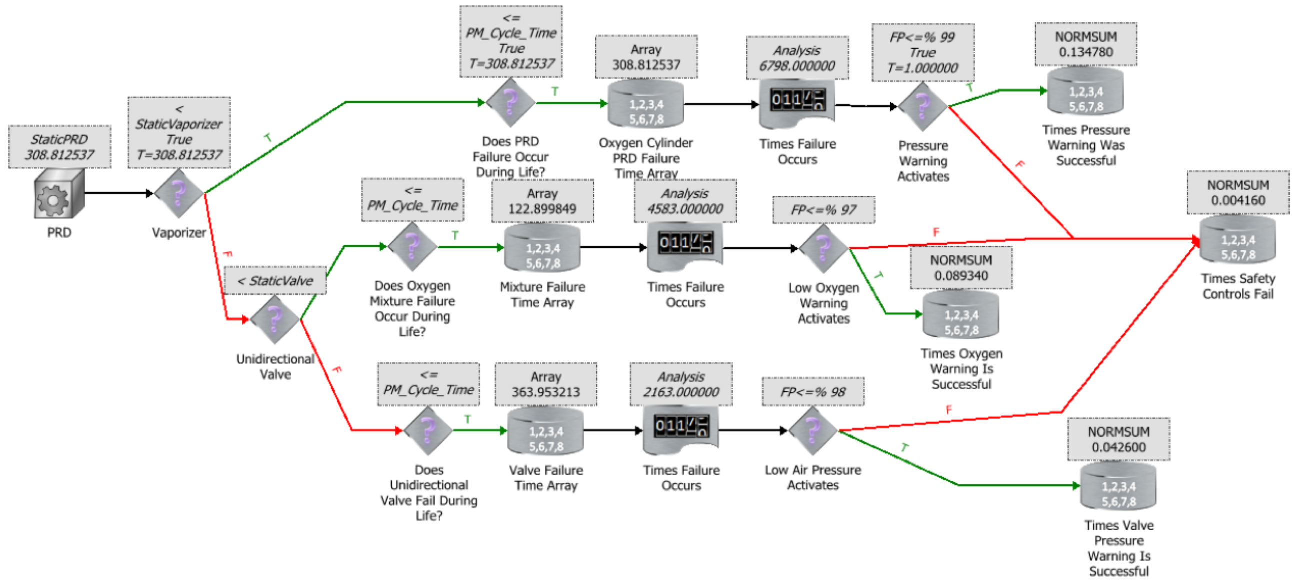

Figure 3

determines the probability that the safety sensors fail, given the probability that a component fails.

In this flowchart solution (Figure 3), 100,000 simulations where run on the flowchart. The results show that there is a 0.42% probability that the safety detectors will fail to detect a given component failure within a preventive maintenance cycle.

A sensitivity analysis may also be run on the above flowchart to determine the optimal number of preventive maintenance cycle hours, given a desired reliability. To the right a two-way (two-variable modified) sensitivity analysis was performed within RENO.

Block Name: Times Safety Controls Fail			
Flowchart(s) Locatior >Diagram			
Storage Type:	Normalized Sum		
Runs Stored:	70		
	Probability of System Failure		
PM_Cycle_Time \ Improvement	1.00	1.10	1.20
100	0.00066	0.00035	0.00038
150	**0.00088**	**0.00080**	0.00070
200	**0.00176**	**0.00137**	**0.00096**
250	0.00218	0.00205	**0.00162**
300	0.00288	0.00257	0.00224
350	0.00446	0.00332	0.00270
400	0.00438	0.00436	0.00314
450	0.00584	0.00520	0.00430
500	0.00688	0.00601	0.00484

Figure 4

The RENO sensitivity analysis spreadsheet, shown on the right, displays the probability of system failure at chosen cycle times, given the current state, a 10% and a 20% reliability improvement.

An analysis like this might be useful to reliability engineers predicting the level of improvement necessary, or the amount of hours needed in a cycle to prevent a failure threshold.

For example, assume our failure threshold is 0.1% and we are operating at 150 hours per PM cycle. If we improved the reliability of each component by 20%, we would be able to add about 50 hours to our PM cycle while keeping the probability of system failure below 0.1%. However, we can see that even with an increase of 20%, increasing the cycle time to 250 hours would put us over our failure threshold.

As demonstrated, customizable flowchart Monte Carlo simulations can be used to generate repeatable simulations that allow an engineer to more accurately estimate the reliability of a system. The sensitivity analysis may prove useful to determine how to best improve maintainability of a system by either increasing component reliability or decreasing PM cycle time. ●

About the Authors

John Leavitt *is a research scientist at ReliaSoft Corporation where he works to develop and support ideas for reliability engineering software products. His work includes risk based inspection (RBI) software, application programming interface (API) software, probabilistic event and risk analysis software. He holds a M.S. in Management Information Systems and a B.S. in Accounting from the Eller College of Management at the University of Arizona.*

Miklós Szidarovszky *is a research scientist at ReliaSoft Corporation located in Tucson, AZ. He is currently involved in the development of various reliability software products and the delivery of training seminars. His areas of interest in reliability include risk based inspection, system reliability, and probabilistic event and risk analysis. His non-reliability interests include rheology and filtration based water treatment. Mr. Szidarovszky holds a B.S. and an M.S. in Chemical Engineering from the University of Arizona.*

Interested In Contributing?

If you are interested in sharing your knowledge in future editions, please contact Russ Vacante at

president@rmspartnership.org.

Articles can range from one page to five pages and should be of general interest to our members.

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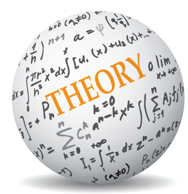

Course List

G300	Introduction to Probability and Statistics
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M301	Introduction to Reliability 3.0 (APM Focus)
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D470B	FMEA Facilitation and Application Skills
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M480A	RCM Principles and Applications
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G522B	Simulation Modeling for Reliability and Risk Analysis
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M560	Reliability-Based Program Planning and Implementation in Asset Management
G588	Applications of Experiment Design and Analysis in Reliability Engineering
G902	Introduction to the Synthesis API

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Are Your Measurements "Stacking Up"?

What is our sole function in the work place as systems architects and engineers? Some SE types will tell you an SE's value can be found in how well (s)he influences the decision process! In the context of this article—measuring something—I agree…one way you influence decisions is via the delivery of relevant, quality measurements and the follow-on analysis and reports or presentations.

Measurements and *the importance of reporting their outcome accurately* have been promoted since the days of Machiavelli. A phrase, coined off the writings of Machiavelli, that's heard often as a heuristic is, "If one cannot measure something, it has little value." From *Thoughts of a Statesman*, Chapter XI, "Notable Precepts and Maxims": "One of the most important things in this world is to know one's self and to properly measure the forces of one's mind and one's condition." And, from *Miscellaneous Writings: Discourse on the Affairs of Germany and on the Emperor*, with respect to choosing between war and negotiation, "To perform your duty well you have to say what the prevailing option is respecting the one and the other. War has to be measured by the number and quality of troops, by the amount of money, of conduct and fortune; and it is to be presumed that the party with the most of these advantages is to be victorious. After having thus considered who is likely to be successful, it is necessary to make it well understood so that the republic and yourselves may better decide on the courses to be adopted…"

From a DoD Acquisition perspective, measurements are important as well. The Clinger Cohen Act requires the use of performance and results-based management in planning and acquiring investments in information technology, including national security systems (IT, including NSS). Additionally, DoD Instruction 5000.2 states: For a weapon system with embedded information technology and for command control systems that are not themselves IT systems, it shall be presumed that the acquisition has outcome-based performance measures linked to strategic goals if the acquisition has a Joint Capabilities Integration and Development System document (Initial Capabilities Document, Capability

Development Document or Capability Production Document) that has been approved by the JROC or JROC designee.

Measures or measurements fall, usually, under a much broader heading: metrics. Metrics is a broad brush-stroke expression that can cover a lot of ground so let's understand the terminology before we go further.

What's a metric? According to Webster's Ninth New Collegiate Dictionary:

> *A part of prosody that deals with metrical structure; a standard of measurement; a mathematical function that associates with each pair of elements of a set of real nonnegative numbers constituting their distance and satisfying the conditions that the number is zero only if the two elements are identical, the number is the same regardless of the order in which the two elements are taken, and the number associated with one pair of elements plus that associated with one member of the pair and a third element is equal to or greater than the number associated with the other member of the pair and the third element*

The above, in its entirety, is tough to decipher so let's take "a standard of measurement" and work with that some. From Webster we find this about a standard: A gauge, a yardstick, a means of determining what a thing should be; standard applies to any definite rule, principle, or measure established by authority.

A measure, established by authority, should work for us all and there are three measurement "terms" that we can utilize in our efforts to influence the decision process—Measures of Merit (MoM), Measures of Effectiveness or Efficiency (MoEs) and Measures of Performance (MoP).

An MoM can be likened to establishing a value to one of the measures; e.g., how well does/did the MoE(s) or MoP(s) work to influence the decision? For MoEs we can turn to people like Michael VanBruaene. Michael, at his blog site, Pragmatic Approaches to Move Organizations Forward, offers a basic primer on Measures of Effectiveness and Efficiency.

Effectiveness

This measure should be viewed in terms of the extent to which the service or system provided meets the objectives and/or expectations of the organization and/or a customer. Examples include: Coverage: The number of customers you serve or the area of coverage for a cell site system; Accomplishment: Measures the overall outcome or achievement of a program or system.

Efficiency

This measure should be viewed in terms of how an organization, system or System of Systems uses its resources or how well it does something. Efficiency measures include: Per unit costs: A measure of per unit cost reveals how many resources are consumed in producing a unit of service;

Cycle time: Measures the amount of time it takes for a process to be completed; Response time: Measures the amount of time it takes to respond to a request for service or how long it takes a system function to be completed; e.g., "waiting or queue-time"; The Rate of something: i.e., measuring rise over run—sortie rate, loss exchange rate, repair rate.

A measure of Performance (MoP) is, simply, how well a system or unit or business entity performs a specific task or completes a function. Examples include: speed, payload, range, time-on-station, operating frequency, time to process a system function or other distinctly quantifiable system or unit performance feature. Most notably, more than one MoP is required to quantify a particular MoE. [In an aside note context, MoEs—effectiveness or efficiency—can mean different things to different people, i.e., the demarcation line between MoEs—effectiveness and efficiency—can be a bit fuzzy…however, the fundamental premise—use MoPs to 'measure' or quantify your expected/desired MoE(s)—remains intact.]

At a balanced scorecard organization website, *balancedscorecard.org*, I found oodles of information on measuring including the seven phases of the performance measurement process that influence one's assessment of the value that performance measurements can bring to your organization. The phases are complementary and supportive; i.e., they work together in an ongoing cycle of measuring, monitoring and applying performance measures. For more on the seven phases, visit:

https://balancedscorecard.org/Resources/Performance-Measures-KPIs/Underestimating-Measurement

From that web site:

Phase 1

Select, i.e., choose and define, what's worth measuring for your organization. Decide specific results to measure and design measures giving the best evidence of those results.

Phase 2

Collect the needed performance data. Define the data requirements for the performance measures you want to report. Design and implement data collection systems to optimize data availability and integrity.

Phase 3

Manage the data so it's quick and easy to access. Use a data referencing model to make data management cost effective & enable cross-functional use of data. Extract, integrate and prepare data for analysis.

Phase 4

Turn the data into information. Ensure it's the most appropriate information by adopting the simplest analysis approach that can produce the information in the form required to answer your driving questions.

Phase 5

Communicate the information effectively. Remember, you are influencing which message(s) the audience focuses on so take care to present performance measures in ways that provide simple, relevant, trustworthy and visual answers to their driving questions.

Phase 6

Translate the information into implication. Define guidelines that signal which differences in performance results are real and which are not so that conclusions, drawn upon performance results, are based on actionable information.

Phase 7

Decide how implication will become action. Design decision-making processes which make effective use of performance measures. Identify the root causes of performance results (getting deeper than the symptoms) and set performance targets that encourage sustainable improvement.

A cautionary note: Treat performance measurement as a system and a process! If any of the above phases are missing or not performed effectively you're probably sacrificing one or more of the principles of excellent performance measurement. Additionally, without thinking carefully about which measures to select, you'll risk having measures that aren't relevant to your purpose or don't help you understand the causes of current performance results.

Finally, the ONE question we need to keep asking ourselves as we measure, analyze and report: Are our performance reports stacking up? If they are stacking up, i.e., unread and unused, then they're obviously not "stacking up" well.

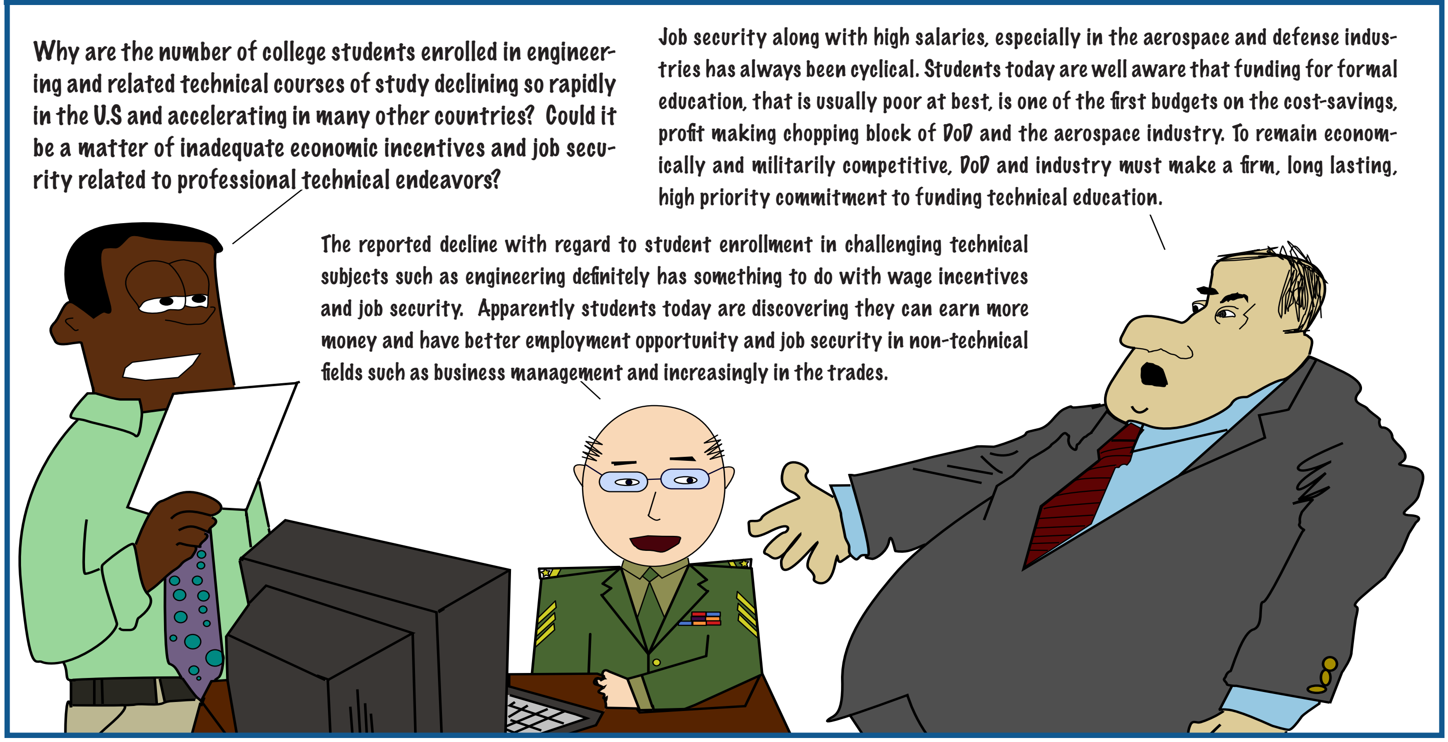
In summary: We see where history is on our side. Machiavelli provided us rationale for measuring, DoD laws and policy demand the same and there is a process to follow to help us influence decisions and remain relevant to the S.E. process. ●

About the Author

Jim Rodenkirch *enjoyed 40 years of Government service (20 years in the U.S. Navy, retiring as a Chief Petty Officer, and 20 years in Civil Service as a Systems Engineer for the U.S. Navy). Albeit retired, he enjoys teaching a graduate Systems Architecting course for the Engineering, Management and Information Systems Department at Southern Methodist University in Dallas, Texas and providing support to the RMS Partnership as editor of the semiannual RMSP Journal.*

Another Day At The Office

by Russell A. Vacante, Ph.D.



The Value of Receiving a Higher Education in the -illities and Related Engineering Disciplines, from page 1

increasing number of students graduating from college with huge student loan debt; a financial burden that follows them well into their adult life. The repayment of their educational debt and the interest incurred, in many instances, is large enough to adversely impact their quality of life, e.g., marriage planning, purchasing homes, automobiles and more. Exasperating as the repayment of student loans issue is, the opportunity to find well paying jobs upon graduating from college that will help to mitigate the economic burden of repaying their student loans is on the wane. While it remains relatively accurate that students with engineering degrees often have a starting wage higher than their classmates graduating with non-technical degrees, it is also correct to say that well paying engineering jobs are increasingly becoming a scarce commodity. This is especially true for engineers specializing in "the illities," e.g., reliability, maintainability supportability and logistics. All of this leads us the next related subject to be discussed.

The cost(s) to run DoD cost and industry profits have increasingly been the driving force for acquisition reform and industry consolidation. This trend most likely began with *The Packard Commission* (1985) report on management and decision-making issues, gained momentum with the *National Performance Review* (1993) that promoted the commercial use of standards, followed by the *Rumsfeld's Challenge* (2001) that underscored issues with an expanding DoD infrastructure and advances in industry technology outpacing the need within the DoD.

Most recently the Under Secretary of Defense for Acquisition, Technology, and Logistics, The Honorable Frank Kendall, wrote in the Forward of the *Performance of the Defense Acquisition System, 2014 Annual Report* the following: "Most of the development and production on acquisition programs is conducted by industry under contract to the government. Therefore, we examine various incentive techniques to see how effective they are at driving cost, schedule, and technical performance." All suggesting that from 1985 to present the emphasis within DoD has been to increasingly shift DoD acquisition and technology tasks to industry, i.e., as means to reduce defense expenditures and remain on the cutting edge of advancing technologies. How's this working for us at a time when other advanced and advancing nation-states are graduating more engineers from college in one year than the U.S. graduates in ten years?

As I have discussed in a prior newsletter editorial, despite the numerous acquisition reform measures implemented by DoD during the last thirty years, disappointing performance, cost overruns and schedule delays remain a persistent nemesis of the DoD acquisition system. The migration of DoD acquisition, technology knowledge, expertise and responsibility to industry, in many instances, has not streamlined the procurement of major weapon systems. As DoD continues working at bringing down the cost of doing business, industry is also on a never ending quest to increase its profit margins. It is well known within the industry defense community that senior technical employees frequently are among the first to get furloughed as a cost reduction or profit seeking measure while individuals with less experience and education are frequently retained or hired to assume the responsibilities and duties of those they have replaced.

The goal to make DoD more efficient while industry partners remain profitable is a notable endeavor. However, to do so at the expense of formal education and technical training in the engineering illities and technical fields in general is misguided. For example, the on-going DoD sequester has significantly reduced DoD and industry support of formal education and on-the-job training. This is occurring at a period in U.S. history when the defense challenge from other countries appears to be escalating. This seems to be a counter-intuitive approach to acquisition reform and national defense. While the cost of promoting and supporting formal education and technical training in engineering and related illities initially may be more expensive, in terms of total life cycle cost savings, it will be proven to be cost effective to DoD in terms of providing systems with improved performance, fewer cost overruns and timely deliveries.

It is important to note that lack of student interest in subjects such as reliability, maintainability, supportability/sustainability and logistics is not what caused students to avoid pursuing an engineering degree. It is low wages, questionable employment opportunity or well-paying jobs and long term, secure employment opportunities are influencers for them to seek other career alternatives. Less focus on government cost savings and industry profit margins would be good for the engineering profession, educational institution and our national defense.

DoD is a large enough proverbial dog to wag the tail of industry with respect to establishing educational priorities within the DoD community. When DoD leadership acknowledges the importance of and need for reliability engineers and related technical disciplines, industry will also make education and training a higher priority for its workforce. As a positive consequence, colleges and universities will have an incentive to grow their engineering programs and students will once again view engineering as an intellectually fulfilling and economically promising career. ●

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