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System Effectiveness Analysis Framework

Introduction and Motivation

Despite the importance of performance measures, an explicit theory for their development and use does not exist and the body of knowledge is sparse. The existing literature is inconsistent with most contributions of the ad hoc or heuristic variety and seems to be a focus on qualitative attributes and when mathematics is used, these attributes do not necessarily provide the desired quantification. This occurs for several reasons: they use different physical units, thus they cannot be compared or combined; there is a lack of physical meaning; the value system used does not accurately reflect the significance of differences; and there is no uncertainty in the measurements (Reed and Fenwick, 2010). As a result, several definitions for performance measures have been advanced, that while similar to each other, do not provide the needed insight into system performance evaluation from concept development to system test. During system test, system performance is evaluated against the criteria specified by the stakeholder during concept development and selection. This can be problematic if the performance criteria used for testing does not satisfy the effectiveness criteria used for concept selection. This occurs when an incorrect approach is used during concept development.

The main thrust of this paper is to lay out a methodology that addresses the shortcomings identified by Reed and Fenwick.

Performance Measures

One of the most important tasks in the military system's development process is that of assessing system performance and effectiveness; i.e., does the system have the ability to perform the intended job? Such analysis is needed to ensure that the system meets its requirements, is delivered on schedule, and developed within allocated costs. It is a customer/user driven process that if performed incorrectly results in a system that does not meet expectations. The process starts with understanding the problem to be solved and its attendant issues. It progresses through an evaluation of solution feasibility to the selection of the most viable alternative.

In concept development, effectiveness calculations are about prediction and the objective of prediction is twofold:

1) System effectiveness predictions form a basis for judging the adequacy of system capabilities, and
2) Cost-effectiveness predictions form a rational basis for management decisions.

Early in the life of a system, prediction is driven by the problem and issues from the user's point of view. At this point, there are generally no hard or quantifiable solutions but there may be candidate solutions that may solve the problem from a qualitative point of view. Thus, prediction is required for feasibility assessment and specification development. With potential solutions in hand, there is a requirement to develop quantifiable results that can be used to make hard comparisons between

THIS EDITION

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Russell A. Vacante, Ph.D.

Technology Innovation Increasingly Dependent on Reliability

Today, there are numerous emerging technologies that are being designed to reduce or totally eliminate human guidance and intervention. This implies that there will be a growing demand for reliability engineers and associated training to ensure reliability requirements remain an integral process of system engineering development throughout the system lifecycle. Unfortunately, as the forecast demand for reliability expertise increases, the availability of technologically competent reliability personnel is decreasing due to an aging workforce and lack of training. This is an important factor to keep in mind as we discuss a few emerging technologies that are reliability dependent in the subsequent paragraphs. In addition, as I mentioned in a previous newsletter editorial, China produces more engineers in

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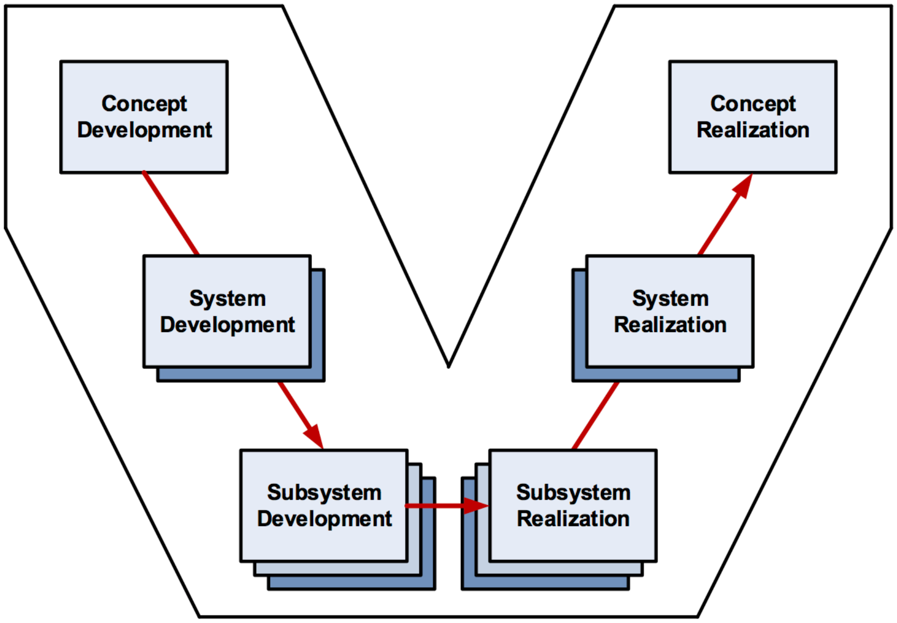

Figure 1. The Systems Engineering "Vee" Process Model

the alternatives; does it indeed meet the performance threshold as required by the user? Subsequently, these quantifiable results can be used in final solution selection and will be the basis for systems development as well as playing a major role in system testing and verification. Proper selection of performance attributes is essential to this process. These attributes or performance measures, commonly called "measures of effectiveness" or MOE's, provide quantifiable benchmarks against which the system concept and subsequent implementation can be compared.

Performance Measures and Design

Systems engineering is a multi-phase process from concept development to system retirement. It is typically represented by a variant of the Systems Engineering "Vee" process model shown in Figure 1.

The issue of performance measures arises early in the concept phase and they are used throughout the process of bringing a system into being; i.e., concept realization. They are extremely useful to the system engineer in five key areas:

1) Establishing requirements;
2) Assessing successful mission completion;
3) Isolating problems to gross areas;
4) Ranking problems relative to their potential to impact the mission; and
5) Providing a rational basis for evaluating and selecting between proposed problem solutions and their resulting configurations.

These five areas define the concept phase: defining the problem, defining a solution to the problem, and selecting a solution from the available options thus, the concept phase may be decomposed into three analysis spaces as follows: the problem space; the solution space; and the selection space. These terms were chosen to help select the appropriate analytical approach as a system goes from concept development to concept selection and are defined as follows:

Problem Space: the focus is on describing what is the problem; understanding what the issues are; and clarifying what are the user requirements. The goal is to discover if there is a feasible solution and if so, what are the performance requirements? The output is the set of concepts that may meet the user's need and the "prime directive" which is the top level requirement that captures the user's need.

Solution Space: the goal is to develop design concepts that satisfy the user's need for requirements consistency from the perspective of the prime directive and requirements completeness from the perspective of the concept of operations (CONOPS).

Selection Space: the purpose is to answer the following questions: what are the design options, tradeoffs, and specifications for the solution for a given set of resources and constraints? Which option is the most viable?

The different outcomes for each space indicates that each space requires its own unique analytical approach. The methodology of this paper separates the overall concept development process into the three defined spaces by the form of the mathematics appropriate to each analysis space. Figure 2 (following page) shows the progression from the Problem Space to the Selection Space.

Both the Problem Space and Selection Space involve the use of similar techniques because there is a decision to be made. The Solution Space requires a different approach because it translates potential options into hard numbers that can be measured and tested. The emphasis of this paper is on the Solution Space because it is here where the mistakes with performance measures are typically made.

Step 1: Analysis of the Problem Space

The user's need is initially assessed in the Problem Space; however, the analysis requires careful consideration of how to express this need. This analysis is characterized by the use of soft or qualitative techniques which, in turn, are characterized by the use of utility theory and weighting schemas to balance the stakeholder's need against possible solutions. Viable analytic tools are the analytic hierarchy process (AHP); quality function deployment (QFD); Pugh Matrices; and multi-attribute utility theory (MAUT)

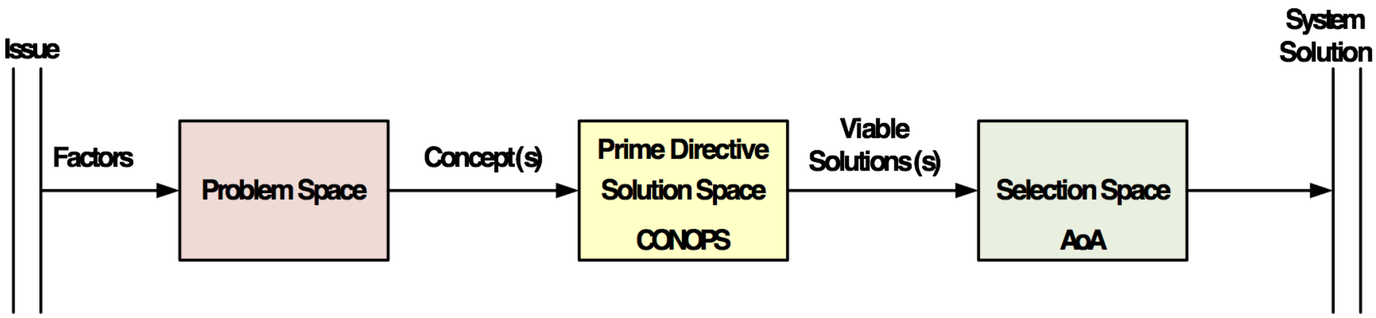

Figure 2. Progression from Problem Space to Selection Space

to name a few. While it is appropriate to apply soft techniques in the Problem Space to help sort through issues and assess information, it is not appropriate to characterize the results as performance measures. The outcome is one of preference or utility for a solution or set of solutions, not the effectiveness of a solution in satisfying the initial problem. Simply stated, preference ≠ effectiveness. In addition, the utility theory approach is not measurable and testable which are key requirements of a performance measure.

Step 2: Analysis of the Solution Space

The Solution Space requires a different approach to analysis and has to answer the question "does the functional solution solve the problem?" The focus is on the prime directive and the resulting CONOPS and the result must be in a form that is measurable and testable. The result is a systems view of the solution.

As an example, the problem may be to defend a particular region against missile attack. The user might state the resulting prime directive as follows: actively defend the region against all missile threats. The analysis of the Problem Space would most likely identify multiple approaches as potential solutions; however, as stated, there is no performance requirement so the selected solution or solution set may be comprised by several options of varying performance. Adding a performance requirement changes the nature of the analysis from what are the possible solutions to the question: do the solutions meet the user's MOE?

Sproles notes that the user views the solution as a black box; i.e., the user is solution neutral as long as the prime directive is satisfied (Sproles, 2000). This is an important point that leads to the following observations:

First, MOE's are viewed external to the system and are independent of any solution.

Second, a black box has only one MOE which follows from its basic description: a system element that can be viewed in terms of its input, output, and transfer characteristics without regard or knowledge of the internal boxes' internal workings (Figure 3). Specifically, the output is predictable for a given input.

This means that the performance requirement of the prime directive is described by one MOE which the selected solution must satisfy.

Third, the MOE is an intended or expected outcome at the most abstract level. Because it is an expected outcome, it is appropriate to express the MOE as a probability. For the cited example the MOE could be expressed as a probability of successful defense (Psd) of the region against missile attack. As a probability the MOE would lie between 0.0 and 1.0 or $0.0 \le P_{sd} \le 1.0$

In reality the black box is composed of

Figure 3. The Ubiquitous Black Box.

a set of functions whose individual contribution must aggregate to the MOE (or to P_{sd} in the example). This implies that there is a performance budget where the MOE is the starting point and the performance is allocated top-down in a manner similar to the process for developing the reliability of components given required system reliability. Figure 4 (following page) is a notional example of a performance budget derived from the work of Marshall (Marshall, 1991). It is important to note that it is the system developers who are focused on the contents of the black box. They have the responsibility to ensure that the performance of the functional elements will aggregate to the desired MOE. This concept provides flexibility in how system performance is viewed. For example, sustainability is not a formal element of reliability theory; however, if sustainability is defined as the ability to continue a desired behavior for a specified period of time, it can be argued that sustainability is the product of survivability and system performance.

Sproles uses this point to further clarify his definition of an MOE and its difference from an MOP.

"An MOE refers to the effectiveness of a solution and is independent of any particular solution; an MOP refers to the actual performance of an entity (Sproles, 2000)."

A corollary of this point is that building a system from existing components may well fall short of the user's requirement because as they are aggregated, their collective performance falls short

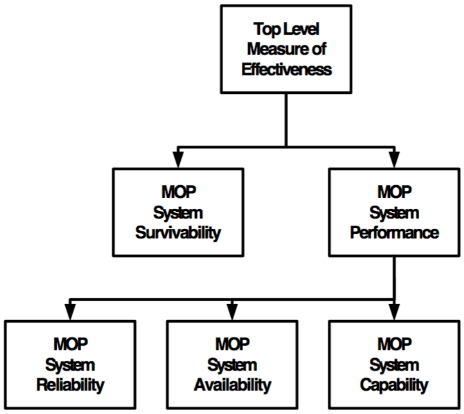

Figure 4. Allocation of System Performance.

of the performance budget.

Figure 5 illustrates the top-down progression from MOE's to the dimensional parameters. This follows from the basic system principle of hierarchy upon which, the above corollary is based. The original diagram had the arrows in the reverse direction implying that the MOE was derived from the parameter set rather than the inverse where the parameters are driven by the MOE.

Figure 5 also captures the external black-box, MOE view of the user and the internal, MOP view of the system developer. Returning to the example, Psd drives the requirement to detect the threat, process the threat, and to engage the threat. This approach allows the process of successful defense to be evaluated using the mathematics of probability resolving the issues raised by Reed and Fenwick.

A subtlety in this approach is that it is process driven and proceeds from the "what needs to be done" to the "how to do it." A process is comprised of functions which in turn are allocated to objects. The prime directive is brought to fruition by the set of functional steps that comprise the process and are instantiated by the set of parameters defined by the objects.

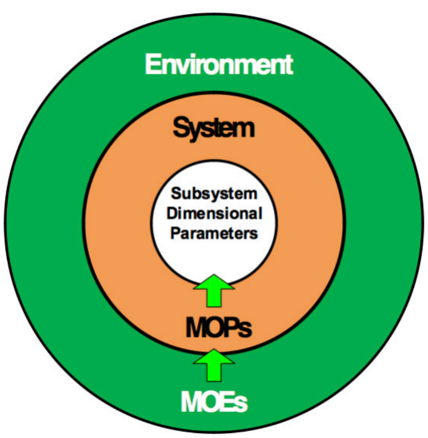

Figure 5. The Progression from MOE's to Dimensional Parameters.

Step 3: Analysis of the Selection Space

The Selection Space is a trade between the MOE and the cost to achieve it. There are two possible contexts available. The first is the willingness to give up performance to achieve cost and the second is the unavoidable tradeoff that results when an improvement in one attribute comes at the expense in the performance of another attribute. Usable techniques are forms of MAUT such as Pareto analysis and value focused theory.

Summary

The existing literature does not address the relationship between the problem space, solution space, and selection space presented in this paper. It typically centers on either value-focused methods or variations of multi-criteria decision making approaches as solutions to the performance assessment problem without accounting for system behavior. Because they are preference-based methods, they do not capture actual system performance. The methodology of Figure 2 resolves this issue by integrating preference and performance with decision making in a phased manner resulting in an approach that covers system concept assessment from the early qualitative stages to making the final decision based on performance and dollars. This paper provides a unifying framework for understanding the difference between utility theory-based analysis and probabilistic methods suitable for developing meaningful MOE's. ●

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QUIZ YOURSELF

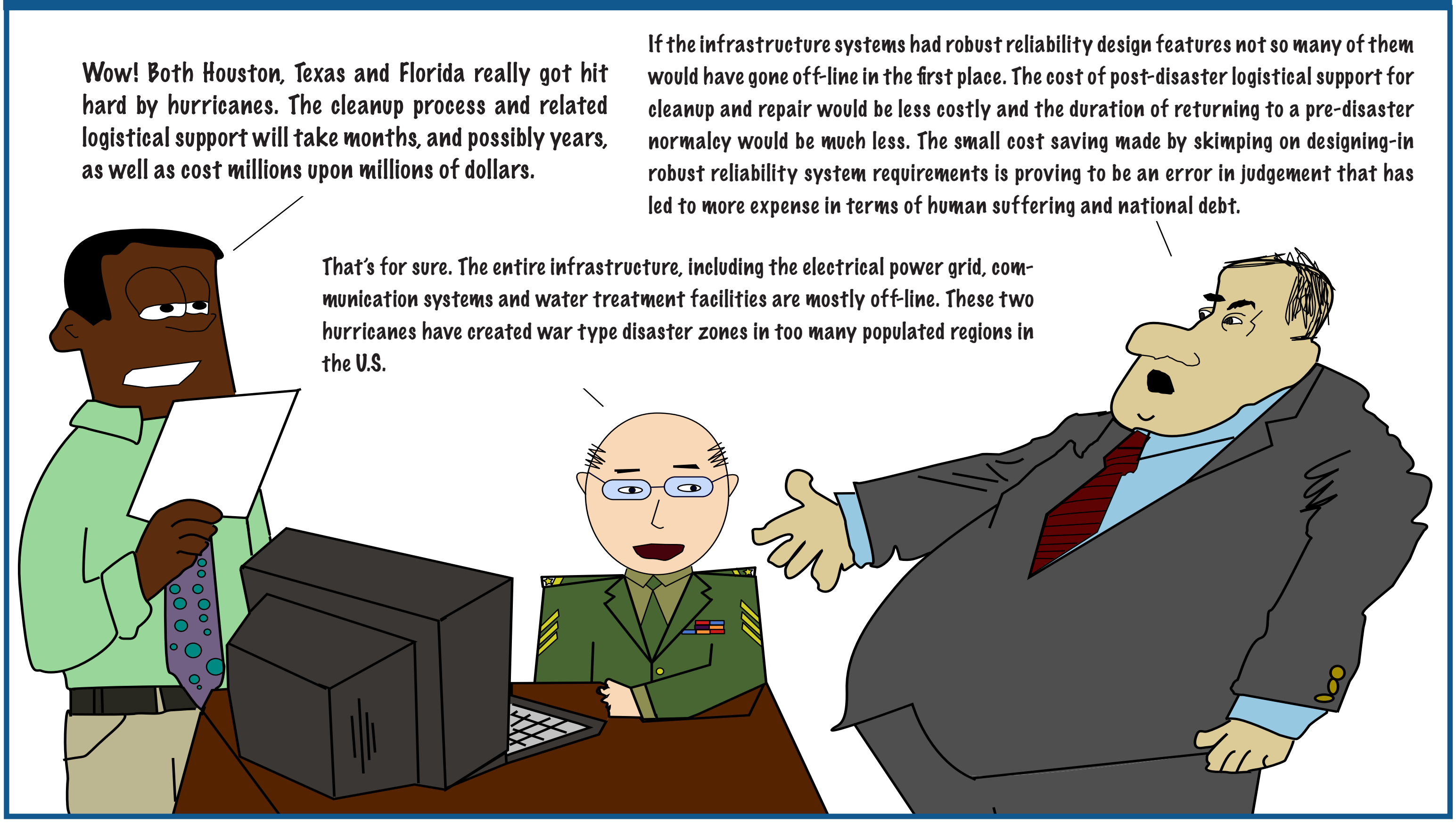
When using Root Cause Analysis (RCA) to determine if a lubricant is suspected of degradation and you want to rule-out Thermal Breakdown, which one of the following tests would you be less likely to perform…

a) Fourier Transform Infrared Analysis (FTIR)
b) Acid Number (AN)
c) Gel Permeation Chromatography (GPC)
d) Thermo gravimetric Analysis (TGA)
e) (Flash Point)

…answer on Page 8.

Another Day At The Office

by Russell A. Vacante, Ph.D.



Katherine Pratt

DoD Global Supply Chain Innovations

The Military Traffic Management Command (MTMC), the surface transportation command of the U.S. Department of Defense (DoD), has been evolving from a supply-based to a distribution-based logistics system since the events of September 11th terrorist attacks. As part of this transformation, this new model reconfigures operations to better support asymmetric warfare, with the reduction of active duty personnel, yet while still supporting weaponry costs in excess of one billon dollars.[1]

These processes, organizational and cultural changes are the mandate of the MTMC serving as a surface deployment and distribution command. The MTMC provides a single "face" to the field for all surface distributions, commercial trucking, handling rail operations, as well as ocean transportation in partnership with the Military Sealift Command (MSC) and the Air Mobility Command.

The Army, Navy, Marine Corps, Air Force and Coast Guard provide support by 730 active duty and reserve members for of all the armed forces of the MTMC, MSC, and the Air Mobility Command, which are a component of the United States Transportation Command (USTRANSCOM).

The Field Commanders transportation requirements are sent to USTRANSCOM, which in turn coordinate with the Defense Logistics Agency (DLA), the supply arm of DoD Logistics. USTRANSCOM uses blends of military and commercial transportation resources. The military transportation components work with commercial motor and rail carriers, barge companies, and ocean liner operators. The private sector industry transportation resources move most of DoD's freight, which includes fuel, ammunition, vehicles, repair parts, food and other commodities.

MTMC's operations are immense. They serve as DoD's worldwide port manager, providing pre-deployment planning, terminal service contracting, cargo stow planning, documentation and customs clearance. In port, the MTMC assemble force packages that contain ammunition, food, and other items into one unit. By implementing this practical change from previous distribution methods, they now load vessels by task organization with unit basic loads, thereby providing capability as apposed to equipment. Another key innovation is OEF/OIF asset and in-transit visibility, which uses radio-frequency tags and applied carrier business rules to provide identification of container contents.

Through recent innovative improvements by an integrated process team that included military transportation, acquisition, legal, and industry representatives, the MTMC now awards Tailored Transportation Contracts that emphasize higher value for responsiveness, time-definite, and consistent levels of service. Through a coordinated effort between MTMC 's industry partners and customers, they have developed performance-based work statements. DoD shippers are now able to select among the carriers operating in their region, and can access a web-based metrics system that tracks and monitors contractor performance.

Clearly all these innovations are practical, sensible, and more productive than past practices. Both the military and the private industry manufacturers outsource services with the same main goal: to cut costs. There are advantages and risks of outsourcing as well as some similarities and some differences between how the U.S. Military and private manufacturers manage their outsourcing practices.[2] To understand the impact of outsourcing, it's important to probe the rationale behind this strategy.

One major reason is because of the Sept. 11 terrorists' attacks, force management constraints compelled the U.S. military to convert many active-duty support units into combat arms soldiers. The military and manufacturers outsource for the same reason: to achieve cost savings. The outsource services common to both the Military and the manufacturers include:

- Specialized: Research and development, or Healthcare
- Technical: Web development or Engineering
- Manufacturing-related: Resulting from Global Supply Chain Management (GSCM) requirements, or Resource proximity
- Services outsourcing determined by cost and or quality considerations.

The formation and the mission of the Defense Logistics Agency (DLA) is a prime example of the Army's strategy of consolidation services. The DLA supports the U.S. Mission in Afghanistan by supplying coalition forces with food, fuel and support elements. The DLA Support Team-Afghanistan is charged with providing more than $10 billion in food and bulk fuel contracts.

However, whenever an in-house function is allocated to others, such as contractors, who often serve under the operational control of military commanders, but are also bound by contractual terms, conditions and allegiances that may not be in sync with the military hierarchy – this increases operational risk. Another inherent risk in outsourcing is this may have an adverse impact on the

1 "Military Logistics Shapes Up" by Leslie Hansen Harps 9-15-13 Inbound Logistics; http://www.inboundlogistics.com/cms/article/military-logistics-shapes-up/

2 "Military and Manufacturing outsourcing: Not all Guns and Roses" by Wallace A. Burns, Jr., Ph.D.. Inbound Logistics 2-18-16 http://www.inboundlogistics.com/cms/article/military-and-manufacturing-outsourcing-not-all-guns-and-roses/

military chain of command – the hierarchical method for organizing information flow, decision-making, power, and authority. Another downside of military outsourcing is significant cost overruns, loss of control, longer delivery times, and less responsiveness to customer requirements.

The Army is currently looking at ways to solve the current outsourcing challenges, and is now training contracting specialists and re-growing our organic capabilities. Both the military and private manufacturer want to reduce the need for highly skilled workers on generic manufacturing tasks to achieve the following benefits:

- Decrease plant and equipment costs.
- Reduce footprint requirements.
- Control reverse logistics costs.
- Develop more reliable schedules.
- Offer greater product options.
- Concentrate on core competencies.

The military have based decisions primarily on cost, and less emphasis has been placed on quality and other priorities, such as executing military operations and the associated performance of core military activities. Manufacturers, similar to the military, need to ensure their outsourcing decisions are not based upon short-term cost savings, but instead on ensuring their customer's organizational health and stability essential to their survival by insuring the quality and timeliness of their support.

Ultimately, the cost to support a war should be subordinate to the result of achieving not only a victory, but also in maintaining the armed services. ●

About the Authors

John M. Green *is currently a Senior Lecturer in the Systems Engineering Department at the Naval Postgraduate School. His previous positions included Senior Principal Systems Engineer with Raytheon Naval and Maritime Integrated Systems in San Diego where he researched interoperability issues related to Network-Centric Warfare and worked on the architecture for Common Command and Control. Before Raytheon, he was Manager of Advanced Systems at ITT Gilfillan, Van Nuys, CA where he led a team developing concepts for high-power, solid-state radars.*

Mr. Green has also worked for Lockheed Martin in Moorestown, NJ where he was Technical Director for the Norwegian Frigate project and System Engineer for the Taiwanese PFG-2 Class Combat System design. In addition, he did research into advanced combat systems for submarines while employed at Electric Boat.

During his military career, Mr. Green served on a variety of ships including a submarine tender, a destroyer, a carrier, and six submarines, rising from Seaman Recruit to Lieutenant Commander.

He holds an MBA and MS in Computer Science from University of New Haven, an MA in International Relations from Salve Regina College, and a BS in Physics from Saginaw Valley State University. He is also a graduate of the Naval War College, College of Command and Staff.

Mr. Green is a Senior Member of IEEE and AIAA. He is also a member of the Military Operations Research Society (MORS); the American Society of Naval Engineers; the Institute for Operations Research and Management Science; the Association of Old Crows, and the International Council on System Engineering.

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Previously he was Professor of Practice and Founding Director of the SMU Systems Engineering Program. He taught graduate-level courses in engineering probability and statistics, systems reliability and availability analysis, integrated logistics support (ILS), and performed/directed systems engineering research and supervised PhD student research.

Prior to joining SMU full time Dr. Stracener was employed by LTV/Vought/Northrop Grumman where he conducted/directed systems engineering studies and analysis, and reliability engineering activities and was ILS program manager on some of the nation's most advanced military aircraft programs

Dr. Stracener was co-founder and leader of the SAE Reliability, Maintainability and Supportability (RMS) Division (G-11) and is an SAE Fellow and an AIAA Associate Fellow. Jerrell served in the U.S. Navy and earned both PhD and MS degrees in Statistics from SMU and a Bachelor of Science in Math from Arlington State College (now the University of Texas at Arlington).

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e) (Flash Point)

http://www.machinerylubrication.com/Read/989/fluid-degradation-causes

Prenscia HBM

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ReliaSoft Corporation continues its ongoing commitment to providing the leading solutions for reliability engineering, quality and maintenance planning needs of product manufacturers and equipment operators.

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- Xfmea, RCM++ and RBI now allow you to create Parameter Diagrams (P-Diagrams), which provide a visual method for documenting input signals, noise factors and control factors that lead to ideal and undesirable system responses
- Siemens SN 29500 reliability prediction standard is now available in Lambda Predict
- The Synthesis Enterprise Portal (SEP) has a fresh new look with responsive design for better performance on mobile devices to access analyses without having the Synthesis applications installed
- Improved performance and updated interface for spreadsheets
- ALTA Stress Profiles and nCode Glyphworks integration to analyze time series data (*.S3T files)

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Editorial, from page 1

one-year than the number of engineers the U.S. graduates in ten-years! China will soon dominate the technology market place unless U.S. employees gain reliability (and related maintainability and supportability) training in the very near future.

The introduction of self-driving vehicles is an emerging technology that most people have heard about and would like to learn more. Within the next few years we can anticipate seeing self-driving vehicles on our highways and by-ways. These vehicles will require high reliability to operate in a safe and dependable manner. If the U.S. wants to maintain a leadership role in the auto industry, the decision makers should be promoting a workplace culture that encourages the training, support and hiring of skilled reliability professionals. Furthermore, for self-driving vehicles itself to gain consumer acceptance, the auto industry will have to demonstrate high vehicle reliability under most road and traffic conditions. The reliability of self-driving vehicles most likely will have to be as good as, if not better than, that of commercial aircraft.

The issue of cost versus reliability will be a challenging issue to be addressed during an era of emerging intelligent technologies. The trending mind-set of reducing reliability requirements to reduce design and development costs must be reexamined in light of the new technologies that will become status-quo in short order. The emerging intelligent technologies, such as self-driving vehicles, will require intensive life-cycle reliability requirements and related testing to ensure the proper dependability and performance of product operation. Producers' reliance on down-stream logistics support (usually at the cost of the consumer) to remedy deficient reliability requirements due to cost trade-offs, is not a viable option. A self-driving vehicle that fails to navigate a mountainous turn, for example, which ends with hurling the vehicle plus its driver over a cliff, has no real-time logistics solution. Therefore, auto makers will have to design-in stringent and correct reliability requirements despite increased upfront design and development costs. Reliability requirements can no longer be traded-off in favor of cost gains or cost avoidance.

The auto industry already has important lessons learned regarding trade-off analysis. The Japanese auto manufacturers took a significant bite out of the U.S. global auto market shares by providing the consumers with highly reliable vehicles at a time when the U.S auto makers modus operandi was to slight the reliability requirements to profit from the sale of spare parts and maintenance repairs.

The intent of this brief editorial is two-fold: to bring attention to the rapid emergence of intelligent technologies that will be reliability-designed dependent, as well as to highlight the current short-fall of well-qualified reliability experts. Such experts will be needed to design-in reliability requirements into the emerging intelligent technologies, thereby ensuring safe and dependable performance. The focus on self-driving vehicles in this editorial serves as an example of an intelligent technology for which most of us have some common understanding. However, intelligent technologies that can improve the quality of life for many are permeating nearly every technology-dependent industry worldwide. These technologies are gradually introducing themselves into the medical, oil, housing, electronic, shopping and banking industries. Who would have thought ten short years ago that many folks would be paying their bills and purchasing a cup of coffee with their mobile phone?

As you may have previously heard me say, "pay a little more to include reliability requirements during the design and throughout the entire life cycle process or pay much, much, more later on." In the case of emerging intelligent technologies, failure to do so could mean the U.S will lose its leadership role as well as a substantial market share if industry doesn't focus on reliability discipline. Succinctly stated, the pace at which intelligent technologies will be implemented across many manufacturing sectors of the global economy is totally "reliability dependent." ●