Abstract - Integrated Diagnostics is an iterative process that lives within Systems Engineering, but to date there has not been a consistent approach for implementing metrics to monitor diagnostic system enhancements or performance. The DoD has often fielded systems or incorporated "diagnostic enhancements" to systems without having a standardized way for acquisition managers to evaluate or monitor these improvements as the system matures. Acquisition managers need to be provided a standardized process that identifies high cost drivers in a system and provides for diagnostic system performance monitoring. The Logistics and Reliability disciplines have been standardized on metrics for some time but the same cannot be said for diagnostics. Diagnostic metrics for the most part have been relegated to FI, FD, and False Alarm indicators. We need to make another step in the diagnostic community and produce additional relevant metrics specific to the diagnostic engineering process. This paper will address the feasibility of establishing a standardized set of metrics for monitoring integrated diagnostics functionality. These metrics need to encompass on-system (BITIBITE), at system (pilot and maintainer interface management), and off-system (information architecture and data mining) performance monitoring. These metrics should integrate all relevant diagnostic support elements, including but not limited to BITIBITE, external SE, technical information, troubleshooting, and technology insertions.

INTRODUCTION

The Department of Defense (DoD) is faced with the challenge of modernizing its weapon system capability to meet new and emerging mission requirements while the cost to sustain and operate this legacy infrastructure escalates. With a fixed budget to cover both these requirements, a continual series of trade-offs are caused at all levels of the acquisition management hierarchy that affect operational performance and life-cycle costs. An effective system diagnostic and test capability should offer assistance, if not solutions, on both fronts of this battle. First, an effective diagnostic capability should enable operators and maintainers to function more efficiently, thereby reducing the operations and support (O&S) cost requirement. In addition, it should also provide decision-makers with the information they need to make the right decision at the right time for the right reason. As was reiterated repeatedly at a recent open industry workshop hosted by the RAND Corporation on improving product effectiveness and economics, today's diagnostic systems fall far short of making these fundamental contributions.

In this paper, I advocate a potentially new if not expanded set of metrics that can be consistently applied as a diagnostic engineering process that is applicable across multiple architectures, as a prerequisite for an effective, integrated diagnostic capability. Integration of these elements is the key to maximizing the benefits of Integrated Diagnostics because it ties together system requirements and actual operational performance.
As shown in Figure 1, there are multiple relationships between the newly partitioned system interfaces themselves and also with the "design" interfaces.

The elements of the integrated diagnostic interface partitioning must include the acquisition and program management decision function associated with implementing diagnostics, the test equipment used to interface with the system, and the actual operations performed in detecting, isolating and recovering from a detected system degradation or fault. Another important facet of this approach, deals with the various levels of system decomposition at which diagnostic functions are performed. This hierarchy extends from the chip-level up to the system-of-system context in which a given product is a component of a larger operational implementation. When partitioning the diagnostic functions, one must be sensitive to the fact that one system implementation is another's subsystem. We must be careful not to sub-optimize, that is investing in or improving one area at the expense of making one or more of the other functions less efficient or more costly to perform. To pursue improvements in the performance of diagnostics through the standardization of diagnostic metrics we can identify a common way to discuss the diagnostic system performance. If there can be consensus on consistent boundaries and partitions to the system in question, we will have progressed a long way.

SHORTFALLS IN TODAY'S DIAGNOSTIC METRICS

Partitioning and Interface management, or lack of, are where existing diagnostic system implementations fall short of their performance goals and technology insertion opportunities. What I have attempted to do in this paper is present a view of the diagnostic system that can be easily managed by the acquisition or program manager. This macro-level view will not only effect initial performance but more importantly long term performance and also technology insertion opportunities for the sustained or improved effectiveness of a system's diagnostic capability.

Communication is another consistently cited shortfall that greatly affects the performance and improvement of system diagnostics. Poor communication of information, specifically turning captured data into useful timely information for decision makers to make more informed decisions, must be a priority. This is apparent where information available in one diagnostic function that could make another function more efficient is not shared, not recorded accurately or not looked for at all due to a lack of traceability to user needs. These barriers also exist between projects and systems relative to both the sharing of lessons learned or the pooling of diagnostic information and operational data on similar components for higher confidence statistical analyses or data-mining. These barriers exist between phases of a system's life cycle, resulting in higher cost products. The source of this information typically requires interfacing with legacy information systems from which historical information is difficult to analyze, if it is retrievable at all. An easily accessible, centralized "data warehouse" that is traceable to user needs and operational requirements is presently not available for many military systems but should be a basic building block to any diagnostic system implementation.

The second main shortfall in today's diagnostic systems is that acquisition and program managers do not fully understand the relationships between diagnostics functions internally to their system and externally to their system. This is not the fault of the manager, this is due to the complexity of today's weapon systems and the numerous acquisition decisions made that effect long term sustainment costs as can be seen in Table 1.
Acquisition managers are not capable of knowing how their decisions will impact all of the relationships, identified in Table 2 below. But all of these decisions do affect sustainment costs. The trades identified in Table 2 are only a small sample of the total number of acquisition decision trades that can increase or decrease the long term life cycle costs of the system.

Table 2 Diagnostic Cost Trades

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<th>ON-SYSTEM INTERFACE MANAGEMENT</th>
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Today’s weapon systems may have hundreds of line replaceable modules. An increase of the component count also increases the possible causes of failure at the system level. In addition to this increase in the number of possible test outcomes, the highly integrated functionality of these systems and dependence on software for this functionality, leads to multiple system states during its operation. Each of these system states typically yield different fault propagation paths, and as a result, different symptoms to a given failure event. One could anticipate a significant increase in diagnostic ambiguity and false alarms without the proper attention being paid to a system’s diagnostics throughout its development. This is of great concern as it is not uncommon to anticipate a high incidence of what are interchangeably referenced to false alarms or “could-not-duplicates” (CNDs), on future systems. Interface management and partitioning is one way to tackle these problems.

ON-SYSTEM METRICS

The venerable standards are of course Fault Detection (FD), Fault Isolation (FI), and False Alarm (FA) rates. These are industry standards that do not need additional discussion here in this paper. But, what the
The acquisition manager needs to do is ensure that these metrics can be monitored in the fielded environment and not just used as a requirement that needs to be checked off as having been met. I also do want to expand on the important testability attributes of observability and controllability of the design. These later attributes, specifically technologies such as the IEEE 1149.1 thru 1149.4 are important for turning data into information, the main purpose being data capture, encapsulation, transmittal, and diagnostic monitoring.

The following diagnostic metrics if implemented should enhance diagnostic system monitoring, performance monitoring and engineering change cost estimating. The diagnostic list below and those that follow are not meant to be comprehensive, specific system applications will need to develop affordability and cost effectiveness metrics. Detailed implementations methods of all of these metrics are defined a paper specific to the diagnostic engineering process.

1. SLOC-BIT: The System Lines Of Code dedicated for BIT is important for LCC tracking and engineering change cost estimating.

2. PROC-BIT: The percentage of the processor(s) time that's dedicated to BIT is useful for load monitoring. I relate this to the percentage of loading in networks which is normally around 8-11%.

3. MEM-BIT: The percentage of memory used for BIT is important to determine the encapsulation and transmission requirements.

4. Detectable Faults: This is often a lost metric but important to determine the total coverage of a diagnostic system. This metric should be implemented more rigorously.

5. Re-Configurability / Redundancy/ Safing: This metric is important for determining the remaining operational capabilities once a system has degraded and can adapt to aging component's tolerance changes.

**AT-SYSTEM INTERFACE MANAGEMENT**

The at-System interface management involves the pilot and maintainer interactions with the system, or human - machine interface which is historically a challenge.

Recognizing and committing to the maturation of a system's diagnostic capabilities is a basic system need. It is important to realize that integrated diagnostics represents a set of distinct hardware and software elements with definable interfaces operating within an integrated process. Improvement is achieved through a coordinated adjustment of the functionality of these elements as well as the activities and linkages of this process. To optimize the adjustments made, one must understand the process enough to set up effective measurements of its performance, or lack thereof. Unfortunately, there does not appear to be a clear, consistently interpreted set of diagnostic metrics that accurately reflects meaningful performance relative to the user interface. For example, it is not uncommon to see a preoccupation with the metric of Mean-Time-Between-Failure (MTBF) on military systems. While important in its own right, if misinterpreted it can mask a significant underlying performance problem. A better metric for diagnostic performance monitoring is Mean Time Between Maintenance Action (MTBMA). This metric provides more emphasis on a system of systems view to ensure external elements of the diagnostic's system can be considered into the supportability equation. Specifically, this requires external elements of the system to be considered such as support equipment and/or technical data, "positive maintenance actions" and false alarm/ CND/RTOK emphasis.

Managers and engineers need to exercise flexibility selecting a set of metrics that make the most sense for a given system relative to its operational requirements. This flexibility, however, requires a disciplined process of analysis that has access to accurate, timely and useful information. One interface that always needs special focus is the support equipment interface being used for system testing and diagnostics.

**AT-SYSTEM METRICS**

1. Data Transfer rates/ methods: This metric will evolve and gain importance as we move to systems that use high bandwidths and wireless transmission methods to interchange data.

2. Automation Levels: This metric fosters data integrity. Most problems with data analyses and reporting is the old "junk in equals junk out" paradigm. By automating the information gathered during diagnostic testing either by the operator, internal testing or external support equipment by machine - human prompting such as pull down screens we can increase data integrity.

3. Pilot Interface: As a subset of automation, this metric defines the methods in which operators insert observable data during a mission as well as the pilot debriefing function.
4. Maintainer Interface: Maintainers are the prime people who can provide relevant information on system diagnostic performance. Ease of allowing the maintainer to document observable indications is the key for this metric. MTBMA as discussed above would fall into this category of metric.

5. Distinct information interfaces: This metric involves designing BIT for two distinct users, the operator and the maintainer. One has a focus on operational capabilities for operator situational awareness, the other focus is on failure identification for maintenance actions. In future diagnostic systems, remote testing, measurement, and control in near real time will need to be considered as a metric in the diagnostic architecture.

OFF-SYSTEM INTERFACE MANAGEMENT

Inability to specify or measure diagnostic performance at the system level is another shortfall that is constantly cited. The challenge highlighted relative to the acquisition of military systems is the use of traditional performance criteria that either directly or indirectly imply a “how to.” As one of the goals of acquisition reform, this practice is being eliminated but often acquisition managers feel constrained in devising ways to stipulate diagnostic performance requirements that result in products that meet their operational requirements. One of the difficulties in this area is the challenge of linking the diagnostic capability of a system with its operational performance and overriding performance goals of the program in order to reduce costs and improve decision making and interoperability.

Beyond the specification of a specific set of requirements, industry lacks the systems engineering tools to effectively allocate diagnostic requirements within the evolving system architecture. Part of this challenge deals with being able to work concurrently with the systems designers to model and simulate the diagnostic performance of a proposed design in a timely fashion.

Finally, given the specification of diagnostic performance requirements, there exists a general consensus that we lack an effective way of testing this performance in a manner that accurately represents a system's intended operational use. The scenario that consistently reoccurs is an inadequate test when the system is accepted during a developmental, independent technical or operational evaluation. The system is then fielded with actual diagnostic performance, falling far short of its intended goals.

One of the contributing factors to this dilemma is the fact that diagnostic capability matures through actual operational use where models do not. Diagnostic maturation is not well understood, so it cannot be modeled and tested accordingly, nor committed to by the required parties to ensure the system actually improves in light of its actual performance. The following metrics should provide indicators of where system interoperability enhancements can be made.

OFF-SYSTEM METRICS

1. Asset visibility: This metric is not new concept but one that is very complex in implementation.

2. Interface Complexity: This is a metric that identifies and documents all of the interfaces for the system. This requires a detailed review of users and capabilities and forces traceability so that information is provided in user preferred formats and methods. Diligent implementations can indicate interfaces where translators are required for technology insertions. Implementations where a CORBA or like industry standard is used will benefit from commercial uses and minimize interface complexity.

3. Bad Actor Management: The benefit of this metric has been clearly defined numerous papers written by the RAND Corporation and has been implemented successfully on some military systems.

4. Data Integrity: The benefit of being able to trust the information provided to the decision maker cannot be over emphasized. When erroneous information is used in data mining and analyses the errors are multiplied.

5. Network View: The Open System Interconnect (OSI) 7-layer model is used as the basis for describing the flow of diagnostic information. The OSI model is a framework for integrating hardware and software elements so as to ensure effective communication and tolerance to evolutions of hardware technology. As Illustrated in Figure 2, each distinct element of a system's diagnostics is modeled as a node on a network.
Nodes communicate over physical media that may be implementation specific or may conform to some standard. Nodes transmit data packets to adjacent nodes over the link layer; nodes transmit data packets to other nodes on the network over the network layer. At the physical layer, nodes use specific voltages, frequencies, or light pulses to transmit data. The data becomes more abstract: first as bits, then words, and finally as temperatures, times, and failure codes, as it moves up into higher layers. Some of the differences between commercial and DoD network partitioning can be seen in figure 3.

**Figure 3. Partitioning Differences between DoD and Commercial**

The solution to these differences are usually worked on a system by system basis unless the acquisition manager defines them up front IAW some well known higher level system interoperability requirement.

**CONCLUSIONS**

Effectively supporting diagnostic requirements in the systems engineering process is essential now and more so in the future. An often cited reason for inadequate diagnostic capability designed into existing systems is that it was traded during the development process for some combination of cost, schedule or operational performance. This is not unique to systems in the DoD. Not surprisingly many programs operate under the same systems engineering paradigm in which constraints are optimized. Whether we are discussing flyaway costs or sticker prices, these are the short term measures of effectiveness on which program managers are forced to focus. Figure 4 shows some of the interface management frustrations of implementing a well documented interface management program. Diligent application and a standardized implementation process will ease this procedure for acquisition and program managers resulting in better products.

**Figure 4. Interface Management Challenges**

There are several dimensions to the acquisition challenge encountered in the diagnostic trade-off arena. To begin with, it is difficult to make the argument for an investment in something that is advertised to yield out year benefits in lieu of an additional or expanded operational capability that will be evident on long after the decision maker is long gone. Another facet of this problem is the difficulty of understanding or communicating the dependencies between a given system capability and lack of that capability’s effect on the ability of a system to achieve its operational requirements in a cost-effective manner. A clear, consistent framework or architecture that communicates to decision-makers these dependencies relative to a system’s ability to achieve some minimum level of performance is lacking. This leads us to a more basic deficiency with the ability to design and implement an effective diagnostic capability in our weapon systems: an ability to specify and measure diagnostic performance metrics at the system level during initial acquisition. My hope is that the 3 system partitions and the 15 metrics provided here can serve as a basis for standardizing the way we think of and discuss diagnostic implementations.
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