An Investigation of Current and Emerging Standards to Support a Framework for Prognostics and Health Management in Automatic Test Systems

John W. Sheppard
Gianforte School of Computing
Montana State University
Bozeman, MT 59717
Email: john.sheppard@montana.edu

Joseph D. DeBruycker
Gianforte School of Computing
Montana State University
Bozeman, MT 59717
Email: jd.debr@gmail.com

***Abstract*—The complexity and widespread use of modern day electronics in today's weapon systems necessitates a robust state-of-the-art framework for the development and operation of automatic test systems (ATS). The Department of Defense (DOD) ATS Framework Working group is developing an information standards-based framework to support interoperability in modern ATS. The expectation is that such ATS will improve overall maintenance, availability, and safety of these weapon systems while also reducing the cost of ownership of the weapon systems and their support infrastructure. A key emerging aspect of this framework is prognostics and health management (PHM). PHM is a field of work concerned with the detection, assessment, and prediction of the health of a complex system. In this paper, we summarize the current state of the DOD ATS Framework and address the functional gaps related specifically to PHM. The intent is to use this as a starting point for defining a corresponding ATS Framework for PHM. To do this, we provide a mapping between the key elements of the current framework to the functional blocks of the Open Systems Architecture Condition Based Management (OSA-CBM) standard, identifying existing standards or standards under development, and providing recommendations for areas that need improvement.**

I. Introduction

Safety, reliability, maintenance, availability, and cost are all important factors when dealing with modern, complex weapon systems. Major forces driving the improvement and advancement of these concepts are modern logistic support concepts such as condition-based maintenance (CBM) and performance-based logistics (PBL) [1]. Applying these concepts depends, in-part, on the health assessment and prediction capabilities of PHM to fully realize their logistic and economic benefits. Furthermore, the increased complexity of combining interrelated subsystems, coupled with the rapid advancement of modern computational resources, makes an advanced testing framework an integral aspect of designing, building, and maintaining such systems. Automatic test systems (ATS) have become a necessity in many fields of engineering in order to help manage system complexity and ensure that the specific maintenance needs of a system can be met, while simultaneously minimizing the required inputs of time and money. Furthermore, a comprehensive standards-based framework is essential for maximizing interoperability and reuse of the test resources on such ATS.

Advancements in the fields of machine learning and artificial intelligence have opened new doors in the field of ATS design, allowing ATS engineers to leverage the power of the test platform to make predictions about the state of the unit under test (UUT), which can aid in the decision making process during maintenance procedures. However, while the health monitoring and diagnostic aspects of PHM have seen rapid advancement in recent years, prognostic capabilities are still in their infancy. The inherent difficulty of making and verifying accurate prognoses presents a unique challenge to those working to advance the field, and the body of standards (or lack thereof) supporting PHM is a testament to the difficulty of the task. While there has been some recent work within the Institute for Electrical and Electronics Engineers (IEEE) standardizing a new PHM framework [2], this standard has not yet reached a level of maturity to be useful within the ATS domain.

This paper looks at the current state of the body of standards that may be suitable to support PHM, as well as analyzing the role of PHM within an ATS. Specifically, we provide a mapping between the current DOD ATS framework and a popular open-system architecture standard, OSA-CBM [3], and we make several recommendations in areas we feel may require further work in order to fully support PHM in an ATS environment.

II. Automatic Test System Framework

The DOD ATS Framework Working Group is a multi-service/industry/academic partnership focused on defining an information framework and identifying standards for next-generation ATS [4]. The current framework consists of 25 key elements divided into three functional categories: the Automatic Test Equipment (ATE), the Test Program Set (TPS), and the Unit Under Test (UUT) (Figure 1). Definitions of the specific elements can be found in Table I.

The ATE consists of the test hardware and accompanying system software as well as the network environment

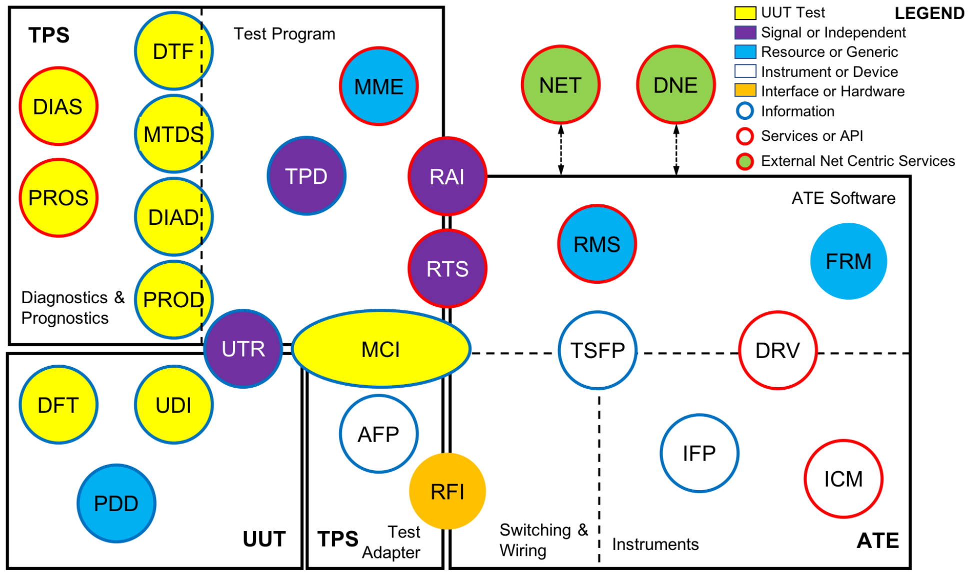

Fig. 1. Department of Defense Automatic Test System Framework Key Elements

with which the hardware interacts. The TPS consists of the automated testing software, the interface devices, and the documentation related to performing and evaluating tests. The UUT is a catch-all term for any piece of equipment or complex system that is connected to the ATE and evaluated via the TPS. The framework also has a list of supporting standards for each key element along with an evaluation of whether those standards satisfy the requirements associated with that element or represent a capability gap, indicating more work is needed in the form of new or additional standards.

In 2007, elements for prognostic data (PROD) and prognostic services (PROS) were added as parallels to the the diagnostic data/services (DIAD/DIAS) elements, acknowledging the important role prognostics will be expected to serve in ATS. However, these elements represent capability gaps in the current framework as there is only a single cited standard to represent all four elements: IEEE Std 1232— Artificial Intelligence Exchange and Service Tie to All Test Environments (AI-ESTATE) [5]. This standard has received multiple updates since its initial creation, and while it does provide support for some PHM capabilities, the field of prognostics has not yet matured to the point for this single standard to encompass the various approaches that are available for PHM systems. This paper examines several standards that might be useful in expanding the PHM capabilities of the framework and thus help cover the current capability gaps.

TABLE I
ATS Framework Key Element Definitions from Figure 1

TPS	AFP	Adapter Functional and Parametric Information
	DIAD	Diagnostic Data
	DIAS	Diagnostic Services
	DTF	Digital Test Format
	MCI	Master Conformance Index
	MMF	Multimedia Formats
	MTDS	Maintenance Test Data and Services
	PROD	Prognostic Data
	PROS	Prognostic Services
	TPD	Test Program Documentation
ATE	DNE	Distributed Network Environment
	DRV	Instrument Drivers
	FRM	System Framework
	ICM	Instrument Communication Manager
	IFP	Instrument Functional and Parametric Information
	NET	Data Networking
	RAI	Resource Adapter Information
	RFI	Receiver Fixture Interface
	RMS	Resource Management Services
	RTS	Run Time Services
	TSFP	Test Station Functional and Parametric Information
UUT	DFT	Design for Testability
	PDD	Product Design Data
	UDI	UUT Device Interfaces
	UTR	UUT Test Requirements

III. Prognostics and Health Management

PHM has been defined as "a maintenance and asset management approach utilizing signals, measurements, models, and algorithms to detect, assess, and track degraded health, and to predict failure progression" [6]. According to this definition, PHM encompasses two primary interrelated tasks, which correspond to the semantic division between diagnostics and prognostics: current state estimation and future state prediction. Each of these tasks entail a variety of sub-tasks that support the goals of diagnostics and prognostics.

Current health state estimation, or diagnosis, consists of signal detection and processing, feature extraction, and fault detection and isolation, and may also incorporate outside information unique to the UUT such as previous operational conditions and maintenance history. Future state prediction, or prognosis, builds upon state estimation, making use of physics-of-failure models, statistical reliability data, Bayesian models, and other data-driven methods such as regression, time-series analyses and neural networks, to attempt to make accurate predictions about the potential progression of a fault and the resulting effects on the overall system. A common prognostic task is predicting the remaining useful life (RUL) or time to failure (TTF) of a component. These measures can then feed into a maintenance advisory that assists in the decision-making process for how to best mitigate an emerging system fault in a way that maximizes system availability and minimizes associated risks and costs.

The diagnostic aspect of PHM, being the foundation of all maintenance tasks, has been well studied [7]. Accurate fault detection and isolation are integral to maintaining and repairing complex systems, and as the complexity and cost of such systems has increased over time, so too has the importance of accurately diagnosing problems that arise during manufacturing and operation. Maintenance strategies have also evolved alongside system complexity; however, their development has had difficulty keeping pace.

In the past, it was common to implement reactive maintenance strategies that waited for a component or system to fail before being repaired or replaced. Alternatively, scheduled maintenance strategies were implemented that focused on regular maintenance intervals derived from reliability analysis. Today there is more focus on so called "condition-based maintenance," which prioritizes component state monitoring and data analysis to determine when maintenance actions are necessary, with the goals of reducing life-cycle cost and increasing system availability [8]. Assisted by modern sensor and computing technology, coupled with advanced built-in test and built-in self test, maintenance has shifted to a more individual assessment approach. This is in contrast to having one policy for an entire line of units, and the intended results are cutting costs by not replacing functional parts and increasing safety by detecting unique incipient faults that occur on a unit-by-unit basis.

Along with the shift in focus to this state monitoring approach and the accompanying increase in diagnostic capabilities has come an increased desire for accurate predictive capabilities. Consistent and accurate state prediction factors directly into the goals of modern CBM logistic strategies. Furthermore, much of the data that is already being collected and processed for diagnostics (for example during the run of a TPS, especially during the return-to-service test) could be reused for prognostic tasks as well. This means that with the right approach, prognostic capabilities could be incorporated in a relatively straightforward way into current testing and maintenance frameworks. Standards development is one key aspect for defining a consistent and effective approach to performing this task.

IV. PHM ON AN ATS

The current DOD ATS framework's key element definitions correspond to the software, hardware, documentation, and environmental components that make up an ATS (Figure 1).

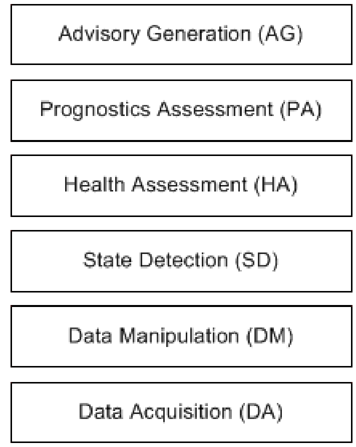

Fig. 2. OSA-CBM Functional Layers/Blocks

Although there are currently four elements included specifically to address the functionality of PHM in an ATS (DIAD, DIAS, PROD, PROS), many of the other key elements will also play an important role in a fully realized PHM-enabled test station. With this in mind, we have mapped the key elements of the ATS framework to the Open System Architecture Condition Based Maintenance (OSA-CBM) framework, an approach we believe will be beneficial to the framework's goals of supporting and enabling CBM and PHM functionality on ATS.

OSA-CBM is an open-architecture standard designed with the goal of specifying the information to be exchanged by the components of a CBM system without requiring any specific or proprietary implementations. OSA-CBM has the added goal of increasing the interoperability and thus the availability of CBM components [3]. This "multi-technological implementation" makes OSA-CBM a good fit for incorporating CBM and PHM capabilities into a general system support framework. The OSA-CBM standard consists of a hierarchy of six (previously seven) functional blocks designed to encompass the full range of functionality required for CBM and PHM systems (Figure 2) [9]. A brief summary of each of the functional blocks follows.

1) **Data Acquisition (DA):** The DA block gathers raw data from sensors and transducers about the system being monitored.
2) **Data Manipulation (DM):** The DM block is responsible for performing signal processing, signal transformation, and feature extraction on the acquired data.
3) **State Detection (SD):** The SD block compares and analyzes the processed data with expected values or system models in order to discover abnormalities in the data.
4) **Health Assessment (HA):** The HA block performs fault detection and fault isolation to find the root cause of system abnormalities.
5) **Prognostics Assessment (PA):** The PA block forms predictions about the future state of the monitored system

and the progression of detected abnormalities and faults.

6) **Advisory Generation (AG):** The AG block suggests potential maintenance actions and alternative operating instructions for the duration of the mission that assist in decision-making logistics actions.

In addition to the current OSA-CBM functional blocks, our mapping also includes a Design block and a Presentation block. The Presentation block was previously a part of the OSA-CBM standard, and we felt it warranted inclusion in this report as it involves synthesizing information from many of the other blocks. We also believe the Design block provides a better fit for some of the ATS key elements and represents an important step in the overall process of developing a CBM/PHM system.

V. Recommended Standards Summary

In our review of current industry standards, we have identified several that we believe could be relevant to supporting PHM capabilities in the DOD ATS framework. We discuss these standards within the context of our mapping of the framework's key elements to the OSA-CBM functional blocks in the areas where we believe they are most applicable. This section provides a brief overview of these standards.

- IEEE STD 1232-2010 Standard for Artificial Intelligence Exchange and Service Tie to All Test Environments [5]: Provides mechanisms for model exchange and API specifications for diagnostic systems. Can be extended to support prognostics as well. Several proposals have been made for PHM extensions, but none have as yet been incorporated into the standard [10], [11], [12], [13].
- IEEE-P21451 Signal Treatment Applied to Smart Transducers [14]: Describes a framework for interfacing communication and sensor technologies. An interesting element of this standard is the defintion of "transducer electronic data sheets" (TEDS) that provide a formal means of storing sensor identification, manufacturer, calibration, and correction data with the device.
- IEEE P1636 Standard Software Interface for Maintenance Information Collection and Analysis [15]: An updated version that recently passed its ballot and is before the standards board for final approval. Updates the SIMICA family to incorporate a "common" data model based on XML and OWL for historical maintenance information collection. Replaces the currently approved IEEE STD 1636-2009 and IEEE STD 1636.99-2013 as well as replacing the EXPRESS models with OWL ontologies.
- IEEE P1636.1 SIMICA Test Results and Session Information [16]: An updated version that recently passed its ballot and is before the standards board for final approval. Updates the SIMICA family to replace the EXPRESS specification with an OWL specification. Supports collecting parametric test information. Retains the XML specification and removes all dependence on the IEEE 1671 Automatic Test Markup Language (ATML) standards.
- IEEE P1636.2 SIMICA Maintenance Action Information [17]: An updated version that recently passed its ballot and is before the standards board for final approval. Updates the SIMICA family to replace the EXPRESS specification with an OWL specification. Support collecting information on historical maintenance and repair actions. Retains the XML specification as well and removes all dependence on the IEEE 1671 ATML standards.
- MIMOSA OSA-CBM [3]: An implementation of ISO standard 13374. Defines six blocks of functionality in condition monitoring systems as an open architecture, focusing on communication between the functional blocks. Through these functional blocks, identifies the key components of a CBM system, most of which are directly applicable to PHM systems as well.
- ISO 10303-239 Application Protocol for Product Life Cycle Support [18]: Describes data exchange via Data Exchange Specifications (DEX) that are defined/derived from Product Life Cycle Support (PLCS) models.
- ISO 13374-1 Condition Monitoring and Diagnostics of Machines [19]: Specifies software requirements for transfer of data between monitoring software. Includes communication requirements for open condition monitoring and diagnostics (see OSA-CBM).
- ISO 13381-1 General Guidelines, Approaches, and Concepts for Prognostics [20]: Describes four phases of prognosis: preprocessing, existing failure mode prognosis, future failure mode prognosis, post-action prognosis.

A. *Other Relevant Standards*

- IEEE 1445 Standard for Digital Test Interchange Format (DTIF) [21]: Defines information content and data formats for the interchange of digital test program data between digital automated test program generators (DATPGs) and automatic test equipment (ATE) for board-level printed circuit assemblies.
- IEEE 1641 Signal and Test Definition [22]: Provides the means to define and describe signals used in testing. It also provides a set of common basic signals, built upon formal mathematical specifications so that signals can be combined to form complex signals usable across test platforms.
- IEEE 1671 Automatic Test Markup Language (ATML) [23]: Specifies a framework for the ATML family of standards. ATML allows ATS and test information to be exchanged in a common format adhering to the extensible markup language (XML) standard.
- IEEE 1856 Standard Framework for Prognostics and Health Management of Electronic Systems [2]: An attempt to define a standard framework for PHM systems, but currently focused only on basic definitions. It is currently not sufficient to cover any capability gaps.
- ISO 10303-11 Industrial automation systems and integration – Product data representation and exchange – Part 11: Description methods: The EXPRESS language reference manual [24]: Specifies the EXPRESS language by which

aspects of product data can be defined. Has been used historically as a means for specifying information models for system product data, as well as system diagnosis.
- ISO 10303-28 Industrial automation systems and integration – Product data representation and exchange – Part 28: Implementation methods: XML representations of EXPRESS schemas and data, using XML schemas [25]: Specifies a means for mapping an EXPRESSS information model into an XML schema. Supports XML-based information exchange with underlying semantics enforced through EXPRESS.
- IEC 60812 Analysis techniques for system reliability - Procedure for failure mode and effects analysis (FMEA) [26]: Describes Failure Mode and Effects Analysis (FMEA) and Failure Mode, Effects and Criticality Analysis (FMECA), and gives guidance as to how they might be applied.
- IEC 61709 Electric components - Reliability - Reference conditions for failure rates and stress models for conversion [27]: Provides guidance on the use of failure rate data for reliability prediction of electric components used in equipment.

VI. Handbooks and Guides

In addition to the aforementioned standards, there are also a number of potentially useful handbooks available that could assist in designing and implementing PHM-oriented test systems. Although we do not include these in our mapping, we list them here for reference.

- MIL-HDBK-217 Reliability Prediction of Electronic Equipment [28]: Provides detailed information for a wide variety of electronic reliability estimates and estimation methods.
- MIL-HDBK-338 Electronic Reliability Design Handbook [29]: Describes the concepts, principles, and methodologies used in electronic reliability engineering and cost analysis. The focus is on providing procurement officers with basic knowledge needed to support the design, acquisition, and deployment of DoD systems.
- MIL-HDBK-472 Maintainability Prediction [30]: Focues on describing maintainability prediction procedures, mostly from the perspective of reliability engineering. Despite being a bit outdated this appears to be generally relevant to the task of prognostics.
- US Army ADS-79-HDBK Aeronautical Design Standard: Handbook for CBM Systems for Aircraft [31]: Addresses data acquisition, signal processing software, data management, and FMECA. Multiple appendices are included for developing CBM systems including planning, fault testing, and software/hardware design. Supported by MIMOSA.
- SAE-J1211 Handbook for Robustness Validation of Automotive Electrical/Electronic Modules[32]: Addresses reliability detection as well as prevention, focusing mainly on hardware - references an upcoming system level handbook that could not be located.
- SAE-J1879 Handbook for Robustness Validation of Semiconductor Devices in Automotive Applications [33]: Addresses reliability detection as well as prevention specifically in the context of semiconductors.

VII. Gap Analysis

As it stands, the DOD ATS framework cites a number of capability gaps between the key elements and their supporting standards. Currently only seven key elements are marked as completely satisfied: digital test format (DTF), maintenance test data and services (MTDS), master conformance index (MCI), multimedia formats (MMF), data networking (NET), instrument communication manager (ICM), and instrument drivers (DRV). Of these, we believe all except MTDS are satisfied with respect to PHM as well.

The remaining elements are divided roughly into two categories: those that are cited by the current framework as representing a capability gap, and those that represent a potential gap either according to the current framework or with respect to PHM capabilities.

A. Capability Gaps

The key elements cited as definitely representing capability gaps with respect to the current framework are: diagnostic data (DIAD), diagnostic services (DIAS), prognostic data (PROD), prognostic services (PROS), distributed networking (DNE), receiver fixture interface (RFI), resource management services (RMS), run time services (RTS), product design data (PDD), and UUT device interfaces (UDI). Of these, the four elements, DIAD, DIAS, PROD, and PROS are highly relevant to PHM and as such represent a significant capability gap with respect to PHM. We also identify the elements RFI, RMS, and RTS to be potentially relevant to PHM and thus represent a potential capability gap with respect to PHM. The remaining elements DNE, PDD, and UDI do not explicitly represent a gap with respect to PHM.

B. Potential Gaps

The remaining elements are cited as potential gaps, either in the context of the current framework or by us as representing a potential gap with respect to PHM. Of these, adapter functional and parametric information (AFP), test station functional and parametric information (TSFP), test program documentation (TPD), resource adapter information (RAI), and UUT test requirements (UTR) are largely addressed in the traditional context of the ATS framework; therefore, we have not made specific recommendations concerning these elements beyond placing them in our mapping. The key elements instrument functional and parametric information (IFP), system framework (FRM), and design for testability (DFT) however are potentially relevant to PHM. We believe that FRM is satisfied with respect to PHM, but IFP and DFT represent potential gaps.

VIII. PHM Deficiencies in Current Framework

Currently the body of standards supporting PHM in complex electronic systems is lacking in both depth and breadth, due in part to the relative immaturity of PHM as a discipline. The standards that do exist focus primarily on data transfer and information exchange, which is important for both ATS in general and enabling CBM and PHM specifically. Especially considering a hierarchical architecture such as the one proposed by the OSA-CBM standard, standardizing the data exchange between the functional layers ensures that, regardless of the specific implementation of each layer, the requisite information from other layers will be readily available in a usable format. For example, historical maintenance information (MTDS) is a key element that we have identified as relevant to all the functional blocks in our mapping since this information provides direct insight into how systems have failed in the past. Therefore, care must be taken to ensure that this information can be communicated successfully to each block. IEEE Standard P1636.2 (SIMICA) provides an XML schema for maintenance action information (MAI), and while this standard meets the current ATS framework requirements, we believe that this element will require careful consideration when developing PHM capabilities and could represent a potential deficiency.

IEEE Standard 1232 (AI-ESTATE) is the primary standard currently supporting the key elements DIAD, DIAS, PROD, and PROS. This standard specifically supports the exchange and processing of diagnostic information as well as control of diagnostic processes. As such it is more suitable in supporting DIAD and DIAS, yet even in these areas it is not sufficient to completely satisfy the needed capabilities. For instance, health information is still limited to discrete outcomes rather than allowing real-valued graded health information. Furthermore, AI-ESTATE was not designed to address the predictive components for PROD and PROS, so these elements still need to be addressed. In addition, AI-ESTATE was developed using the modeling practices of the ISO EXPRESS modeling language; however, the complexity and usability of this language may be one of the issues preventing the wide-spread adoption of this standard. Consequently, plans are underway to develop a replacement standard that would address all four elements (DIAD, DIAS, PROD, and PROS) using accepted practices in semantic modeling through languages such as OWL.

The standards currently cited supporting RFI (IEEE 1693), RMS (IEEE 1641 Annex K), and RTS (IEEE 1671 Annex D) are listed as capability gaps in the current framework; furthermore, we do not identify these standards as being relevant to PHM in their current form. As these key elements could potentially be useful for PHM, these represent deficiencies for PHM.

IEEE Standards 1149.1 Test Access Port and Boundary-Scan Architecture, 1149.2 Extended Digital Serial Subset, and 1149.4 Mixed Signal Test Bus are currently listed as emerging standards that might represent a capability gap in the current ATS framework. These also represent a potential deficiency with respect to PHM, as the key element DFT is applicable across the OSA-CBM functional blocks for Design, HA, PA, and AG, but we do not believe these standards will fully cover these blocks.

IX. Recommendations

With respect to the cited gaps and deficiencies we make the following recommendations.

1) Maintenance information should be made readily available to any prognostic service, and an analysis should be done to ensure that this data can be incorporated easily into a prognostic advisory system. We have recommended ISO Standard 10303 AP 239 as a potential standard for transfer of maintenance data; however, more work needs to be done to ensure that this data can successfully be incorporated into a PHM system in a way that enables data models and inference algorithms to take advantage of the information being communicated.
2) Diagnostic data and services must continue to be refined to support PHM applications more fully. Much more work is needed to extend these elements into the area of prognostics. A new standard taking the place of AI-ESTATE that focuses on clarity, usability, and explicitly incorporating diagnostic data and services is a potential solution to the current gaps and deficiencies in this area. To help meet these goals we recommend replacing the EXPRESS specification with an OWL specification, following the updates to IEEE 1636. We have also recommended ISO standard 13381 as being useful for supporting specific prognostic capabilities in ATS. Several other standards might also assist in more clearly defining the PROS element of the framework: SAE J1879, IEC 61709, and ISO 10303 AP239.
3) For incorporating the elements RFI, RMS, and RTS into PHM, we have identified IEEE 1451 and ISO 13374 (of which OSA-CBM is an implementation) as potentially useful at the data manipulation level; however, these standards may require a closer look to evaluate their overall applicability. We also recommend ISO 13374 to extend the key element IFP to the DM functional block.
4) We have identified the FRM element as relevant across all of the OSA-CBM functional blocks. The current recommended standards (VPP-2 and IEEE 1671 ATML), however, are only applicable to the DA, DM and SD blocks. We recommend multiple standards for extending this element across the remaining blocks. Specifically, the combination of OSA-CBM and ISO 13374 can provide guidance for the informational exchange across all levels of the system, meeting the specified goal of the key element to reduce costs by incorporating interchangeable components into the ATE. In addition, AI-ESTATE and ISO 13381 will be useful for ensuring that the health and prognostics assessment blocks are factored into the system framework appropriately. We believe that with these recommendations the FRM element will be satisfied with respect to PHM.

X. Conclusion

The ATS Framework Working Group has been working for several years to identify or define informations standards that support interoperability of key elements in an automatic test system. Recently, the DOD has been placing considerable emphasis on refining maintenance strategies by incorporating methods for condition based maintenance (CBM) and prognostics and health management (PHM) into their weapons system support strategies. With the tremendous investment into ATS for weapon system support, coupled with the fact new maintenance strategies are required for existing and legacy systems, it makes sense to consider methods for incorporating PHM technologies into ATS. For this to be successful, the ATS Framework needs to be adapted to consider PHM-related issues as well.

This paper has focused both on how the standards currently identified in the ATS Framework satisfy PHM requirements and on how other standards that have been defined might help satisfy these requirements. As a result of the associated analysis, we have concluded that considerable work remains to be done. We have identified a number of gaps to be satisfied and have made some limited recommendations on how to go about filling these gaps.

PHM is still a very new discipline. While the time may be right to consider what constitutes an appropriate framework to support PHM, it is still too early to say what the standards plugging in to that framework should cover. Much of the research being performed is based on work in artificial intelligence, data mining, data analytics, and machine learning. Until these fields stabilize, at least with respect to PHM, it is difficult to imagine what complete coverage of the PHM requirements would constitute. But that does not mean work should stop. Instead, standardization efforts should proceed by addressing the information requirements and interactions of the systems that are currently being deployed, with room for the standards to be extended, enhanced, and modified as the technology matures.

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