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Analysis of Standards for Lifecycle Management of Systems for US Army --- a preliminary investigation

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Analysis of Standards for Lifecycle Management of Systems for US Army --- a preliminary investigation

Executive summary

The need to exchange data among multiple business partners, developers, suppliers, users, and maintainers is the normal day-to-day complex business environment for the U.S. Army and other Department of Defense (DoD) Services. Product lifecycle management (PLM) is a function or a business strategy for creating, sharing, validating, and managing information about product, process, people, and services within and across the extended and networked enterprise covering the entire product lifecycle spectrum.

A number of institutions including the National Institute of Standards and Technology (NIST), Department of Defense (DoD), the European Ministries of Defense and, more recently, by the vendor and end-user communities have recognized the importance of interoperability across the phases and functions in PLM. A 1999 study commissioned by NIST estimated that imperfect interoperability of engineering data costs at least $1 billion per year to the members of the U.S. automotive supply chain. By far, the greatest component of these costs is the resources devoted to repairing or reentering data files that are not usable for downstream applications. This is parallel to the Army's lifecycle logistics support costs for any given weapon system and its components. As reported in a Government Accounting Office report for DoD, operating and support costs make up about 60-70 percent of a weapon system's total lifecycle costs. Many of the current ground weapon systems will continue to be in service for another 20-30 years. The Army needs the ability to support systems after production while reducing sustainability costs. The PLM challenge faced by the Army is to implement standards and protocols that allow legacy systems as well as future technological innovations to interoperate seamlessly.

To meet its responsibilities, the Army has committed to a Single Army Logistics Enterprise (SALE) framework. SALE is designed to correct a long-standing problem in the Army's logistics information management, notably: lack of a common operating process for measuring and analyzing materiel readiness and combat posture. Using SALE, the Army intends to integrate its national and tactical logistics systems into one fully integrated, end-to-end enterprise. SALE will bring together three component systems: the Global Combat Support System-Army (GCSS-Army) Field Tactical (F/T), the Logistics Modernization Program (LMP), and GCSS-Army PLM+. PLM+ is the technical enabler proposed to link the field-level logistics system, GCSS-A with the National-level logistics system, LMP, and to establish a single access point interface to integrate all the Army's external systems.

Such a commitment to the concepts of SALE is no longer an option for the Army, but a logistics imperative. The US Army Materiel Command (AMC) is responsible for this logistics support. To achieve their goal AMC Headquarters has formed the Army Product Data and Engineering Working Group (PEWG).

The PEWG is chartered to provide solutions and a plan of action for the Army solutions to address the complexities of the engineering and logistics supply chains within the Army, and to integrate these with Original Equipment Manufacturers (OEMs) and their associated enterprises that create and maintain the data in today's global business environment.

This report is in response to two milestones for PEWG's Work Package 2:

- Identify standards that could be used for lifecycle product data standardization, interoperability, and exchange among Army's and its OEMs' enterprise systems (e.g., SALE, Future Business System).
- Help build a business case for using standards.

Today's standards, particularly in the area of computer-aided design (CAD), have produced direct improvement in productivity, especially in the manufacturing arena, by reducing transaction costs and increasing the richness of interactions between suppliers and customers. The initial use of ISO 10303, informally known as the STandard for the Exchange of Product model data (STEP), has brought proven cost savings in the automotive industry. In research conducted in another NIST-commissioned economic impact study on the cost of doing business if STEP were not implemented, it was found that the biggest impact was felt lower in the supply chain than by the OEMs. First tier suppliers estimated a $250 million savings per year from adopting STEP standards; and sub-tier suppliers estimated almost $200 million in savings.

Achieving efficient PLM requires being able to understand the ecosystems supporting the lifecycle logistics. We propose a standards typology (i.e., a classification system) for the Army to use to identify the suite of standards best suited to meet its product lifecycle needs. Given the proven savings from implementing STEP, NIST believes STEP standards could provide a strong foundation supporting PLM, and be developed within the typological framework described in Section 5.

This report (primarily in Section 4) provides a preliminary investigation of a selected set of standards and frameworks. These were mentioned during our site visits and interviews at various US Army Research Centers (See Appendix A) and also cited in DoDD 5000.1 or identified for defense use by memoranda. The standards included in the scope of this report are:

- ISO 10303, Product data representation and exchange, is a suite of standards used to exchange product model data.
- ANSI/GEIA-927, Common data schema for complex systems, is an integrated multi-domain data schema for representing product and process data.
- EIA-836, Configuration management and data exchange and interoperability, provides a means to create a central source of configuration management information for exchange among necessary partners.
- ANSI/EIA-649, National consensus standard for configuration management, describes configuration management functions and principles and defines a neutral terminology.
- MIMOSA OpenO&M is intended to provide a harmonized set of information technology standards for the exchange of operations and maintenance information.
- ASD/AIA-S1000D, International specification for technical publications utilizing a common source database, pulls together the use of other international standards to support the production and use of electronic documentation.

- DoD architecture framework (DODAF) defines a common approach for DoD architecture description development, presentation, and integration.

In general, the use of internationally developed, industry-driven, and industry-maintained standards allows the maximum freedom of choice for the AMC; and will drastically reduce expense across the product lifecycle. Information technology standards are a key enabler to manufacturers and participants in the lifecycle management of the product's data for bridging the gap between the multitude of enterprise systems and the asset management systems. This aspect is critical to the U.S. Army as most of its asset management systems and associated product data still lie within the ownership, or at least physically located with, the OEM delivering the product and associated support. A movement toward the adoption and implementation of data representation and exchange standards to support fully the product's lifecycle processes has proven a good business practice.

Based on our analysis of the list of standards selected for review, we made the following observations:

- Some of the standards are extensions of the others, e.g., EIA-836 complements the well-established ANSI/EIA-649 standard for configuration management and incorporates its principles.
- Some of the standards are built as an integration of others, e.g., GEIA-927 is an integration of ISO 15926, PAS20542, ISO 10303-AP212, and AP239; and more standards are currently being integrated into GEIA-927.
- A number of the same functionalities are supported by more than one standard, e.g., configuration management is included in ANSI/EIA-649, EIA-836, 10303-AP203, ISO 10303-214, and 10303-AP239. To compound this overlap, several standards are being developed within the United States, while similar development efforts are, or have occurred, in the international arena, e.g., GEIA-0007 and ISO 10303-239, EIA-836 and ISO 10303-203, and ANSI/EIA-649 with ISO 10007. (The latter is not covered in the scope of this report.)
- EIA-836 appears to be a thorough and good start for managing configuration data within the Army, but it appears the funding of the work and the interest in the work is only by the government. Without much industry buy-in, such a project and direction in employing standardization will be an expensive approach for longer-term maintenance and enhancement by the Army.
- ISO 10303 appears to have the most breadth and depth of coverage for product lifecycle data. ISO 10303-239 (Product Lifecycle Support, PLCS) is currently the only international standard available that covers the entire lifecycle spectrum. NIST believes that PLCS has great potential to handle the Army's PLM requirements, but recommends the Army resolve certain challenges before firmly committing to its adoption. More technical details on AP239 and recommendations for its use can be found in Section 4 and Section 7 respectively.

We offer the following recommendations for the Army:

- Review its investments and pilot results for various STEP AP projects, and investigate further integration of these application protocol commitments with AP239 for full product lifecycle support. The Army has been investing in the development and piloting of several other ISO 10303 application protocols, including AP203 edition 2; and a "manufacturing" suite comprised of at least AP203, AP219, AP223, AP224, AP238, and AP240.

- Investigate and understand more fully the ramifications and long-term effects regarding issues associated with maintenance and ownership of existing OASIS Data EXchange Sets (DEXs) and Reference Data. If OASIS standardization in PLCS is determined the best viable solution, the Army should:

  – Assess the coverage by existing OASIS DEXs and reference data to meet the Army's needs.

  – Participate in the development of necessary DEXs and reference data sets within an international standards development forum.
- Promote the transfer of national standards into the international standards development arena. The Army has invested significant resources into developing national standards such as EIA-836, GEIA-927, and GEIA-0007. Adoption and use of these standards may improve if this work is incorporated into the international standards development efforts. For example, the business rules available in EIA-836 could possibly be turned into a configuration management DEX within OASIS. Similarly, the business rules being developed in GEIA-0007 could be turned into a logistics support analysis DEX.
- Ensure standards-based product lifecycle support by vendors and users by developing a template of contractual language that consistently and expressly calls out the recommended standards of choice and commits the Army to a standardized solution as the only way to do business.
- Act upon Under Secretary of Defense Krieg's recommendation in his memorandum of June 23, 2005, "Standard for the Exchange of Product Model Data (STEP) --- ISO 10303" to review and implement STEP as the Army's interoperability standard.

The time allowed for this report did not permit a uniform in-depth study of the standards investigated in this report; nor on the full suite of prospective PLM-related standards --- their use, their maturity, and supporting software tools; or the gaps and the overlap of the standards through a formal approach using a typology and information models. NIST proposes in Section 8, as a follow-up to this report, several additional short and long-term joint efforts with the Army, which include providing a more in-depth assessment of a larger suite of candidate PLM standards, identifying the gaps, and producing a formal process that will assist the Army in its selection of necessary standards. As part of this extended assessment, NIST would include review of the linkage or overlaps between PLCS and S1000D, and PLCS with MIMOSA.

Additionally, NIST could work with the Army to:

- Develop strategies for the creation of common and discrete ontologies that best facilitate the interoperability and fluidity of information flow between the Army, its OEMs, and other allied countries.
- Develop a reference model for the Army's product lifecycle information ecosystem.
- Develop a methodology to create test beds for evaluating information standards and their implementations.
- Investigate application and potential benefit for the Army from NIST's Long Term Knowledge Retention project that deals with digital technical product documentation.

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List of abbreviations[1]

Acronym	Meaning
AECMA	European Association of Aerospace Industries
AIA	Aerospace Industry Association
AMC	Army Materiel Command
ANSI	American National Standards Institute
AP	Application Protocol
ASME	American Society of Mechanical Engineers
BOM	Bill of Material
B-Rep	Boundary Representation
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CALS	Computer-aided Acquisition and Logistics Support, or Commerce at Light Speed
CAM	Computer-Aided Manufacturing
CD	Committee Draft
CGM	Computer Graphics Metafile
CM	Configuration Management
CORBA	Common Object Request Broker Architecture
DAMF	Defense Acquisition Management Framework
DEX	Data EXchange Set
DIS	Draft International Standard
EIA	Electronic Industries Alliance
ERP	Enterprise Resource Planning
GEIA	Government Electronics & Information Technology Association
GSC	Global Standards Collaboration
IS	International Standard
ISA	Instrument Society of America
ISO	International Organization for Standardization
IT	Information Technology
NATO	North Atlantic Treaty Organization
NC	Numerical Control
NGS	Non-Government Standard
NIST	National Institute of Standards and Technology
NTTAA	National Technology Transfer and Advancement Act
OASIS	Organization for the Advancement of Structured Information Standards
OEM	Original Equipment Manufacturer
OMB	Office of Management and Budget
PAS	Publicly Available Specification
PDM	Product Data Management
PLM	Product Lifecycle Management
RAND	Reasonable and Non-Discriminatory

[1] Acronyms associated with product lifecycle standards are defined in Appendix C.

Acronym	**Meaning**
SALE	Single Army Logistics Enterprise
SCRA	South Carolina Research Authority
SGML	Standard Generalized Markup Language
Tcl/Tk	Tool Command Language/Toolkit

1. Background

The objective of this report is to provide the results of a preliminary investigation of selected standards and related technologies that might support the Army's lifecycle management of products and services necessary to maintain the mission-readiness of its troops. A secondary objective is to provide input to the U.S. Army Materiel Command (AMC) through its Product Data and Engineering Working Group (PEWG). The PEWG is determining AMC's direction forward and making implementation decisions for future contracts.

1.1 *Need and mandate for lifecycle support*

The need to exchange data among multiple business partners, developers, suppliers, users, and maintainers is the normal day-to-day complex business environment for the U.S. Army and other DoD Services. Product lifecycle management (PLM) is a function or a business strategy for creating, sharing, validating, and managing information about product, process, people, and services within and across the extended and networked enterprise covering the entire product lifecycle spectrum.

DoD 4140.1-R [2003], "DoD Supply Chain Materiel Management Regulation," outlined product support data requirements and procedures for defense sustainability and lifecycle support. The few excerpts from [1] exemplify what is necessary for product support, and brings the responsibility for lifecycle support home to bear on AMC and other DoD agencies:

> "Product support data consists of weapon system and equipment program, configuration, and performance data and technical manuals; weapon system reparable item test, failure, and usage data and repair manuals; and weapon system item support cost data. The DoD Components or a third party with guaranteed access shall collect and maintain product support data to ensure lifecycle sustainment and continuous improvement of product affordability, reliability, and supportability."
>
> "Product support data users should have online access to product support data, regardless of the geographical location of that data."
>
> "To warehouse product support data where necessary, the DoD Components should provide for data repositories, data management systems, and related access capabilities. The data management system for product support data should control the technical baseline (e.g., configuration documentation, technical data, and technical manuals) for weapon systems and other equipment."
>
> "The DoD Component shall provide the capability to exchange product support information with allies to enhance international interoperability and cooperation."

As cited in IDS Sheer Group, 2005 [2], "the logistics process inefficiencies have resulted in:

- Ineffective theater distribution capability
- Inadequate bandwidth and communications infrastructure
- Lack of asset visibility, leading to:
  - $1.2 billion discrepancy between material shipped vs. material received
  - Backlogs of hundreds of pallets and containers
  - Requisitions duplicated and supply system worked around
  - Inability to locate parts in theater pipeline led to the cannibalization of vehicles and a reduction in equipment readiness."

To meet its responsibilities and resolve these costly inefficiencies, the Army has committed to a Single Army Logistics Enterprise (SALE). SALE is designed to correct a long-standing problem in the Army's logistics information management, notably: lack of a common operating process for measuring and analyzing materiel readiness and combat posture. Within the context of SALE, the Army intends to integrate its national and tactical logistics systems into one fully integrated, end-to-end enterprise. SALE will bring together three component systems: the Global Combat Support System-Army (GCSS-Army) Field Tactical (F/T), the Logistics Modernization Program (LMP), and GCSS-Army PLM+ [3]. PLM+ is the technical enabler proposed to link the field-level logistics system, GCSS-A with the National-level logistics system, LMP, and establish a single access point interface to integrate all their external systems. The components that comprise PLM+ are implemented by the combination of SAP©'s Product Lifecycle Management and NetWeaver© products.

Such a commitment to the concepts of SALE is no longer an option for the Army, but a logistics' imperative. As reported in the Government Accounting Office report [4], operating and support costs make up about 60-70 percent of a weapon system's total lifecycle costs. Many of the current ground weapon systems will continue to be in service for another 20-30 years. The Army needs the ability to support systems after production while reducing sustainability costs. The AMC is responsible for this support.

1.2 *The AMC drive for lifecycle support efficiencies*

The following quotes from AMC's website underscore the breadth and depth of AMC's critical role in the entire spectrum of product and services that it provides for US Army:

> *"If a soldier shoots it, drives it, flies it, wears it, or eats it, AMC provides it."*

> "AMC operates the research, development and engineering centers, Army Research Laboratory, depots, arsenals, ammunition plants, and other facilities; and maintains the Army's pre-positioned stocks, both on land and afloat. The command is also the DoD Executive Agent for chemical weapons stockpile and conventional ammunition. To develop, buy, and maintain materiel for the Army, AMC works closely with Program Executive Officers, the Army Acquisition Executive, industry and academia, the other services, and other government agencies.
>
> AMC's main effort is to achieve the development, support, and sustainment of the future force in this decade. At the same time, AMC is key to supporting and

sustaining the interim force and to sustaining and recapitalizing the current force. Its maintenance depots continue to restore weapon systems continuously needed as the Army makes its way to full transformation. The command's overhaul and modernization efforts are enhancing and upgrading major weapon systems – not just making them like new, but inserting technology to make them better and more reliable.

AMC handles diverse missions that reach far beyond the Army. For example, AMC manages the multi-billion dollar business of selling Army equipment and services to friends and allies of the United States, and negotiates and implements agreements for co-production of U.S. weapons systems by foreign nations. AMC also provides numerous acquisition and logistics services to the other components of the DoD and to many other government agencies [5]."

Changes in DoD acquisition and sustainment strategy are impacting AMC's product and technical data business processes and enablers. To achieve its goal AMC headquarters has formed the Army Product Data and Engineering Working Group (PEWG). The PEWG is chartered[2] to:

- Provide solutions and a plan of action to implement the spirit of such standards as DoD 4140.1-R.
- Address the complexities of the engineering and logistics supply chains within the Army.
- Integrate these with original equipment manufacturers (OEMs) enterprises that create and maintain the data in today's global business environment.

The mission for PEWG is to**:**

- Support HQ AMC by providing an Army-wide forum for determining requirements for, and resolving issues associated with management, and use of product data.
- Develop strategies and approaches for lifecycle management of engineering, technical, and product data across all Army business domains and throughout the weapon system or part lifecycle.
- Develop contractual policy, procedures, and guidance to order access or delivery of data on any Army contract.
- Support enterprise IT system efforts to ensure a seamless flow of product data throughout the lifecycle of any weapon system.

To carry out this mission, the product data user community has identified significant issues, which were grouped and mapped into four Work Packages:

1. Define Product Data
2. Identify Data Standards
3. Clarify/Develop Product Data Policies & Training
4. Define Product Data Business Processes

This report is in response to two milestones for PEWG's Work Package 2:

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[2] PEWG Charter of 31 MAR 2005.

- Identify standards that could be used for lifecycle product data standardization, interoperability, and exchange among Army and its OEM enterprise systems (e.g., SALE, Future Business System)
- Help build a business case for using standards

To this end, the National Institute of Standards and Technology (NIST) conducted a preliminary investigative study in collaboration with Army personnel to assess the level of current pilot or production use of various military, national, or international standards during the lifecycle support of any given weapon system component or part. The investigative study questions found in Appendix (A) were used to engage Army and OEM personnel in discussion to better understand the role of standards in their activities. The questions were used to encourage dialogue and solicit insight into processes and standards the AMC sites may be employing – whether in prototype or production fashion. Note that no direct questionnaire results are being provided in this report since the survey was used only for discussion.

1.3 *Report content*

The report is organized as follows; Section 2 presents Army product data processes that are important for this study. Section 3 provides a general background on standards and standardization. A review of relevant product data standards is discussed in Section 4. Section 5 highlights the results of NIST's research on state-of-the-art application of selected product lifecycle standards, and offers a way the Army may want to approach it's selection of PLM standards for use. The convergence and integration of PLM standards are also discussed in this section. Section 6 discusses implementation issues and presents the current and future challenges in standards development for PLM. Section 7 provides some observations and recommendations to the PEWG, and Section 8 on next steps and areas in which NIST could help. Acknowledgements, NIST's disclaimer, and references conclude this report as sections 9-11 respectively. Several appendices are at the end of the report. They provide general information to supplement the report's content.

While numerous acronyms are used in this report to enhance readability, many are subsequently spelled out only in the List of Acronyms, found in the beginning of this report.

2. Product Data Related Activities and Issues in the US Army: a Current Perspective

The United States Army holds one of the largest volumes of product data to build and support its fleet of combat vehicles. Efficient management of such large volumes of product data that is geographically distributed between government agencies and private industry contractors cannot be done without extensive use of product data representation, product data management, and product data exchange standards. This section discusses the specifics of product data management within the US army.

The Army has a number of PDM systems that store weapon system technical data. These distributed systems are managed by Program Managers (PMs), Research Development and Engineering Centers (RDECs), depots, and system support; and are mostly based on Commercial off the Shelf (COTS) and Government-developed products. Furthermore, on many programs, the PMs have made the contractual decision to have the OEMs or other support contractors manage the product technical data. As a result there is currently no single system that stores data relating to the entire weapon system.

As a weapon system goes through the acquisition lifecycle, various organizations have primary responsibility for the technical data generated during the acquisition process. It is clear that as the product advances through different phases of the lifecycle, new supporting product data is being continuously generated. The COTS solutions that are used in various phases are not standardized as each organization uses a system that best fits its requirements. This leads to silos of product data locked up in proprietary systems that cannot be exchanged easily among the various organizations that generate and use the data. A standards-based Product Lifecycle Management framework would allow the Army to exchange product data from proprietary systems using open architectures and standards to achieve interoperability. The Defense Acquisition Management Framework (DAMF) (a brief explanation of DAMF is provided in Section 4.2) illustrated in Figure 2 is one such effort.

Unlike private industry, the Army cannot mandate the use of a single homogeneous system for its entire supply chain. Not only is this cost prohibitive and impractical, in most cases it would not result in the best value for the government. It therefore makes sense to allow Army organizations and OEMs to continue to use their product data generation and management tools of choice that meet individual program requirements. For example, on the Stryker program, Pro/ENGINEER♣ and Windchill♣ may be the systems selected by General Dynamics Land Systems; whereas the HMMWV program and AM General Corporation may elect to use Unigraphics NX♣ and Teamcenter Engineering♣. A standards-based Army PLM strategy can address these diverse geographically distributed product data formats and systems to manage the data.

In general, the lifecycle of Army combat systems is much longer than lifecycles of commercial products like automobiles. It is not uncommon to see weapon systems in use today that are over 50 years old. Combat vehicles such as the Abrams tank and Bradley Fighting Vehicle are expected to be in active service for another 25-30 years and are an integral part of the Army's transformation to the future combat systems brigade combat teams [6]. It is estimated that weapon system sustainment costs are as much as $50 billion per system [7]. An extended lifecycle implies that the system will go through constant change to adapt to the war-fighting environment. Extended lifecycles also require long-term data retention and archiving where product data needs to be usable decades after the data were originally created and potentially after vendor products used to generate the data have gone out of business. Again standards can provide a solution for long term data retention since they are open, published and forward compatible. In March 2006, NIST held a workshop on "Long Term Knowledge Retention (LTKR)" [8]. The purpose of the workshop was to identify challenges, research, and implementation issues in digital preservation of information with an emphasis on design and

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♣ See Disclaimer Section 10.

manufacturing. It brought together researchers and practitioners from disciplines including manufacturing engineering, library sciences, knowledge representation, and space science.

It is clear that a number of PDM and logistics systems have to be integrated as part of a total Army PLM solution. Many excellent commercial Enterprise Application Interface (EAI) middleware solutions are available today to connect these enterprise solutions, but they have three major drawbacks:

1. They are proprietary one-to-one mappings between enterprise solutions. Such interfaces add an additional level of proprietary data to the existing systems making them difficult to manage and maintain.
2. They are version dependent and have to be migrated along with upgrades to the systems being integrated. When there are a number of systems being integrated this can turn into a very complex problem.
3. They are very expensive to develop and maintain. Each interface can cost upward of $1 million to develop and an additional $300,000 per year to maintain [7].

Below is more detail on some of the Army's business processes routinely conducted within the product's lifecycle. By using standards in these activities, the number of interfaces required is greatly reduced because each system will only require an import and export translator from the internal data format of the commercial system to the standard data model. This is illustrated in Figure 1.

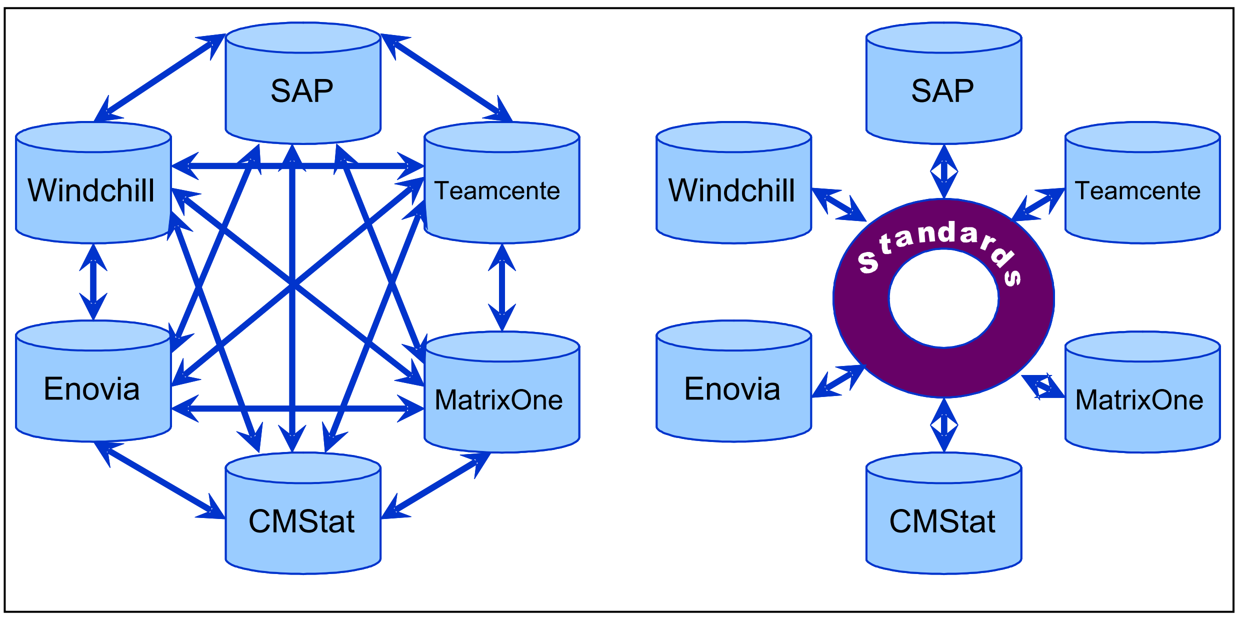

Figure 1: Interfaces versus translators among systems

2.1 *Product data delivery from contractors*

When DoD cancelled many of the MILSPECs and MILSTDs during Acquisition Reform [9] it offered to contractors the opportunity to deliver product data to DoD in contractor formats. While this potentially reduced costs associated with delivery of data it also turned into a challenge for DoD to handle a large variety of contractor formats that could not be directly used with existing DoD systems. Such a transition in data exchange has made it imperative for DoD and the Army to adopt international standards that are well supported by the private sector. This will enable the Army to use the best commercially available implementations of standards without imposing DoD-specific standards on the contractors and OEMs. Product baseline definitions to the Army are typically delivered as two separate deliverables – engineering or technical data (drawings, CAD models, etc.), and logistics supportability data (Logistics Support Analysis Record (LSAR) - provisioning, maintenance requirements, training material, reliability, availability and maintainability, etc.). There is still widespread use of MILSPEC-1388-2B[3] for LSAR within DoD, and a multitude of proprietary formats to represent CAD data today that are not interoperable.

2.2 *Collaborative product development*

Most weapon systems today are developed by OEMs in an iterative mode with the Army. This requires the Army and its OEM engineers to work collaboratively while potentially using disparate commercial software for such collaboration. Standardizing on a single commercial software solution is not an option since most OEMs select CAD and PDM systems that meet their internal business process requirements. Due to a lack of interoperability between these systems today, data and data exchange processes are being reduced to the lowest common denominator - typically exchange of drawing images on CDs. This inefficient and time-consuming process cannot work in rapid field projects to support the war fighter. Manual entry and re-entry of data between systems can lead to serious human errors, duplication of data, poor data integrity, and lack of configuration management. It is important for the Army to enable interoperability and automation of processes using standards to obviate the need for manual intervention.

2.3 *Depot manufacture and overhaul*

The Army is currently unable to efficiently balance the work load across the various depots and arsenals as a result of non-standard systems, applications, and processes in place at each depot. While it is not reasonable to replace and align all systems across the depots to one vendor or one solution, the use of standards to enable the effective exchange of manufacturing process data among the depots is a viable alternative.

2.4 *Condition-Based maintenance and failure feedback*

There are a number of databases and systems today that collect failure feedback information from either on-board sensors or maintenance tasks but are unable to be analyzed collectively as a result of disconnected and separate databases. While it is reasonable to expect multiple databases to store such information it is also important to be able to consolidate and integrate this information in order to perform an effective analysis of the data. Such standardized data can then be fed back into product improvement processes to enable proactive redesign of parts. Failure and maintenance feedback information is another area that requires examination for applying product lifecycle standards within the Army.

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[3] Military Specification 1388B, Logistics Support Analysis Data, was cancelled for use by the Department of Defense November 26, 1996.

2.5 *Performance-Based logistics support*

For lifecycle support of a weapons system, it is important for the Army to have visibility and on-demand access to data from the OEMs or other support contractors to ensure that readiness levels are being met. This business process requires the weapons system program manager to continually monitor key performance metrics and the data supporting such metrics. Using standards to enable the access to data between organic systems and contractor systems would allow the data to continue to reside on the contractor's systems while allowing the Army program manager a more effective way to provide logistical support.

2.6 *Item unique identification*

A major aspect of the DoD's mandate for a Unique Identification (UID) initiative includes the standardization of UID information using international standards such as ISO 10303[4]. As Army assets are uniquely identified, this information relating to parts, assemblies, and systems need to be propagated to "as-built" and "as-maintained" configurations of the systems to enable audit tracking. Standardization of such information can enable this data to be exchanged across a number of cross-domain applications such as manufacture, maintenance, asset valuation, and disposal.

2.7 *Configuration management*

End-to-end configuration management of a weapon system across organizations and systems is a tremendous undertaking for the Army. While product data can be quite effectively managed within a Product Data Management (PDM) or Enterprise Resource Planning (ERP) system, such software can only manage data that is resident within the system. Configuration management requirements involve the entire lifecycle of the weapon system starting with "as-planned," "as-designed," "as-built," "as-maintained" through "as disposed of" configurations. Change propagation that is initiated outside of the system cannot be handled by most commercial systems today, so it is not realistic to expect that all configuration management requirements will be managed within a single software system.

3. Why standards?

Standards are the bridge to communicating information among recipients with diverse user requirements, and as Section 2 noted, diverse and proprietary systems where key critical data reside. The Global Standards Collaboration (GSC) initiative saw the merits of collaborating to build such bridges [10]. GSC is comprised of national participating organizations around the world who are concerned with the promotion of global standards in areas of common interest. In a key resolution passed in October 2004, GSC defined that a standard should:

- Support fair trade and fair competition.
- Increase user, consumer, and government confidence.
- Facilitate interoperability.

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[4] See Jun 23, 2005 memorandum, Krieg, Kenneth J., Under Secretary of Defense, "Standard for the Exchange of Product Model Data (STEP) --- ISO 10303," found in Appendix D.

- Stimulate innovation.

While many unfortunately perceive standards to be a barrier to technology advancement, standards can actually enable innovation by proving a stable platform:

- On which to build vertical applications.
- For expanding existing markets and creating new markets.
- For propagating innovation across industries [11].

The critical role that standards play in all of the activities that we engage in is emphasized by CSA International: “Standards touch our lives every day, affecting nearly every product or service we encounter--- from the pipes in the wall to the lights overhead. When you sit down at your desk, plug in an appliance, drive over a bridge, or put on a helmet, standards are at work. Standards help to ensure that products and services live up to our expectations. In many cases they define safety and quality requirements; in some cases they focus on efficiency or environmental practices. For manufacturers, standards help to lower production costs. They promote interconnectivity and harmonization among products and components, and help open doors to new markets. For consumers, this means a wider selection of goods and services and a more competitive marketplace. It also means greater convenience and consumer confidence [12].”

So what exactly is a standard? How can standards help the AMC reduce weapon system lifecycle sustainability costs and facilitate better digital information transfer among its users? In this report, we attempt to answer these and other important questions.

3.1 *Categories of standards*

A standard can be classified into different categories based on purpose, based on the specific requirements, and process by which it was developed. In this and the following section we briefly discuss the different categories of standards and the rationale behind this categorization.

3.1.1 As Defined by Congressional Authority

The term "standard” or "technical standard" as cited in the National Technology Transfer and Advancement Act (NTTAA) of 1995 [13], includes all of the following:

- Common and repeated use of rules, conditions, guidelines, or characteristics for products or related processes and production methods, and related management systems practices.
- The definition of terms; classification of components; delineation of procedures; specification of dimensions, materials, performance, designs, or operations; measurement of quality and quantity in describing materials, processes, products, systems, services, or practices; test methods and sampling procedures; or descriptions of fit and measurements of size or strength.

3.1.2 As Supplemented by the Executive Branch

The Office of Management and Budget (OMB), in its Circular A-119 Section 3 [14] further elaborates on standard classifications. This Circular classifies standards according to their purpose and manner in which standards specify requirements:

Based on Purpose

- A basic standard has a broad ranging effect in a particular field, such as a standard for metal, which affects a range of products from cars down to screws.
- Terminology standards (or standardized nomenclature) define words permitting representatives of an industry or parties to a transaction to use a common, clearly understood language.
- Test and measurement standards define the methods to be used to assess the performance or other characteristics of a product or process.
- Product standards establish qualities or requirements for a product (or related group of products) to assure that it will serve its purpose effectively.
- Process standards specify requirements to be met by a process, such as an assembly line operation, in order to function effectively.
- Service standards, such as for repairing a car, establish requirements to be met in order to achieve the designated purpose effectively.
- Interface standards, such as the point of connection between a telephone and a computer terminal, are concerned with the compatibility of products.
- Standards on data to be provided contain lists of characteristics for which values or other data are to be stated for specifying the product, process or service.

International Standards have been developed through a process that is open to participation by representatives of all interested countries, transparent, consensus-based, and subject to due process. The existence of non-harmonized standards for similar products, processes, and services in different countries or regions create barriers to trade. Therefore, export-minded countries and industries have recognized the need for internationally accepted standards to help rationalize the international trading process.

Based on manner in which standards specify requirements

- Performance standards describe how a product is supposed to function. A performance standard for water pipe might set requirements for the pressure per square inch that a pipe must withstand, along with a test method to determine if a specimen meets the requirement.
- Design standards define characteristics or how the product is to be built. The specification that a pipe is made of a given gage of copper would characterize a design standard.

Government agencies are encouraged to write technical regulations and standards in terms of performance, rather than design characteristics.

3.2 *Standardization methods*

As there are different classes of standards [15; 16], there are also different processes to develop standards.

- De Facto: De facto standards are those set by the marketplace; it is usually a proprietary application used so universally as to become a standard for exchange of information across trading partners, e.g., Microsoft Word©. A de facto standard is usually in production use, evolving from the bottom up according to the forces that drive the market. Global exchange among partners is only as effective as the de facto standard will allow. Users do not have access to the source code of the application (closed source) to improve upon exchange or to better ensure interoperability; this is left to the desires and priorities of the corporation or entity owning the de facto standard to add into their product.
- Voluntary Consensus: Standards can be set through organizational processes that reduce transaction costs and facilitate information exchange and negotiation among trading partners. Such processes can provide better coordination and security when the levels of uncertainty are high, when there are frequent recurring exchange activities among the partners, or when information exchange is complex. The most known international voluntary consensus process for thousands of standards is under the direction of the International Organization for Standardization (ISO).
- Regulatory: Standards also result from political choices. Such standards are often referred to as regulatory standards [17].

3.3 *Voluntary consensus standards*

Under the provisions of Public Law 104-113 signed into law by the 104th Congress, the NTTAA of 1995 [18] requires that all federal agencies are required to use voluntary consensus standards in preference to agency- or government-specific standards for procurement and rule-making activities, except where such use is impossible or inappropriate [19].

OMB issued a revised version of OMB Circular A-119 entitled, “Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities,” to implement the provisions of NTTAA. It states, “The use of voluntary consensus standards, whenever practicable and appropriate, is intended to achieve the following goals:

- Eliminate the cost to the Government of developing its own standards and decrease the cost of goods procured and the burden of complying with agency regulation.
- Provide incentives and opportunities to establish standards that serve national needs.
- Encourage long-term growth for U.S. enterprises and promote efficiency and economic competition through harmonization of standards.
- Further the policy of reliance upon the private sector to supply Government needs for goods and services." [14]

ISO is a collaboration among the national standards institutes of 156 countries[5]. Each country is given a single vote on any given standards development and approval. ISO standards aid in

[5] The American National Standards Institute (ANSI) is the United States member and voting representative to ISO.

more efficient, safer, and cleaner development, manufacture, and supply of products and services. ISO as a non-governmental organization is able to act as a bridging organization in which consensus can be reached on solutions that meet both the requirements of business and the broader needs of society, such as the needs of stakeholder groups like consumers and users. ISO has a supporting Central Secretariat located in Geneva Switzerland that is responsible for the coordination of all the standards' development activities, and the publication and distribution of resulting standards [20].

3.4 *Importance of industry-driven standards*

The *United States Standards Strategy* (a revision of the *National Standards Strategy for the United States* [20] that was approved in August 2000) states the following to underscore the critical role that standards play in all our activities: "Standards are essential to a sound national economy and to the facilitation of global commerce. The global standards landscape is rich with entities, systems and processes, and both the U.S. government and private sector participate in international standards activities in a variety of ways: through treaty organizations where governments are members; through private, voluntary organizations where the United States is represented by a single 'national body' organization; through professional and technical organizations whose membership is on an individual or organizational basis; and through consortia, whose membership is typically technology based. … The government should recognize its responsibility to the broader public interest by providing financial and legislative support, and by promoting the principles of our standardization system globally. Global competitiveness of U.S. industry depends critically on standardization, particularly in sectors that are technology driven."

Standards make trade between countries easier and fairer. Internationally developed standards such as those in ISO serve to simplify the lives of, and safeguard consumers of products and services. You will read later in this report the benefits specific to the prototype and implementation of international, industry-driven standards.

In [21], C.F. Cargill states that the use of standards also provides the user with a more solid and long-enduring technology, independent of the system on which the data resides. Mergers and bankruptcies are becoming commonplace worldwide, and there are no guarantees that the system you use today will be available or supported tomorrow. Being able to repeatedly and consistently translate and interpret intelligently the data independent of the commercial system on which it resides, is a strong argument for the use of mature international, industry-driven, standards.

In contrast to the openness and international participation of vendors, users, academia, and government in the ISO community, is the cultural and historical precedent use of military specifications and standards. DoD has been called the most diversified and largest developer and user of standards in the United States, and possibly the world. DoD primarily uses standards for procurement purposes, requiring equipment and parts suppliers to provide products that conform to detailed product specifications. But these defense-specific product specifications have far-reaching impact and expense on the lifecycle support of that product. DoD has also been the most active government agency in standards reform, and has its own historical examples of quantitative benefits resulting from its reform away from military-specific specifications and standards [19].

The proliferation of DoD-specific standards and specifications was a post World War II response to inadequate or nonexistent private-sector standards. Thus military specifications (MILSPECs) and standards (MILSTDs) were born. A MILSPEC describes the essential technical requirements for purchased material that are military-unique or are substantially modified from commercial items. A MILSTD establishes uniform engineering and technical requirements for military-unique or substantially modified commercial processes, procedures, practices, and methods [22]. For products that were common to military and civilian uses, MILSPECs in most cases did not simply adopt the industry standards, and thereby the unique military requirements specified in the MILSPEC required suppliers to develop separate methods and machinery to accommodate both a supplier's commercial and defense markets. A study of military contractors by the management consulting company Coopers & Lybrand determined that the use of a group of 120 MILSPECs increased the price DoD pays for industry goods and services by about 18 percent.

Since 1962, DoD has been working to reduce unnecessary defense-specific requirements and associated excess costs by supporting the use of private-sector standards; and in fact, the original 1982 version of OMB Circular A-119, mentioned in Section 2, was based on DoD's established policy at that time. These ongoing efforts have accelerated since 1994, when Secretary of Defense William Perry ordered the MILSPEC Reform Initiative. (This correspondence can be found in Appendix D.) This reform's immediate purpose was to review the current military-unique specifications and determine if any of those specifications could be replaced reasonably by industry standards. Since the beginning of MILSPEC Reform, DoD has reviewed over 29,000 agency-specific standards and has cancelled or replaced 9,600 of them. These profound efforts continue today under the direction of the Defense Standardization Program Office. Additional Defense correspondence and brief examples of several initiatives in DoD and the Army further exemplify this reform in Appendices (D) and (B) respectively.

Today, the DoD has created the Defense Standardization Program under the auspices of the Defense Logistics Agency [23]. Its mission is to champion standardization throughout DoD that will lead to a reduction in costs and improved operational effectiveness. Consistent with the legislation of NTTAA and OMB Circular A-119, the DoD is committed to be proactive in the adoption and use of non-government standards, wherever possible, instead of developing new or updating existing government specifications and standards. To this end, DoD policy encourages its employees to collaborate with the private sector and other government employees on technical committees of non-government standards (NGS) development organizations. Such participation best ensures proper consideration of DoD requirements, enhances the technical knowledge of DoD personnel, and allows DoD employees to contribute their considerable technical capabilities to the development of world class standards. At the same time, it allows defense personnel to recognize and better understand the requirements and priorities of those outside the defense environment, learning through experience, the old adage, "we are more alike than we are different."

In review, "Standards enable products, systems, and even organizations to work together. Standards can promote competition. They can stimulate innovation. And they can also promote our well-being and improve our quality of life." [24]. "It's not about whether or not to use standards, but knowing which standards from the existing plethora best meets your requirements." [25]. Appendix (C) provides a starter list of possible product lifecycle -related standards, and some of the supporting standards development organizations.[6]

4. Preliminary analysis of standards for lifecycle management

In this Section, we will discuss various standards that may contribute toward the interoperability of various systems that manage product lifecycle information and provide administrative and operational support.

4.1 *Product lifecycle management*

Product lifecycle management (PLM) is a function or a business strategy for creating, sharing, validating, and managing information about product, process, people, and services within and across the extended and networked enterprise covering the entire product lifecycle spectrum.

The importance of interoperability across the phases and functions in PLM has been recognized by a number of institutions including NIST, DoD, the European Ministries of Defense and, more recently, by the vendor and end-user communities [26; 27]. While there has been articulation of the need, the issue has not been fully addressed due to the divergence of interests on how interoperability should be achieved. The challenge is to create standards and protocols that allow legacy systems as well as future technological innovations to interoperate seamlessly. This requires dealing with a multiplicity of computer languages that can represent the complete product description.

A 1999 study commissioned by NIST [4] estimates that imperfect interoperability imposes at least $1 billion per year on the members of the U.S. automotive supply chain[7]. By far, the greatest component of these costs is the resources devoted to repairing or reentering data files that are not usable for downstream applications. This is parallel to the Army's existing lifecycle logistics practices. The report's estimate is considered conservative because the study could not quantify all sources of interoperability costs. Members of the automotive industry that participated in this impact study generally acknowledge that imperfect interoperability is an important and expensive problem. A number of potential solutions have been developed over the years. These include:

- Standardization on a single system for each OEM and its suppliers and sharing of files in native format.
- Development of point-to-point translators.

None of the solutions that have been widely used in the past has been successful at significantly reducing interoperability problems. Single system standardization forces suppliers to maintain

[6] Another complementary source for hundreds of standards in the database and network communication domains can be found in "Survey of Languages, Specifications, and Standards for Database and Network Communications," by David L. Brock, Auto-ID Center, MIT-AUTOID-WH-015, November 1, 2002.
[7] The full executive summary from this report and other related economic impact reports prepared by NIST can be found in Appendix E.

redundant systems and does not eliminate interoperability problems. Point-to point translators work reasonably well for some well-defined data translation tasks, but each combination of sending and receiving systems requires a different translator. Neutral format translators such as the Initial Graphics Exchange Specification (IGES) [28] and Data eXhange Format[8] have proven successful in some limited applications, but have a number of identified weaknesses; hence, standardization initiatives such as ISO 10303, informally known as STEP – the STandard for Exchange of Product model data have emerged.

Today's standards, particularly in the area of CAD, have produced direct improvement in productivity, especially in the manufacturing arena, by reducing transaction costs and even more so by increasing the richness of interactions between supplier and customer [29; 30]. Before assessing the worthiness of any investment in a maturing international standard such as ISO 10303 (STEP), one has to reconcile the current state of interoperability – both what level of interoperability is necessary to manage effectively the lifecycle of a product, and whether the technology is there to support the need. The real cost of the lack of interoperability is generally difficult to measure and is often buried in day to day operations of individuals needing the information or needing to transmit the information.

The big picture must effectively account for all the necessary integration links necessary to support a product throughout its life, even when that lifecycle is 20 or more years. It is also important to first recognize the problem, and then build a business case for the solution. Dr. Dale Hall, the Director of NIST's Manufacturing Engineering Laboratory, further underscores this:

> "The interoperability of computing systems is emerging as a top priority issue for productivity increases in the U.S. manufacturing sector, including the aerospace industry. Computer usage has helped reduce inefficiencies and improve performance of manufacturing systems, but this reliance has come with enormous costs associated with a lack of interoperability. For systems to be interoperable requires the ability to share and exchange information between and among dissimilar computer systems. Often the incompatibilities among such systems alter or lose information.
>
> Different participants in the manufacturing supply chain use different software systems for similar manufacturing functions. And within individual companies, multiple, often complex software systems are used to conduct different business and technical tasks. Software systems tend to use proprietary data representations that are frequently incompatible with those used by other software vendors. Recent studies have shown that the economic (inefficiency) costs of this incompatibility in the automotive supply chain alone are estimated to exceed $1 billion a year."[9]

How big is the problem faced by supporting components of the product's lifecycle support supply chain? The following are some examples of how big the problem really is:

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[8] DXF is AutoCad's proprietary format.

[9] Presentation to the National Research Council Assessment Panel, by Dr. Dale Hall, Director, Manufacturing Engineering Laboratory, NIST, 2002.

“Of 13 million engineering hours spent on (a recent aircraft program), 8 million were spent on data correction and administration.”[10]

"Imperfect interoperability imposes at least $1 billion per year on the members of the U.S. automotive supply chain.” [4]

“U.S. aerospace industry estimates that $10M of capital equipment takes 100 person-years to integrate.”[11]

“The lack of integrated data systems also hampered U.S. reconstruction efforts in Iraq, Smith said. ‘I can’t begin to tell you how much of that $18 billion was spent on just trying to get systems to talk to one another.’”[12]

In the context of PLM the need for standards at different levels of expressiveness becomes critical in supporting the processes of information exchange. The role of Standards in PLM support has been discussed in a recent study conducted at NIST [16]. The study presented a model of communication between two partners and extended it to the PLM context and described the current support for PLM and the need for information exchange in supporting PLM.

4.2 *Standards relevant to the Army’s product data management*

The fundamental principles and procedures that DoD is expected to follow in achieving its objectives are described in DoD Directive 5000.1, “Defense Acquisition Guidebook” and DoD Instruction 5000.2, “Operation of the Defense Acquisition System” [31]. These directives also mention various standards that are relevant and important for DoD. These directives define policies and procedures for DoD to rapidly acquire quality products that satisfy user needs with measurable improvements to mission capability at a fair and reasonable price. These two directives also outline various standards that are essential to achieve these goals. Our study focus (questions found in Appendix A) re-emphasized the policies of DoD-5000 directives in terms of DoD standards implementation and policies.

The acquisition process is structured by DoDI 5000.2 into discrete phases separated by major decision points (called milestones or decision reviews) with a number of key activities to provide the basis for comprehensive management and informed decision making. The number of phases and decision points are tailored to meet the specific needs of individual programs. This is called the Defense Acquisition Management Framework (DAMF) and is illustrated in Figure 2. The key activities shown in Figure 2 include the following:

- Concept Refinement (CR)
- Technology Development (TD)
- System Development and Demonstration (SDD)

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[10] STEPTools Inc., Weekly Newsletter, 13 April, 2000.
[11] J. Evans, NIST ISD, 2001 GATE-M Presentation
[12] Quote by Gen. Lance Smith, Commander U.S. Joint Forces Command, in Josh Rogin FCW.com article, “DoD Seeks Common Data Strategy,” August 21, 2006.

- Production and Deployment (PD)
- Operations and Support (OS)

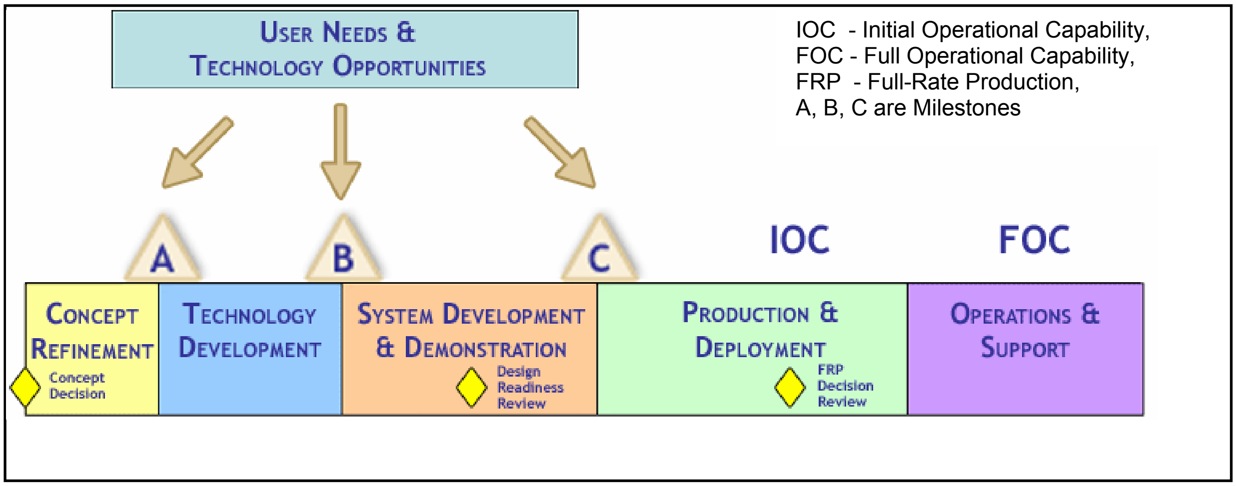

Figure 2: The Defense Acquisition Management Framework (source: [32])

To realize the Defense Acquisition Management Framework, DoD needs to use various standards and frameworks that cover the entire lifecycle spectrum as shown in Figure 2. For this report we limited the scope of our review of relevant standards and frameworks to several called out in DoD 5000.1 or that were mentioned during our site visits and interviews. We also included MIMOSA OpenO&M as it is mandated for Defense use by Defense Adoption Notice of MIMOSA OSA-EAI-2004, December 20, 2004; and GEIA-927 --- a later effort supported by DoD resources:

- ISO 10303, Informally known as STEP --- STandard for the Exchange of Product model data (covers all the DAMF activities)
- GEIA-927, Common data schema for complex systems (CR+TD+SDD)
- EIA-836, Configuration management and data exchange and interoperability (CR+TD)
- ANSI/EIA-649, National consensus standard for configuration management (CR+TD)
- MIMOSA OpenO&M, Information standards (PD + OS)
- ASD/AIA-S1000D, International technical publication specification (OS)

We have mapped each of these standards to its functional applicability to satisfy a portion or the whole of the lifecycle spectrum in Figure 2 (within parentheses after each standard in the above list). The complexity within the army context is to define a system-to-system approach for PLM where the main goal is to make the Army systems understand each other, and seamlessly interoperate.

4.2.1 ISO 10303 STandard for Exchange of Product model data (STEP)

ISO 10303, or STEP, deals with product structure, geometry, and part-related information [33]. It uses the EXPRESS information modeling language to define a generic product model [34]. ISO 10303 is a complex standard comprised of many parts. STEP has been officially approved as an international set of standards since 1994, but it became more trustworthy (accurate, effective, and popular) to implement and use two or three years later. Acceptance and adoption of STEP by manufacturers and software developers has been very slow because the user community that would benefit from its implementation contractually adopt more short-term solutions; also, perhaps because of the perceived (or real) view that STEP is an expensive solution to implement. While real dollar figures for the cost to implement STEP could not be found by NIST, as [35] suggests, imagine the economic benefits to the Army if:

- Product configuration information was always accurate, up to date and immediately accessible.
- Maintenance information was precisely tailored to the specific task(s) to be performed, i.e., reflecting resources skills, facilities, and material available.
- Spares and inventory costs were minimized through vendor involvement in an integrated reliable supply chain.
- In-service feedback was accurate, including the operating context under which it was gathered and was readily available to product designers and support managers.
- Change was easy to manage throughout the lifecycle and the impact of change proposals could readily be evaluated.
- Unscheduled maintenance events could be dealt with efficiently and effectively.

NIST commissioned an economic impact study [36] on the cost of doing business if STEP is not implemented[13]. The impact down the supply chain was more intense than at the OEMs. Figure 3 shows what the study discovered in those interviewed from the automotive industry.

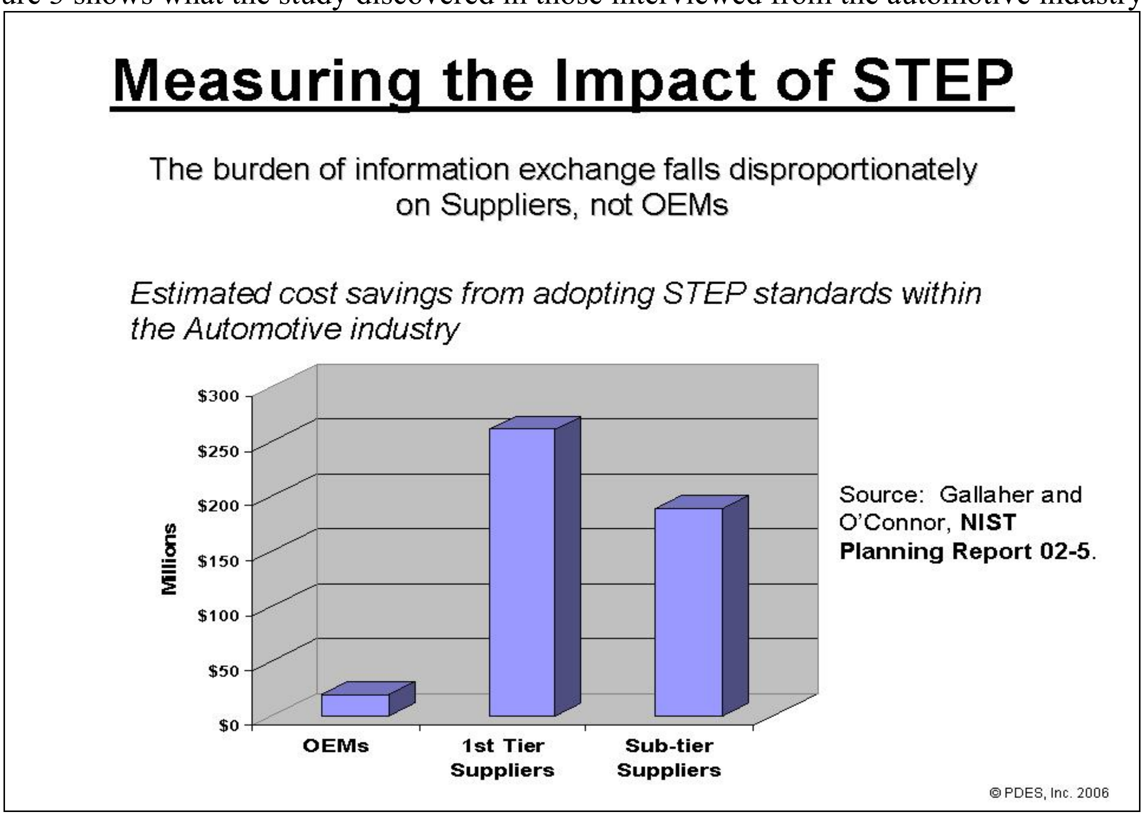

Figure 3: Measuring the impact of STEP in the automotive industry (source:[36])

STEP, or more appropriately, specific standards under the umbrella standard, ISO 10303, has proven to save efficiencies in time, material, and staff. In NIST's planning report 02-5, there

[13] The complete executive summary from this study can be found in Appendix E of this report.

were projections for the Transportation Equipment Industries that STEP has the potential to save $928M/year by reducing interoperability problems in automotive, aerospace, and shipbuilding industries. Testimonials cited that the benefits would accrue to end users through increased interoperability of computer-aided design, engineering, and manufacturing; and product data management systems.

In [37], industry examples of savings have also been cited:

- Lockheed Martin has found in their business analysis that by using STEP (AP203, AP219 [38], AP232 [39], and AP233), it has shown a reduction in model rework, improved model quality, and lower span times with activities such as design integration/collaboration, procurement activities with suppliers (bidding/build), and integration with complementary tools (e.g., numerical control and analysis). Lockheed Martin has already realized significant savings using STEP: During engineering design, pilots show a 10% improvement in reliability of data exchange, 10% process savings for non-composite parts, and 50% process savings for composites. For manufacturing, projected savings for tool design on CAD/CAM systems is 27% and 38% for NC CAM systems due to elimination of data re-entry.
- Raytheon's pilot use of STEP demonstrated significant labor and cycle reduction for the preparation and delivery of technical data packages to its suppliers using STEP: 50% - 88% labor and 59% cycle time savings at Raytheon, with a 42% labor and 95% cycle time savings at the suppliers' end.
- EPM pilots using AP239 (mentioned later in this section) resulted in data discrepancies having dropped from over 20% to less than 2%, the number of engineering change orders was dramatically reduced, and the time required to distribute data has dropped from weeks to hours.

As introduction to the technical discussion on several STEP application protocols that follows, Figure 4 provides a very cursory summary of the historical integration concepts across the whole of STEP and its various international specifications. For a more detailed introduction to STEP, please refer to [33].

In the modular approach of STEP [40], information models form modules and integrated resources (IRs), from which specific content standards (called application protocols or APs) are developed. Each AP has a scope that indicates what is and what is not addressed in the AP, and an associated set of conformance classes (CC) that can be implemented within an application. In the following sections, we present a subset of STEP APs that may be important from the PDM/PLM point of view. For each presented AP we indicate its scope, conformance classes, and give known examples of implementations of it.

The programs that convert data from proprietary formats to STEP and vice-versa are called translators. To verify the conformance of STEP AP translators, a joint industry/government consortium for accelerating the development and implementation of STEP, called PDES, Inc.[41], started testing STEP translators for conformance and interoperability within and among CAD systems. Interoperability continues to be tested within the CAx Implementor Forum [42], which is jointly run by PDES, Inc. and ProSTEP iViP [43].

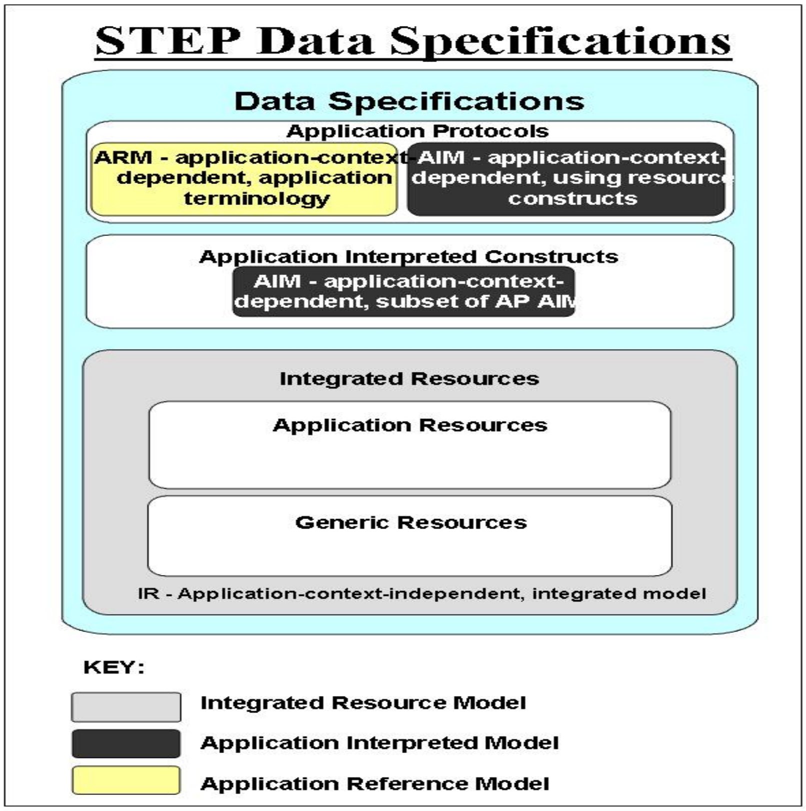

Figure 4: STEP data specifications

In the context of this report, "STEP implementation" is a software application that offers the functional capability of one or more APs of ISO 10303 to exchange product information, or makes it possible for other applications to do so. Thus, STEP implementations include software applications that run on CAD systems, PDM systems, bill of materials systems, stand-alone translators, and other packages that make it possible to develop the above systems [44].

STEP implementations are abundant for several conformance classes of AP203 (primarily CC6a, along with CCs 2a & 4a) and CC1 and CC2 of AP214, which is essentially AP203 with a different set of configuration management data. The conformance classes of each AP are briefly explained below. These are the AP/CC implementations that most of the CAD/CAM vendors have chosen to implement. There are many successful commercial STEP translators available on the market today that can produce digital product data that is compliant with STEP APs. A summary of commercially available STEP translators for most of the major CAD/CAM/CAE vendors and comments on some of their near term future implementation plans are given in the fourth chapter of the STEP application handbook [45]. An updated list can also be found on the PDES, Inc. or STEP Tools, Inc. web sites [46; 47].

In the spirit of embracing STEP, DoD, in its memorandum of June 23, 2005 (Appendix D), requested the secretaries of the Army, Army Materiel, and Air Force implement a similar approach to that implemented within the Navy for adopting ISO 10303 to enhance interoperability.

1) AP203 *Configuration controlled 3D designs of mechanical parts and assemblies*

This application protocol defines the information model for the exchange of parts and assemblies as well as for configurations. AP203 belongs to the first standardized set of specifications of ISO 10303 and became an international standard in 1994. It looks at the definition of product as an integration of the specification of its shape, the specification of its configurations, and the applicability of its possible multiple definitions to a particular configuration. It defines the exchange of product definitions with 3D shape representations together with the data, which defines and controls the configuration of those product definitions. In this AP, the configuration is about what parts compose a product and how they are composed together. This configuration management is based on ANSI/EIA-649, but it does not cover all the configuration management principles that are defined in EIA-836.
Figure 5 shows the scope of AP203 structured around four topics: configuration management, geometric shapes, product structure, and specifications.

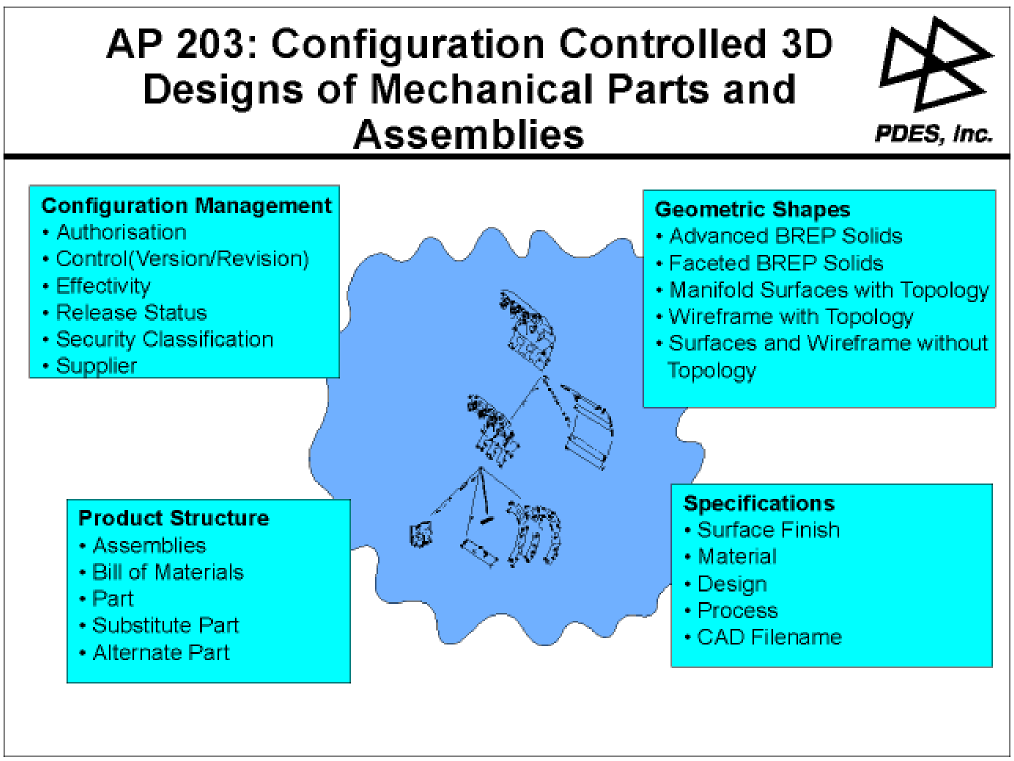

Figure 5: The scope of AP203 (source:[48])

AP203 can be used to represent product definition data for mechanical parts and assemblies. It captures information of design activities (shape, material, process, surface specification) and change control (data that are necessary for the tracking of a design's release, or for the approval of a design; a design aspect, or a configuration control aspect). Analysis or test data of a design is captured only if it is necessary as evidence for a design change. The shape of a product can be described using five types of shape representations (wireframe and surface without topology, wireframe geometry with topology, manifold surfaces with topology, faceted boundary representation, and boundary representation). AP203 provides alternate representation of the data by different disciplines (different views on the manufacturing processes) during the product's lifecycle. Security and organizational data such as responsibilities, approvals, suppliers, and contractors are also in the scope of this AP.

From the design point of view, AP203 does not cover product definition data and configuration control data pertaining to any lifecycle phase other than the design phase. The data that is used in, or results from, the analysis or test of a design that is not used as evidence for consideration of a change to a design, and the data that results in changes to the design during the initial design evolution prior to its release are also not covered in this AP. From the product shape point of view this AP does not cover the use of constructive solid geometry for the representation of objects and the data that pertains to the visual presentation of the product. The business data for the management of a design project is also out of the scope of this AP.

AP203 has 12 conformance classes (CCs) noted 1a, b through 6a, b. AP203's CCs are characterized as follows:

- the CC 1a, b is dedicated to configuration controlled-design information without shape (CC 1a is a specified "product identification" subset of CC 1b). This class is also part of the remaining classes.
- CC 2a, b is composed of CC 1a, b and 3D geometrically bounded wireframe and/or surface models.
- CC 3a, b: CC 1a, b and 3D wireframe models with topology.
- CC 4a, b: CC 1a, b and manifold surface models with topology.
- CC 5a, b: CC 1a, b and faceted B-Rep.
- CC 6a, b: CC 1a, b and advanced B-Rep. According to [45] very few vendors who claim to have an AP203 translator have implemented CC 5a,b; most have implemented CCs 2a, 4a & 6a (i.e., with a "minimal" subset of configuration management data).

The first edition of AP203 was approved in 1994; this edition is now mature and well adopted by various industrial sectors. It has been used as a replacement for IGES for successfully transferring geometric data between various CAD systems. Several uses of note for AP203 can be found in [37]:

- The automotive OEM Delphi Delco Electronics Systems, was using STEP to exchange solid model data with Chrysler and Saturn corporations in 1997. Those files imported into CATIA that did have problems, required about 30 minutes of rework to remove unwanted reference geometry. Even with this rework, using STEP dramatically reduced the design cycle time and costs, and increased the accuracy and quality of the geometry input into, and output from, CATIA. For example, 12 files transferred using STEP saved approximately 50 hours of manual intervention [49].
- It has been used in the aerospace industry with considerable success. Boeing routinely uses STEP in everyday production activities throughout the company. It uses AP203 first edition for collaboration across project participants and information delivery to customers.
- A STEP-based pilot project developed within the PDES, Inc.'s Aerospace Engine Alliance (AEA) is used in production at Pratt & Whitney and AIRBUS. This pilot was initiated in 1999 with the participation of AIRBUS, Pratt & Whitney, General Electric, Theorem Solutions, PTC, and Unigraphics Solutions. The pilot included a "Validation Properties," process that allows fully validated assembly exchange capable of validating the position of each component within an assembly or sub-assembly. In addition, the pilot incorporated a mechanism to break up very large CAD models using external references.

- At IBM, STEP comprises over 25% of IBM's global e-procurement design data exchange. In the area of collaborative design, IBM is focused on a process of Common Building Blocks (CBB) to help drive down costs. STEP is used to enable the CBB process, which requires sharing designs between CATIA V5 and other CAD systems.
- Lockheed Martin has adopted AP203 as a primary means for exchanging CAD data with suppliers.
- Electric Boat uses AP203 for the exchange of data for thousands of solid models each year. It is also using XML and STEP for the Web to demonstrate production and development efforts using AP203 (and AP216, AP218 and AP227).
- Rockwell Collins is using AP203 (and AP210) for simulation for flexible manufacturing, computer integrated manufacturing, integration of electrical/mechanical design, and capturing the product definition.

The second edition of AP203, currently published as a technical specification. is now a Committee Draft (CD) and going through the ISO subcommittee to make it an international standard [50]. This second edition of AP203 offers a modular approach to ISO 10303 AP development. The intent is to eliminate the proliferation of APs that are creating "islands of APs," and move more toward a plug-and-play integration where users could choose from a set of capabilities to satisfy their product data exchange needs.

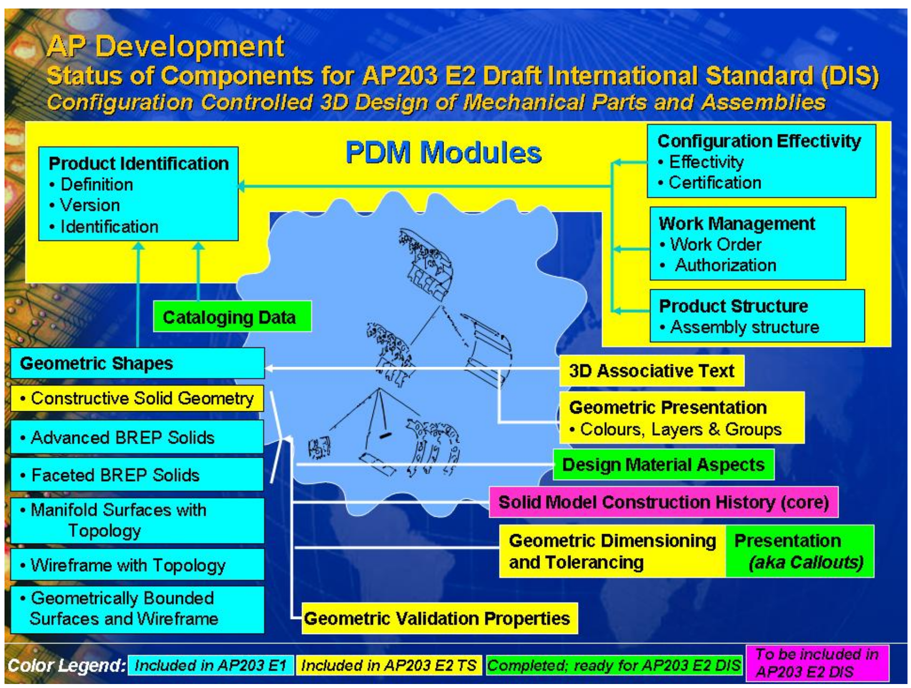

Figure 6: ISO/CD AP203 edition 2 (source: [51])

Based on experiences gained through early development and implementation of other STEP APs, some of the high-level industry requirements that were identified for future APs were to:

- Reduce the high cost and lengthy time to develop an AP.
- Allow implementation of a combination of multiple APs or extension of AP implementations with additional capabilities.
- Enable application software reuse.

- Eliminate duplication and repeated documentation of the same requirements in different APs.
- Reuse data generated by an implementation of one or more APs, by an implementation of one or more different APs (AP interoperability) [52].

Figure 6 shows the current functional coverage of ISO/CD 10303-203E2, which includes: the original international standard 10303-203, what was added in the approved technical specification (ISO/TS 10303-203E2), and what is being added to the specification before ISO distributes to its member countries for a draft international standard ballot. The primary focus of AP203 Edition 2 is tracking and managing the product. It defines the context, scope, and information requirements for the exchange of 3D designs of mechanical parts and assemblies in a configuration-controlled manner. While still a technical specification, several vendors have committed to building tools to handle importing or exporting geometry (solids, open shells, curve wire surfaces, facets, and wireframes), colors and layers, and annotation [46]. Boeing is using STEP AP203 Edition 2 for long-term data retention in development for its 787 and C-17 programs.

***2)** AP214 Core data for automotive mechanical design processes*

This AP is targeted at the automotive mechanical design processes; it covers the product and resource data of development process chains. It was approved and published as an ISO standard in 2001. This AP is the result of 7 years of work on which most of the automotive manufacturers have contributed through manufacturers' associations such as GALIA for France, VDA for Germany, Odette Sweden for Sweden, JAMA for Japan, and AIAG for United-States. (A copy of this memorandum of understanding can be found at [53].) Figure 7 shows the scope of AP214 classified in six categories including geometry, presentation, analysis, manufacturing specification and configuration, and technology data.

From the product structure point of view, AP214 covers the product definition data (part, assembly, shape) and configuration control data pertaining to the design phase of a product's development. The notion of product includes parts, assemblies of parts (with tolerances and kinematics), tools, and assemblies of tools. The tools include those specific to the product produced and used by various manufacturing technologies. Shape information includes data that pertains to the form features' representation of the shape of the whole product, as well as its parts. This AP extends the five types of shape representation of AP203 to include eight types of representation (2D-wireframe, 3D-wireframe, geometrically bounded surface, topologically bounded surface, faceted-boundary—known as faceted boundary representation (B-Rep), B-Rep, compound shape, and constructive solid geometry—known as CSG). Hybrid geometry representations for parts and tools defined as a mixture of these types are also possible. Another major contribution of this AP is its coverage of the notion of form-features, which allows the use design and manufacturing features for product descriptions. Change management is captured through the tracking of the versions of a product and data related to the documentation of the change process, and the management of alternate representations of parts and tools during the design phase.

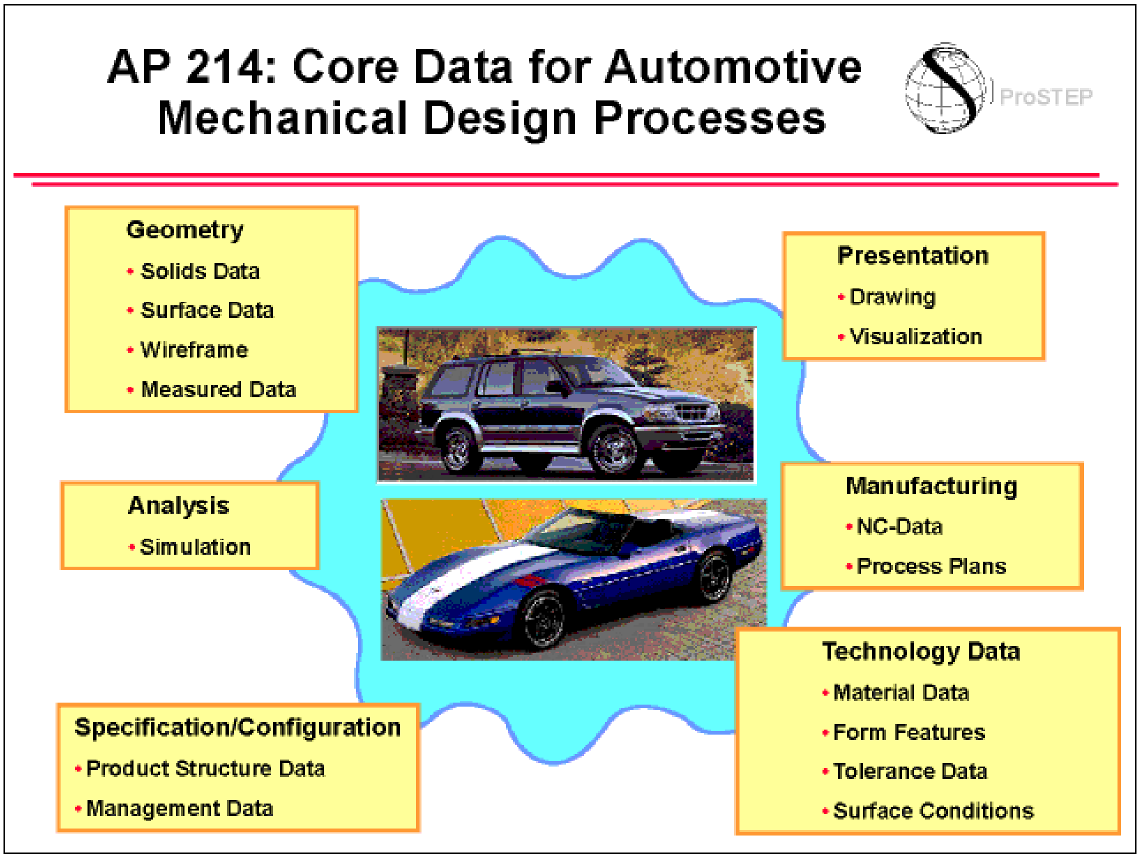

Figure 7: The scope of AP214 (source: [54])

From the processes side, the AP covers process planning information to manage the relationships among parts and the tools used to manufacture them. It also manages the relationships between intermediate stages of parts or tools, referred to as in-process parts. Supported processes include product definition, styling, design, prototyping, production planning, tool design, tool production, and quality control.

From the resources point of view the AP covers product documentation represented by explicit and associative draughting; references to product documentation represented in a form or format other than that specified by ISO 10303; and organizational and administrative data that allow the identification of persons, responsibilities, approvals, suppliers, and contracts.

Although the shape representation was enhanced by this AP compared to AP203, it is still not possible to have a general parametric representation of the shape of the part or tool. The AP does not cover any product data that is not related to the design phase, the financial data for the management of a design project, or the data that describes the pneumatic, hydraulic, electric, or electronic functions of a product. The capture of data for continuous kinematics simulations over time and for describing the input or output of finite element analysis are also outside the scope of this AP.

AP214 has a set of 20 conformance classes that cover essentially the entire spectrum of automotive design. Each CC is specialized in some particular sub-domain. CC 1 to 5 are dedicated for CAD/CAM applications, CC 6 to 10 for product structure and configuration management, CC 11 to 13 for process planning, CC 14 and 15 for feature based design, CC 16 and 17 for simulation and quality control, CC 18 and 19 for configuration control of process planning with 3D digital mockup data exchange and sharing, and CC 20 for complete data storage and retrieval. According to [45], most vendors who claim to have an AP214 translator have only implemented CC1 and/or CC2 that are essentially identical to AP203 geometry/topology with a somewhat different set of configuration management data.

AP214 is recognized as the basis for a number of data exchange tools and product data management (PDM) systems as it also comes with a data model that covers a large number of sub-domains. This data model captures various types of data related to design activity and relevant to these PDM systems. Reference [52] states the Defense Logistic Agency's interest in looking at using AP214 data for mechanical system spares acquisition; and the Naval Sea Systems Command intends to use AP214 as a migration strategy to overcome technical, contractual, and cultural resistance. Also, the Joint Engineering Data Management Information Control System (JEDMICS) (described in Appendix B) is looking at AP214 data storage for mechanical systems, and is preparing to accept AP214 3-D data for long-term DoD support. Daimler-Chrysler is using AP214, CC8 for exchanging BOM data [55]. The EADS Military Air Systems has decided to use AP214 for archiving their construction data on the Eurofighter project [56].

3) *AP224 Mechanical product definition for process planning using machining features*

This AP includes information needed to manufacture and assemble a machined part. In addition to part geometry (shape, dimension and tolerance) information, AP224 captures part features, material, surface finish, and other notational information needed in manufacturing. In AP224, the product definition includes the representation of the product shape, the definition of the machining features, and the initial shape of the material before machining. Figure 8 shows the scope of AP224 categorized into six application areas: machining features, measurement limitations, part administration data, manufacturing part properties, feature definition items & profile, and shape representation. The first two editions of this AP were approved as international standards in 1999 and 2001.

AP224 Edition 2 extended the scope of the first edition to address the representation of manufactured assemblies, so the content of the new AP224 is expanded to include a new set of machining features (cutout, recess, rib top, and shape profile). Several already existing machining features (planar face, n-gon profile, n-gon base shape, and the addition of a rectangular boss subtype) were enhanced. This edition allows the grouping of features. Features, dimensions, and tolerances are harmonized with AP214. The third edition of AP224 will expand the scope of this AP to include Gears.

AP224 covers information regarding product definition (for a single mechanical part manufactured by machining processes), and information regarding machining features and processes (products that are to be manufactured by either milling or turning processes. machining features for defining shapes necessary for manufacturing, and machining features definition items necessary for creating machining form features). AP224 tracks a large set of administrative data (needed to identify requirements and track the status of materials and equipment needed to manufacture a part; customer order data to track receipt of an order for a part to the shop floor, but not including tracking of the order on the shop floor; and approval data to authorize the manufacture of a part). Data for the tracking of the state of raw stock for documenting the manufacturing history of a part and the tracking of design exception notice of a part are also within the scope of this AP.

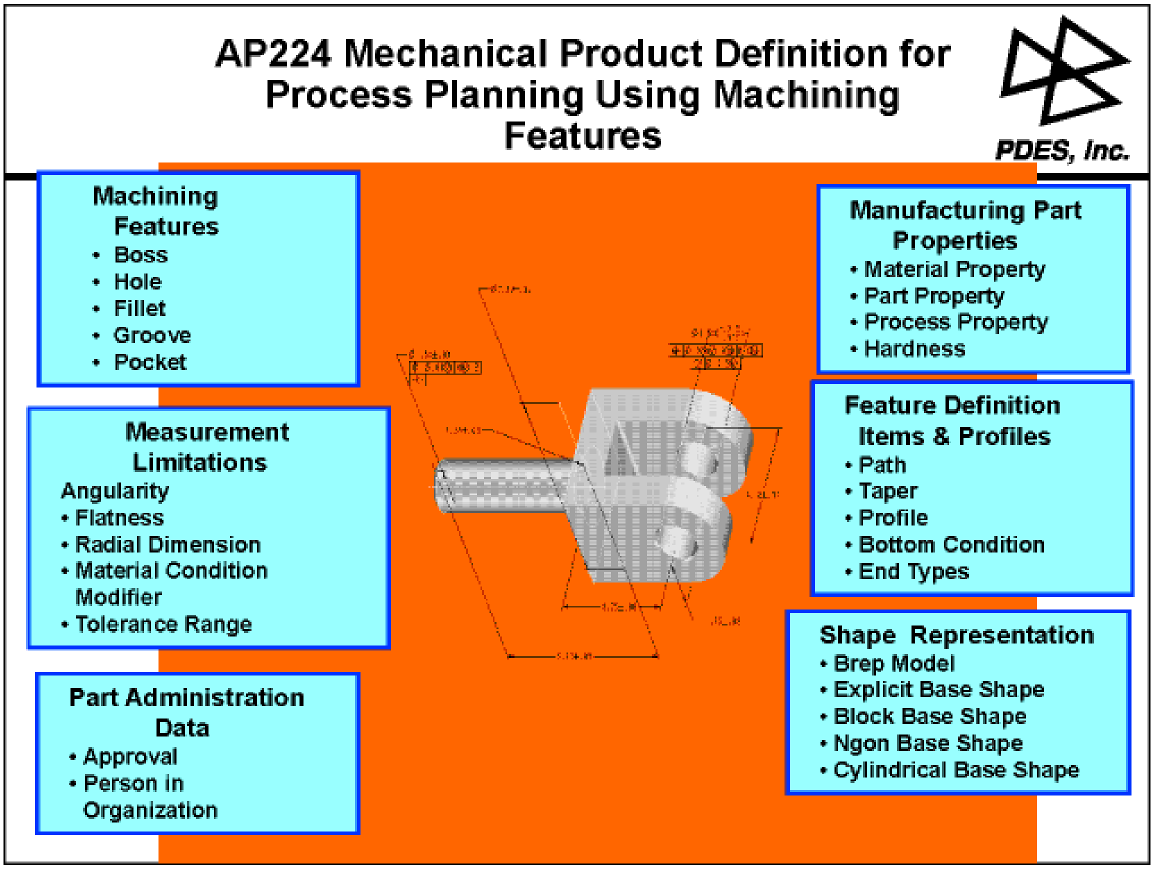

Figure 8: The scope of AP224 (source: [57])

The scope of AP224 does not cover data resulting from process planning. Information regarding design features of a part, schedule for completing a work order through the manufacturing process, configuration control, and various representations (assemblies, composite and sheet material parts, part pedigree) are also not covered.

AP224 has a single conformance class: feature-based process planning and shape represented by advanced B-Rep. AP224 is tailored for downstream manufacturing; it is used in the design-to-manufacturing phase as it provides a computer-interpretable data that can be re-used. It is also used for the exchange of design and manufacturing analysis data between CAD systems. A set of reports about AP224 implementations can be found in [58]. Interested readers can refer to [59] for an example of a STEP AP224-based design and manufacturing evaluation system. The Army has invested heavily in the development of this standard and pilots that emerged from this standard. AP224 was developed and implemented as part of the Rapid Acquisition Of Manufactured Parts (RAMP) Project (described in Appendix B) that has been in existence since 1986, to address standards-driven applications for the manufacture of mechanical and electrical parts and assemblies. Standards-driven applications were developed in an R&D environment and put into production at DoD Depots and several commercial sites.

While the STEP manufacturing suite comprised of a set of manufacturing related APs (AP203, AP219 [38], AP223 [60], AP224, AP238 [61], AP240) has tremendous potential to reduce manufacturing costs and lead times at the Army depots, challenges remain that need to be addressed before adopting these application protocols for use in a production manufacturing environment. It is in the Army's interest that an integrated process oriented approach be adopted to better leverage the capabilities of these standards.

4) AP233 Systems engineering data representation

AP233 is targeted to support the needs of the systems engineering community. It provides neutral data models as communications pipelines to exchange and integrate information between systems engineering tools. It is built from a set of reusable information model "modules" for compatibility across application domains. This AP was registered as Publicly Available Specification (PAS) 20542 within ISO TC184/SC4, but its standardization process is not yet finished, its publication as an international standard is planned for January 2008. However, even though not yet an ISO standard, a large number of applications and tools have already implemented some parts of this AP. For more information on AP233 please refer to [45; 62; 63]. This AP is structured around a set of modules as shown in Figure 9. These modules cover the following functionalities: requirements, structural models, behavioral models, validation and verification, data representation, risk analysis, analysis interfaces, scheduling, cost models, organizational structure, PDM, security, and rules. Some of these modules are still under development.

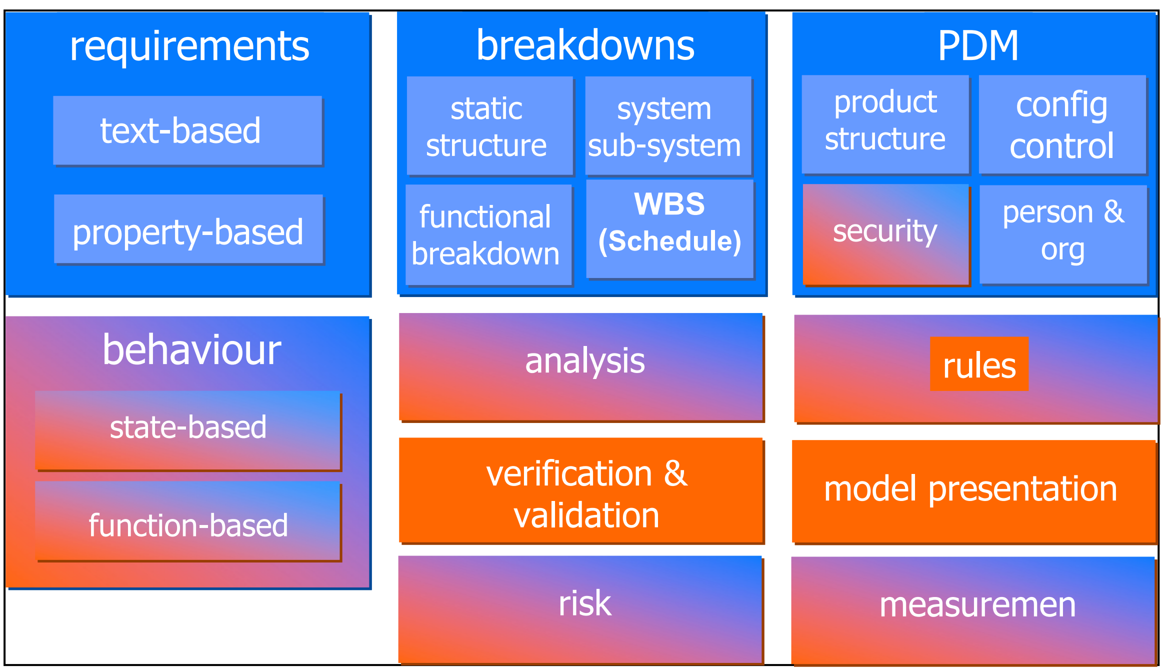

Figure 9: Modules of AP233 (source: [64])

This AP looks at systems engineering data from discipline views as well as from the data type point of view. Discipline views focus on the definition of other systems the system interacts with; the context for the system in each lifecycle phase; the support of hierarchical break down and object-oriented modeling techniques, the functional and non-functional requirements of the system in each lifecycle phase, the definition of the static and dynamic behavior of the system. From the data type point of view, the following types of data are within the scope of this AP:

data to describe the system, its requirements, and its static and dynamic behaviors; data to support the physical architecture, the partitioning of the system, and configuration management; data to support the verification and validation of the system; and data to support project and industrial management;

AP233 does not cover the following lifecycle stages: support the feasibility assessment of the system; domain engineering; realization, operation, maintenance, and decommissioning of the system. Also, the following types of data are outside the scope of this part of ISO 10303: data used solely in the domain engineering; and data used solely in the lifecycle stages feasibility assessment, realization, operation, maintenance and decommissioning of the system. AP233 provides a set of 25 conformance classes noted CC-A through CC-G, and CC1 through CC19. As an example of the options covered by these CCs, here is the specialization of the first set: CC-A for Administrative information; CC-B for Work management; CC-C for Change management; CC-D for Document reference; CC-E for Element classification; CC-F for Element prioritization; CC-G for Graphics. For a full description of all CCs we refer interested readers to [65].

AP233 is well integrated with other existing standards. It uses DODAF to classify the different views on a system, Systems Engineering Modeling Language (SysML) to represent the information in each view [66], and AP233 to exchange data between DODAF, SysML, and legacy tools. Industries that can benefit from using AP233 are automotive, aerospace, shipbuilding, process planning (e.g., petroleum), electronics, and others with complex products and processes. Some industries have already started implementing or incorporating AP233 modules in their applications: AP233 was used by UGS to update customer requirement data for the transition from TeamCenter v4 to v5 [67], Telelogic integrated recent AP233 modules in their requirement management applications [68]. Eurostep has also implemented a number of AP233 modules in Share-A-space [63; 69]. ThreeSL Cradle included an AP233 demonstration tool on a distribution CD to enable customers to move requirements data between formats [70]. PTC developed a prototype implementation driving parametric models from AP233 property-based requirements [71]. AP233 interfaces have also been developed to a number of different tools: DOORS™ from Telelogic [68], Slate™ from EDS [72], Cradle™ from 3SL [73], Core™ from Vitech [74], Requisite Pro™ from IBM-Rational [75], StateMate™ from iLogix (as part of SEDRES project) [76], Software Through Pictures™ from AONIX (as part of SEDRES project) [77].

DoD Open System Joint Task Force [78], INCOSE [79], BAE Systems [80], NASA [81], and the UK MOD [82] are supporting the development of more and more AP233 interfaces with many other systems. More information regarding AP233 implementations can be found in [40; 64; 66; 82-84].

5) *AP239 Product Life Cycle Support*

ISO 10303-239 (AP239) became an international standard in 2005. The development of AP239, also known as Product Life Cycle Support (PLCS) [14], has been motivated by the growing need to keep the information required to operate and maintain a product aligned with the changing product over its lifecycle. PLCS grew out of work on the NATO CALS

[14] We use AP239, ISO 10303-239, and PLCS interchangeably throughout this report.

(Appendix B) project in the late 1990s and a growing recognition by industry that ISO 10303 could be extended from its current applications in the concept, design, and manufacture of products where it is already in use. In [84], the authors describe the PLCS startup initiative as, PLCS, Inc. was an international consortium established to develop an ISO standard (ISO 10303-239). The consortium comprised: US Department of Defense, UK Ministry of Defence, Finnish Defence Forces, Norwegian Ministry of Defence, FMV (Swedish Ministry of defence), DNV, Boeing, BAE SYSTEMS, Rolls Royce, Lockheed Martin, SAAB, Hagglunds Vehicles, BAAN, LSC, PTC, Aerosystems International, Pennant. Eurostep Limited provided the technical leadership and program management for the consortia.

Although STEP is adopted by many for information exchange in the early phases of equipment life, it needed to be more robust to embrace the in-service and disposal lifecycle phases. PLCS provides a significant aspect of this coverage. PLCS has its roots firmly in the standards that have evolved over the past decade or so. It specifies an information model to represent support of a product throughout its lifecycle, and a mechanism to maintain the information needed to support complex products, systems, and assets. This information model is represented by using the EXPRESS information modeling language. AP239 defines an extension to the capabilities of AP203, AP214, and the Product Data Management (PDM) Schema and Modules [85], to define the requirements for Configuration Management over the complete product life. AP239 also addresses the information requirements needed to define and deliver lifecycle support for complex assets.

The following functionality is enabled by the standard:

- Activity Management - Functionality to request, define, justify, approve, schedule, and capture feedback on activities (work) and related resources.
- Product Definition - Functionality to define product requirements and their configuration, including relationships between parts and assemblies in multiple product structures (as-designed, as-built, as-maintained).
- Operational Feedback - Functionality that describes and captures feedback on product properties, operating states, behavior and usage.
- Support Solution and Environment - Functionality to define and maintain the necessary support solution for a product in a specified environment including the opportunity to provide support (scheduled downtime), tasks, facilities, special tools and equipment, and personnel knowledge and skills required. PLCS will also relate organizations, personnel, and facilities with the product needing support.

As part of the ISO STEP series of standards, AP239 defines an application-specific, but flexible and extensible, information model. The information model can be modified by specific industry and organizations through the use of Reference Data Libraries (RDL). The role of RDL is to complete the semantics of the PLCS model necessary for implementation in a specific industry.

The benefit of AP239 is its integrated view. It has a large and generic information model that is larger in scope than most business processes require or most IT applications can manage; therefore, it allows better flexibility. AP239 handles scoping for specific IT applications by defining Data EXchange Sets (DEXs).

PLCS DEXs:

A DEX provides a way of extracting the PLCS information model into sections suited for a specific business process. A DEX provides a subset of the PLCS information model and usage guidance. A DEX can be used to contract against, or for setting conformance to, but AP239 implementations do not have to use DEXs. While AP239 was published as an ISO standard in 2005, the DEXs are initially being standardized by publishing the subset of ISO 10303-239 and associated usage guidance material as OASIS standards [86]. Conformance classes in AP239 are different in concept from those of earlier APs, in the sense that AP239 provides one single CC called "CC1: Product Life Cycle Support," but includes extensively used DEXs as CCs. The DEX architecture is shown in the following figure.

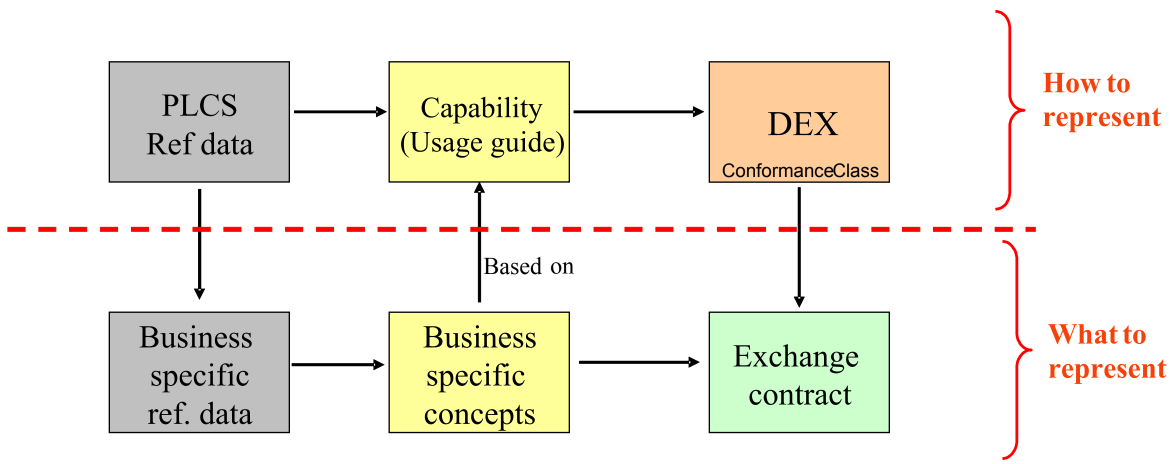

Figure 10: DEX architecture (source: [86])

The PLCS DEXs can be used to:

- Automate the process of populating one single Lifecycle PDM system.
- Automate an ongoing exchange of data between different IT systems that are PLCS compliant and share the same information management rules.
- Demonstrate compliance of a software application to an agreed set of information management rules, based on the PLCS standard.

Each DEX consists of a scope and the business process and description of the business process that the DEX is supporting. It also includes identification of the process in the AP239 activity model supported, usage guidance for the model, DEX-specific Reference Data, and the subset of the Information model supported by the DEX. The DEX will contain the EXPRESS information model and XML Schema (derived from the EXPRESS). The following are the initial set of OASIS DEX specifications:

- D001 - Product Breakdown for support: Exchange of the relationship of the parts assembly structure, derived from a PDM system, to an LSI/LCN structure used to manage support, and the links to relevant documents

- D002 - Faults related to product structures: Exchanges the output from Fault Analysis programs in a form that can be used to identify required diagnostic and maintenance tasks, and to provide coherent fault reporting
- D003 - Task Set: Exchange of a set of task descriptions, to support a work plan, or for use in multiple support solution definition.
- D004 - Work Package Definition: Exchange and negotiation of a work package for a specific support opportunity including the list of required tasks, location, dates, products and resources.
- D005 - Maintenance plan: Exchange for defining and communicating the work required to sustain a product over time including the results of any Logistic Support Analysis.
- D007 - Operational Feedback: The exchange of the observed configuration, location, state or properties of an actual product, and the communication of work requests to resolve issues arising from feedback on its usage
- D008 - Product as Individual: Exchange and collation of manufacturing and serialised part information and its relationship to the product assembly structure from which it derived.
- D009 - Work Package Report: The exchange to support the reporting of work completion against a work package definition.
- D010 - System requirements: The exchange of requirements information related to a system.

There are a number of parts of the PLCS model that will be common to many DEXs. (e.g., date and time). Rather than each DEX replicating the usage guidance for these, they are packaged into chapters called "Capabilities" that are reused across different DEXs.

PLCS Capabilities:

The Capabilities are the building blocks from which a DEX is constructed [87]. DEXlib, owned and managed by OASIS, is the development environment used to develop the PLCS DEX (Data Exchange Sets). It contains up to date versions of all the PLCS DEXs and their constituent components.

Capabilities perform a similar function to STEP application protocols' modules although there is no one-to-one correspondence. They are used to accelerate DEX development and to avoid different interpretations of equivalent concepts in different DEXs. Each Capability contains: an introduction, explaining the nature and purpose of the Capability; a business overview; a description of the information model used by the Capability, with examples of its use; and a full specification of the information model used by the Capability, derived from the relevant AP239 implementation module.

A Capability is a portion of the PLCS data model that is reused in instantiations of the data model. A Capability is independent of business context and domain of the instantiations. Reusability is solely based on the structural similarity of the instantiations; a Capability consists of a fixed set of entities, relationships, and internal, fixed-value attributes. A Capability may be regarded as a macro-entity with a set of parameters. Its purpose is not in data modeling, but in describing typical instantiations of a portion of a data model.

Capabilities ensure a common interpretation of PLCS, avoid multiple dialects of PLCS, reduce the amount of documentation for the PLCS usage guide, and simplify instantiation of the PLCS data model.

<u>Reference Data</u>:

Reference Data is defined to be lifecycle data that represents information about classes or individuals which are common to many facilities, or of interest to many users. A Reference Data Library (RDL) is a managed collection of reference data. Reference Data is a key success factor for consistent sharing and integration of data, i.e., to ensure the consistent meaning of data. The reference data add semantics to the AP239 model.

- PLCS Reference Data: The standardized PLCS Reference Data is created and published using the W3C Web Ontology Language called OWL [88], which became a W3C Recommendation in February 2004. While OWL may have any of several formats, the OWL XML syntax is used for the PLCS Reference Data. This allows the use of XML-related languages and tools for the creation and management of the Reference Data.
- Business-specific Reference Rata: These reference data are business specific and will not be subject for standardization through OASIS.

The overall PLCS information model, DEX, and RDL is shown in Figure 11. The numbers in brackets denote the number of PLCS architecture elements available. For example, there are 20 DEXs, approved or in-progress, available from OASIS as of today.

DEX, Capability, Business concept, and PLCS RDL in the DEX architecture are subjects for standardization. The standardization of Reference Data may take place before, during, or after the development of the data model (or application) which uses it. Applications using the *same data model* but *with different Reference Data* will *not* interoperate until the two sets of Reference Data have been harmonized or mapped. The ISO community has a good procedure for Reference Data management but no business model to support its implementation.

The US Army TACOM is working with General Dynamics Land Systems in its Abrams Unique Identification project, to set up a process to access the BOM information using AP239. The United Kingdom Ministry of Defence (UK MoD) is mapping PLCS into their UMMS (Unit Maintenance Management System. The work they have completed to date:

- Mapping of the existing UMMS export data set to the AP239 data model
- Development of an XML-based architecture to implement an AP239 compliant exchange
- Embedding the new PLCS capability into the UMMS application
- Building matching PLCS capability into the Devonport Dockyard ERP System (PEPS)

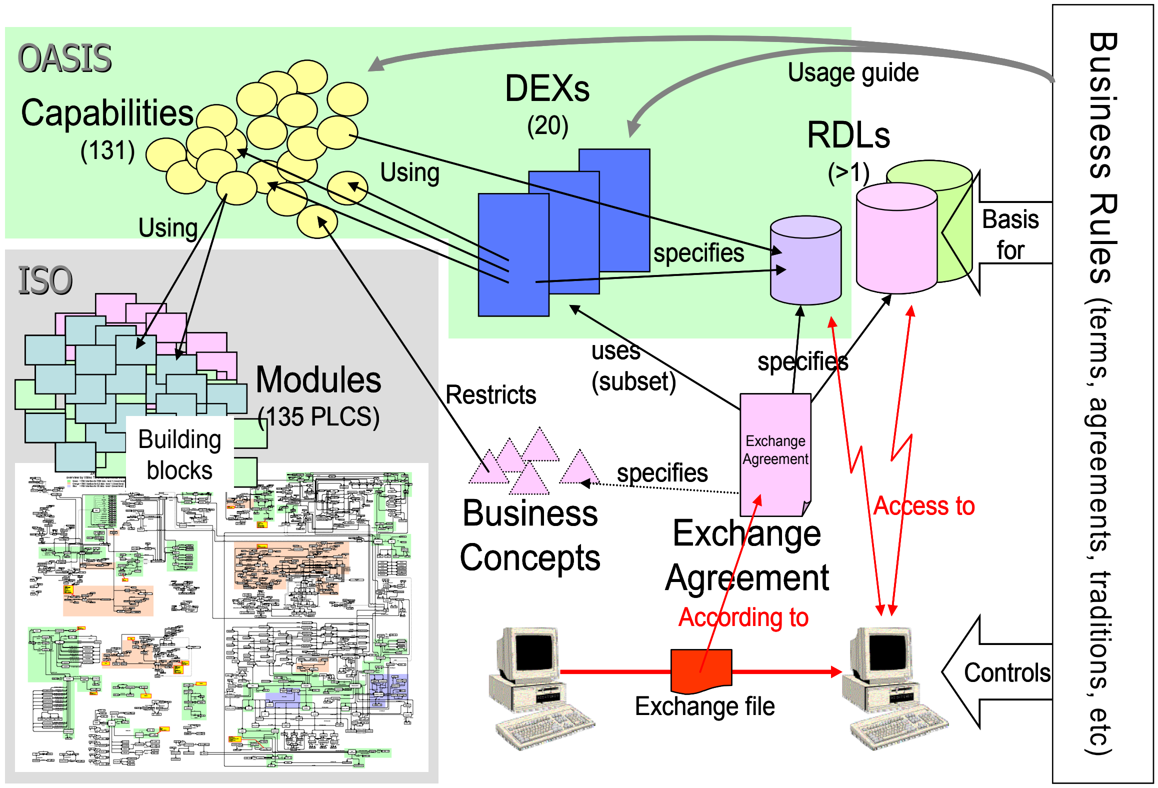

Figure 11: From information model to exchange (source: [63])

The UK MoD work still in progress on this mapping:

- Developing a Reference Data Library and RDL Service in support of the exchange
- Revising the existing mapping to reflect the newly developed Work Package Definition Data Exchange Specification (DEX 4)
- Developing an architecture to implement the PLCS DEX and RDL compliant revised interface [89].

Lockheed Martin has a pilot implementation plan for adopting PLCS on the F-35 program beginning in 2006. EPM has initiated pilots with Aerospace and Defense organizations to measure the value of using STEP for Long Term Data Retention and Product Life Cycle Support [37].

6) AP240 Process plans for machined parts

ISO 10303-240 [90], which was approved as an international standard in 2005, complements the missing link between design and manufacturing in machinery manufacturing. With design based on 3-D CAD systems becoming popular, ISO 10303-203 and ISO 10303-214 are being implemented. In addition, the CNC data model now being developed at ISO TC 184/SC 1 is also moving toward practical use. With the international standardization of ISO 10303-240, the entire flow from design through manufacturing will become seamlessly linked, making possible the development of an innovative design-manufacturing process. Figure 12 highlights the functional capabilities of AP240.

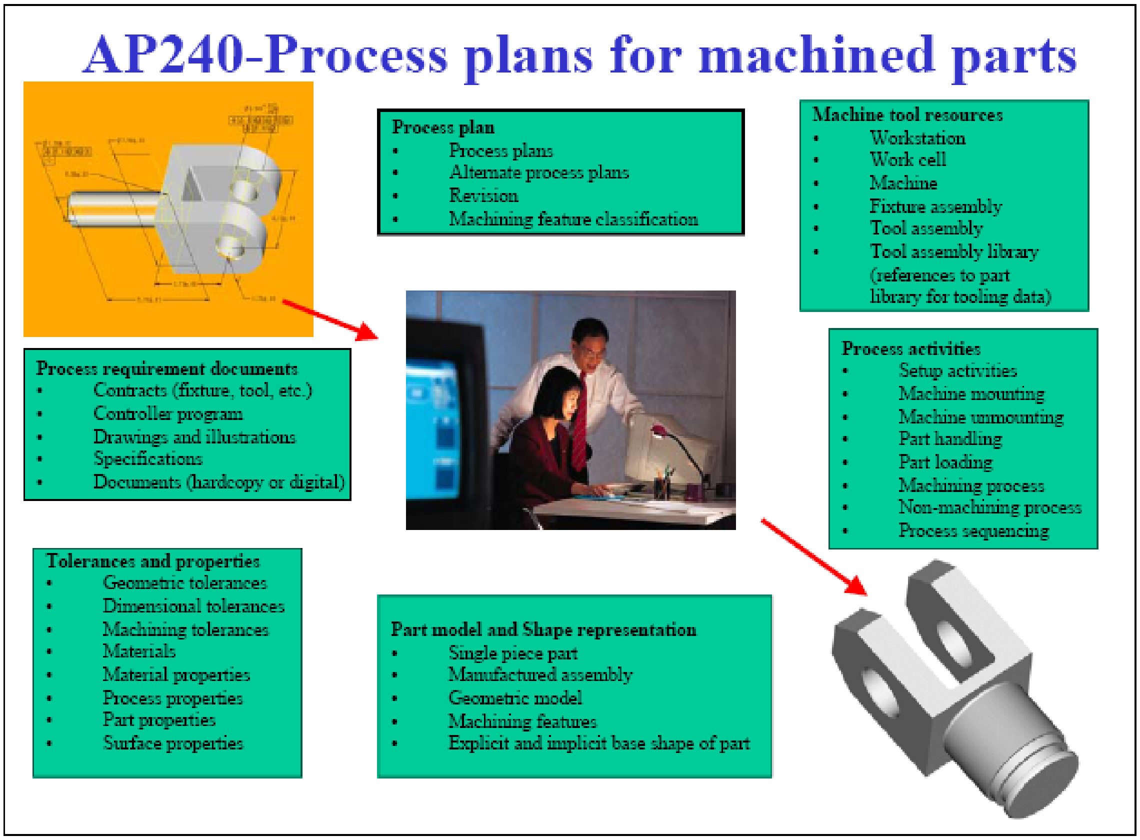

Figure 12: AP240 (source: [91])

With this standard, design and manufacturing-system information without drawings will become available for sharing. In addition, a mechanism for improved reuse of the data can be created. This means that a mechanism can be created for keeping in storage production-floor expertise that cannot be stored in existing information systems. ISO 10303-240 is expected to enable the communication of information concerning work results of process design, which requires mostly processing expertise, so that the evolution of machine processing itself can be promoted to lay the foundation of new machinery manufacturing.

SCRA and the Army have conducted demonstration pilots using AP240 in the N-STEP project, and have shown a reduction in process planning lead-time for machined parts and assemblies.

4.2.2 GEIA-927 Common data schema for complex systems

The Government Electronics & Information Technology Association (GEIA) [92] is an ANSI-accredited standards development organization that focuses on supporting its electronic and IT membership. One of the many standards GEIA has developed is GEIA-927, "Common Data Schema for Complex Systems." GEIA-927 became a standard in 2006, and is now in continuous maintenance. The standardization activity has been a collaborative effort supported and funded by DoD [93; 94]. The GEIA-927 working group consisted of representatives from industry (e.g., Lockheed Martin, Raytheon), universities (e.g., Johns Hopkins University) and the Army. The primary aim of this project is to provide a unified schema that integrates the best available schemas for data representation for modern complex systems. The GEIA-927 is intended to be a key enabler for product data representation and exchange within complex systems.

The elaboration of GEIA-927 started by choosing ISO 15926, Integration of lifecycle data for oil and gas production facilities [95], as the basic building block on which a set of other standards is integrated.
Figure 13 shows the order in which these standards are added one after the other to constitute GEIA-927. Data models from PAS20542 (ISO/CD 10303-233, Systems engineering data representation) [96], AP212 (ISO 10303-212 electrotechnical design and automation) [97], and AP239 have been integrated [98]. The most recent version of GEIA-927 passed ballot in April 2006; other APs will be integrated in the next version of the standard.

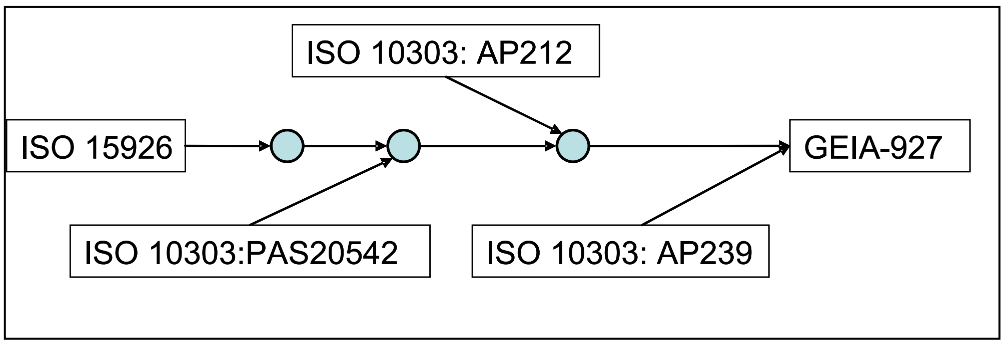

Figure 13: Initial components of the GEIA-927 standard

GEIA-927 addresses product data exchange and sharing across the entire product lifecycle within a complex system from viewpoints of multiple disciplines such as functional and non-functional requirements of the system, definition of static and dynamic behavior of the system, and the context of the system in each lifecycle phase. Lifecycle phases included in the scope of GEIA-927 are system engineering, feasibility assessment, requirement definition, domain engineering, system realization, system operation, system support, system maintenance, and the decommissioning of the system.

Although a large spectrum of data types may be needed to cover all the product lifecycle phases, the data types included within the scope of the standard should “at least theoretically” be sufficient to represent the full range of information generated and treated during the entire product lifecycle. Among these various data types we have: data to describe the system, data to specify the requirements of the system and their allocation to functional object, physical objects and physical implementation, data to specify the dynamic behavior of the system, data to describe the functional decomposition of the system, and data to support the physical architecture of the system. Such types of data allow the analysis of requirement/function/form mapping and function/behavior studies --- two very useful operations for complex systems.

GEIA-927 is organized into a set of functional views: functional/system/physical architectures, activity, common, documentation, product, product lifecycle, requirement, property, logistics, and effectivity views.. Each view is structured around a set of key entities. Functionally important entities are shared between multiple views. Structures which are useful to all other views are grouped within the Common view. The physical description of a product/system is defined in the Physical Architecture view. The structure of the product is represented by the Product view; this view may be seen as a limited version of the Physical Architecture view in which versioning information is added. The functional description of a system/product is given by the Functional Architecture view. These three views (Product, Physical Architecture, and functional Architecture) can be used together to provide a complete representation of a system or product.

As recently as January 2006, a second standard, GEIA-927-1, focused on logistics product data, and was still intended to be an accompanying standard to GEIA-927. GEIA-927-1 in its initial drafts included an implementation model of the LSAR Data, LSAR XML Schema, LSAR Data Definitions, implementation element mappings to GEIA-927 [94]. GEIA-927-1 has since been evolved into an independent standard under development, called GEIA-0007, "Logistics data implementation model." GEIA-0007 defines logistics product data generated during the design of a system, end item, or product; and provides data exchange mechanisms as it is shown in Figure 14. The purpose of GEIA-0007 is to provide an industry standard for acquisition and exchange of logistics product data by industry and DoD, re-establishing industry and DoD's ability to exchange LSAR. GEIA-0007 represents a DoD business DEX, and the Army hopes to work with OASIS to incorporate GEIA-STD-0007 logistics data into the appropriate DEXs (1-5), and create new DEXs where gaps exist. The Army Logistics Support Activity (LOGSA) is a voting member of OASIS. [94] GEIA-0007 is currently under development and is anticipated to be accepted as a standard within this calendar year.

4.2.3 ANSI/EIA-649 National consensus standard for configuration management

ANSI/Electronic Industries Alliance (EIA) Standard 649 (EIA-649) was last published April 1, 2004 as ANSI/EIA-649-A. The purpose of ANSI/EIA-649 is to provide Configuration Management (CM) principles that are applicable to a broad range of industries [99]. The standard describes CM functions and principles and defines a neutral CM terminology for use with any product line. Among the described CM functions there are: CM planning, configuration identification, configuration change management (change control), configuration status accounting, and configuration verification.

ANSI/EIA-649 was issued in 1998 to replace MIL-STD-973, and was adopted in 1999 for use by the Department of Defense (DoD). To facilitate the implementation of this standard, a handbook (HB-649, "Implementation Guide for Configuration Management") was released in 2005 [100]. It provides implementation guidance for:

- Tailoring to fit various applications regardless of industry
- Preparation of CM plans
- Evaluation of CM systems
- Creating CM Metrics
- Demonstrating compliance with principles

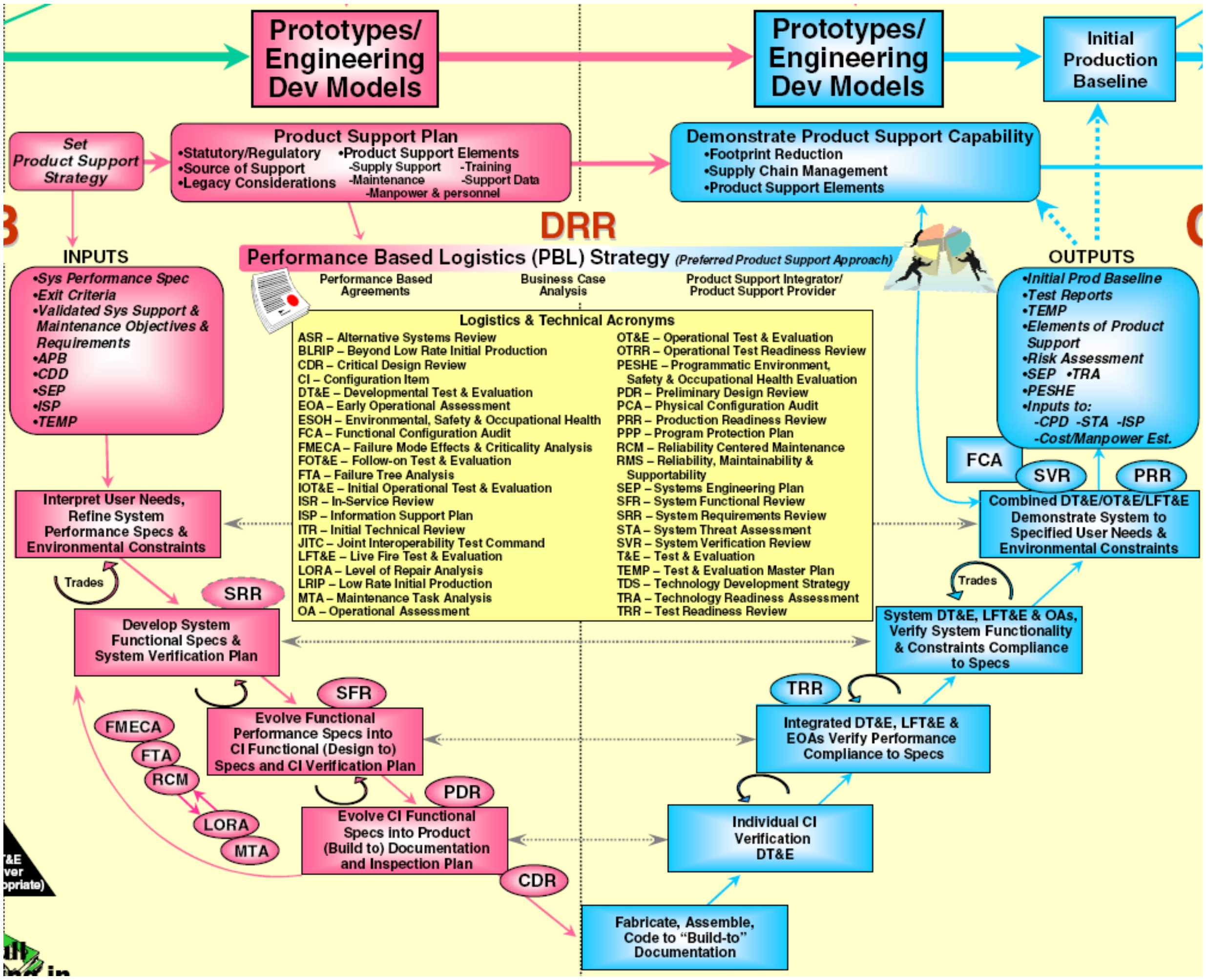

Figure 14: Types of logistics product data generated during design (source: [101])

A few companies have software application implementations for ANSI/EIA-649:

- InSync's integrated support systems (ISS) provides support for legacy and current CM standards such as MIL-STD-973, MIL-STD-2549, and ANSI/EIA-649 [102].
- PTC Windchill's Aerospace & Defense Module and Windchill PDMLink Enhanced compliance with configuration management standards ANSI/EIA-649, MIL-HDBK-61A and CMII [103].

4.2.4 ANSI/EIA-836 Configuration management data exchange and interoperability

The Government Electronics & Information Technology Association (GEIA) launched (in the year 2000) a standardization project, in partnership with the DoD and several industry participants, to develop a new configuration management (CM) data exchange and interoperability standard. The proposed ANSI/EIA-836 standard includes a CM data element dictionary and reference schema, and a set of XML schemas and XML document templates for CM business objects. The standard has a configuration management focus, specifically with respect to the transfer of controlled information and data required to perform CM functions throughout a product's life cycle. It provides fundamental reference information to facilitate

CM data exchange and interoperability regardless of specific data encoding and transport methods.
The level of interoperability between dissimilar systems is determined by trading partner agreement. XML [104] is used to facilitate data sharing and exchange among different systems. Some key characteristics of EIA-836 include:

- It embodies a data dictionary that lets all participants speak a common CM language. The data dictionary contains the complete set of technically credible CM data element definitions [105]. It supplies a fundamental reference vocabulary for access, sharing and exchange of CM data, and for developing CM data management tools, databases, and systems.
- It applies the principles in ANSI/EIA-649, but does not dictate how to practice CM in any given organization. A set of rules is established for the mapping of the content of EIA-836 to the underlying principles in ANSI/EIA-649.
- It embraces Web-based communications technology in the form of eXtensible Markup Language (XML), which allows the exchange of data across diverse hardware, operating systems, platforms, languages, and applications.
- It facilitates interoperability regardless of specific schema or specific method of data transfer.

Figure 15 from [106] shows that the main focus of EIA-836 is on data element definitions, relationships, and business objects for product information exchange. Templates are created and provided for exchange of CM business objects. As in ANSI/EIA-649, a product is any item including any of the generic categories of hardware, software, document, processes, data, materials, or services.

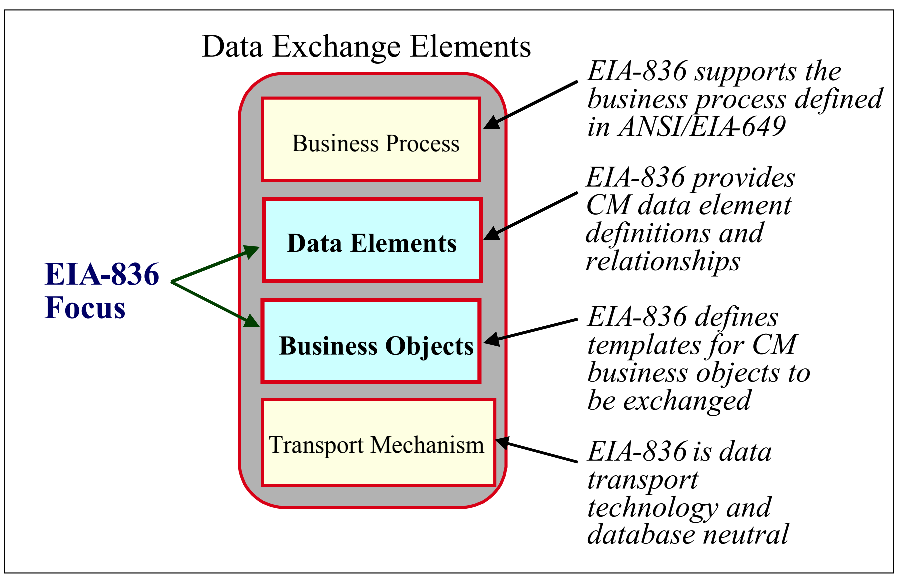

Figure 15: EIA-836 focuses on data elements and business objects

Information such as product definition geometry, topology, tolerances, features, specification requirements, and process description details are considered out of the scope of the EIA-836 standard. For these types of information one can use other standards such as ISO 10303 [33], ASME Y14.5 [107], ISO 1101 [108], and ASME Y14.41 [109]. EIA-836 provides a comprehensive reference vocabulary [106]. It includes definitions of all CM data elements and attributes considered to be within the CM domain that address:

- Product identification and relationships
- Configuration identification
- Configuration change management
- Configuration status accounting
- Configuration verification and audit
- Data and document management

The content and structure of EIA-836 business objects can be used as defined in the standard or modified to be tailored to suit specific partner situations or domains. Additional business objects may also be created. The data element schemas may also be adapted or extended to capture new business rules and definitions. To obtain tailored views of CM data, XML style sheets need to be developed by the standard's users and used to visualize their CM data and business objects. EIA-836 has been designed to be used within networked environments, through Internet, WWW, and related information technologies and e-business frameworks such as XML and ebXML – electronic business XML [100].

According to the EIA-836 reference document [106], the standard supports the PLCS activity data models and complements ISO 10303, STEP application protocols so that data may be exchanged with users of these standards.

The initial release of EIA-836 was published 15 June 2002. Revisions are ongoing as the development of EIA-836 continues to be a collaborative project involving the GEIA G-33 (Configuration and Data Management) Committee, DoD, the ManTech Enterprise Integration Center in Fairmont, WV (under the guidance of the Systems, Standards and Technology Council (SSTC), and an Oversight Group providing advisory partnerships with other associations such as the Aerospace Industries Association). To harmonize related efforts the EIA-836 team plans to collaborate with other e-business initiatives including STEP (ISO 10303), the Product Life Cycle Support (PLCS) Program, and the Aerospace Industries Association Electronic Enterprise Working Group. While EIA-836 appears to be a thorough and good start for managing configuration data within the Army, its developmental effort within an industry standards development organization appears to be primarily funded by the Army for the Army. By the publication time of this report, we were unable to find any examples of EIA-836 software tools development to support its use.

4.2.5 MIMOSA Open Operations & Maintenance (O&M) framework

A joint effort by MIMOSA, OPC foundation, and ISA is underway to harmonize their standards and specifications and establish an architecture framework for operation and maintenance activities. The three organizations are collaborating to provide the standards and technology that form an interoperable framework for the exchange of O&M information. Such a single interface, called Open O&M [110], intends to enable easy integration of operations and maintenance systems through a free information exchange between applications across manufacturing, processes, and maintenance.

From the organizational point of view, Open O&M is a virtual organization maintained by MIMOSA. From the technical point of view, the Open O&M framework is built around the following set of standards from the three participating organizations:

- MIMOSA Open Systems Architecture for Enterprise Application Integration (OSA-EAI)
- MIMOSA Open Systems Architecture for Conditioned-Based Maintenance (OSA-CBM)
- ISA-95 – Enterprise/Control System Interface Standard [111]
- ISA-99 – Control System Cyber-Security Standard [111]
- ISA-OMAC – Open Modular Architecture Controls group standardizing packaging machinery interfaces [111]
- OPC interface specifications and data transport standards [112]

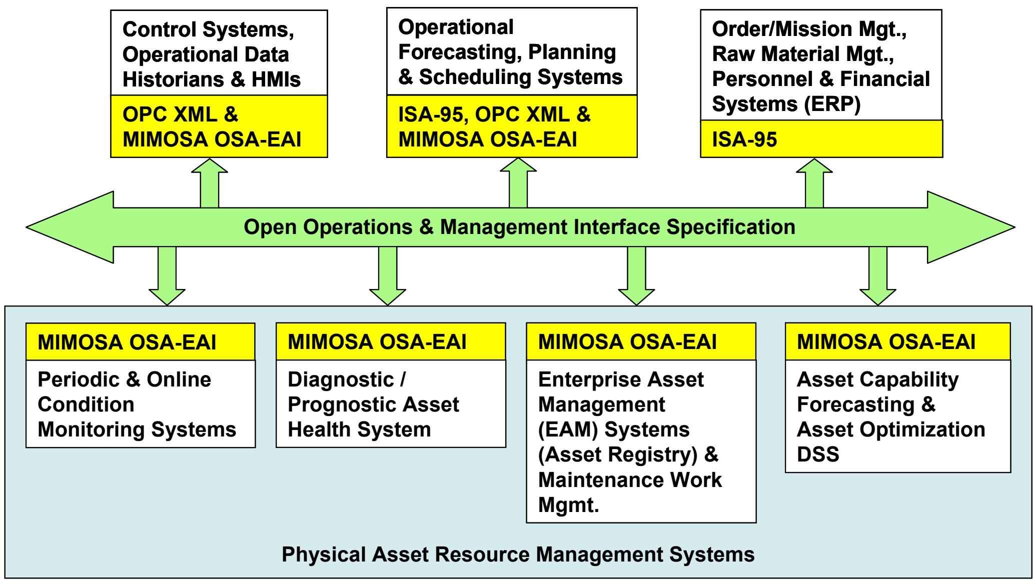

Figure 16: OpenO&M framework reduces the number of interfaces (source: [110])

Figure 16 shows how the Open O&M framework is used as a single interface to reduce the number of interactions between O&M systems. Open O&M integrates MIMOSA's OSA-EAI and OSA-CBM and the ISA-95 data exchange formats and utilizes the OPC interface specifications as the pipe to transport the information between systems. The client/server technology of OPC will be used to exchange OSA-EAI and ISA-95 format data. The use of OPC also enables the use of state of the art technologies such as web services and the ability to provide secure data exchange [110].

OSA-EAI implements Conditioned-Based Maintenance (CBM) and Conditioned-Based Operation (CBO) through a set of XML schemas to facilitate the exchange of critical maintenance information related to condition based monitoring, asset based registry, maintenance work & parts management, etc.

The ISA-95 standard supports vertical exchange of manufacturing data between business and control systems. The ISA-95 standard has been accepted by the IEC and ISO as the joint-logo international standard. In some literature, it is also referenced as ANSI/ISA-95.

For a given multi-manufacturing site enterprise, the Open O&M framework is an enabler for CBO and CBM and collaborative asset lifecycle management (CALM) strategies. The framework can also be used in a wider scale through to the entire enterprise supply chain and supporting infrastructure covering fleets, facilities, and manufacturing plants in both public and private sectors.

Various vendors, such as ABB, Emerson Process Management, Invensys, Microsoft, PeopleSoft, Rockwell Automation, Yokogawa, and many others are supporting the idea of one single architecture. Open O&M is also attracting major end-users in the refining, utilities, and manufacturing industries as well as the military services [113]. The US Army Product Manager of the Test, Measurement, and Diagnostic Equipment program at Redstone Arsenal, AL, is a corporate member of MIMOSA. OpenO&M has been adopted by DoD (see Appendix D). British Petroleum (BP) in its project to integrate fourteen majority-owned BP refineries committed to using MIMOSA OpenO&M to connect maintenance, laboratory, document management, drawing management, and other remote database management systems [114].

4.2.6 ASD/AIA-S1000D International specification for technical publications utilising a Common Source DataBase

S1000D is an international specification for technical publications developed by the European Association of Aerospace Industries (AECMA). It uses international standards such as the Standard Generalized Markup Language [115], XML, and Computer Graphics Metafile [116] for the production and use of electronic documentation. Implementations of S1000D should be able to handle a wide range of information types such as descriptive, procedural, maintenance schedules, fault isolation, and crew/operators.

S1000D is organized in a modular approach based on the Common Source Data Base (CSDB) principle for data creation and storage. A data module is defined as a "self contained unit of data" and has two sections: one containing the data required by the user (the content section), the other containing all the metadata necessary to control the data module and its configuration (the identification and status section). A Data Module Code (DMC) is associated to each module and permits the use of a database to store and manage the complete information set. It also ensures that the information is not duplicated in the CSDB. Any shared information is stored only once as a single data module and used many times in different contexts.

Two groups made up of representatives from France, Germany, Italy, Spain, Sweden, UK, and USA are responsible for the technical development (the Electronic Publication Working Group EPWG) and maintenance (the Technical Publication Specification Maintenance Group - TPSMG) of the specification.

According to [117] the benefits of using the specification are:

- It reduces maintenance costs for technical information.
- It allows a subset of information to be generated to meet specific user need.
- It can generate many different output forms from the same base data set, which ensures strong and efficient data configuration at the user interface level.
- It allows neutral delivery and data management.

The potential of S1000D to unify the large number of documentation approaches and delivery mechanisms is driving interest in this standard. Earlier use of S1000D in Europe could ease its adoption in the United-States through its NATO partners.

According to [118], S1000D will soon be adopted by DoD as the new standard for US military documentation: "Unlike many European defense organizations, the Department of Defense hasn't officially signed up for the specification. But growing numbers of U.S. defense programs are using the specification, and there are a number of pilot projects in progress. Many believe it is only a matter of time before the DoD officially adopts S1000D. At the recent Aerospace Industries Association's product support conference (May 13,2005), titled: Logistics Transformation, A Systems Approach. Jerry Beck of the Office of the Assistant Deputy Under Secretary of Defense, Logistics Plans & Programs emphatically stated that OSD will be adopting S1000D as the new standard for the US Military."

S1000D standard claims to offer many advantages. It reduces support costs, enables modularity and content reuse, makes it easy to share data across different computing platforms, and allows users to view electronic documentation via a common web browser or text viewer. However, one of the major S1000D challenges will be the task of converting legacy documentation.

A number of tools that support authoring, publishing, viewing, and distributing manuals are already available through the European adoption of S1000D. Raytheon Missile Systems has incorporated S1000D implementation capabilities in its Non Line-Of-Sight-Land Systems (NLOS-LS) program. NLOS-LS is in development for the US Army by Netfires LLC, a joint venture between Raytheon and Lockheed Martin, under a $1 billion contract. NLOS-LS is anticipated to be a key element in the US Army Future Combat Systems (FCS) warfighting transformation concept [119]. General Dynamics Canada has also implemented S1000D [120].

5. An initial typology of information standards

The proposed typology primarily reflects the *content* to be communicated and implies the appropriate expressiveness and language choices for each type of content. Within each type, individual standards may be classified as to origin, intent, development process and, to some extent, scope by the typologies listed below. This typology is based on the one initially presented in [121]. For illustration, we give some examples of standards in each type below, and a more thorough list of standards that may apply can be found in Appendix C.

Type Zero: Standards for implementation languages

These standardized languages include programming, scripting, assembly level and other computable languages used to implement the Type One, Type Two, and Type Three standards. Examples include: Basic, FORTRAN, C, C++, Java, C#, Prolog, Perl, Tcl/Tk, OpenGL.

Type One: Information modeling standards

Semantically rich modeling language standards, based on different forms of logic, include the Knowledge Interchange Format (KIF), OWL, and RDF that support reasoning over the information representing a content domain [88; 122; 123]. OWL includes the RDF/XML interchange syntax and has three sub-languages of different expressiveness and complexity (OWL Lite, OWL DL, OWL Full). All of these efforts are directed towards building formal ontologies that are expected to aid semantic interoperability.

EXPRESS [124] and UML (Unified Modeling Language) are two examples of information modeling languages. EXPRESS is used in the STEP-based systems [125], while UML is based on the object-oriented methodology [126]. UML is primarily intended for specifying, visualizing, constructing, and documenting components of software systems as well as for business modeling and other non-software systems. The expressive power of EXPRESS is comparable to the combination of UML and the Object Constraint Language (OCL), a formal language used to describe expressions in UML models [127]. XML Schema is becoming popular for expressing the structure and typing constraints for data embedded in XML documents. XML Schema offers a higher level of expressiveness than the earlier XML DTD (Document Type Definition) descriptions.

A NIST focus area is the standardization of the representation of manufacturing processes, called the Process Specification Language (PSL) [128]. Process data is used throughout the lifecycle of a product, from early indications of manufacturing process flagged during design; through process planning, validation, production scheduling and control. PSL uses first order logic and OWL-like representations [88].

Type Two: Content standards - domains of discourse

Content standards pertain to information models specifically defined for particular domains using a generic information modeling language (Type One) or an extension of one (for example, UML with its extension, SysML). SysML is directed towards the specific domain of systems engineering. SysML is derived from the basic UML to cover the requirements, structure, behavior, parametrics, and the relation of structure to behavior (allocation) [129].

Content standards subdivide into several categories based on the specialization of the content addressed. To keep it in context further clarification on the typology, the principal categories are briefly described below. Content standards might use general Type Zero languages for implementation. Product information modeling and exchange standards are used to model the information necessary to support the product. Visualization standards are used to extract adapted views of the information.

Product information modeling and exchange standards

ISO 10303 deals with product structure and geometry and part-related information [33]. As we know STEP uses the EXPRESS information modeling language to define a generic product model. In the modular approach of STEP, information models form modules and integrated resources (IRs), from which specific content standards (application protocols or APs) are developed (for example, AP214 [130]). These specific content standards can use specific catalogs. As another example, UML and its extension SysML, can be used to define specific system (say, control system) standards. This hierarchy is illustrated in the following figure (The arrows represent "uses").

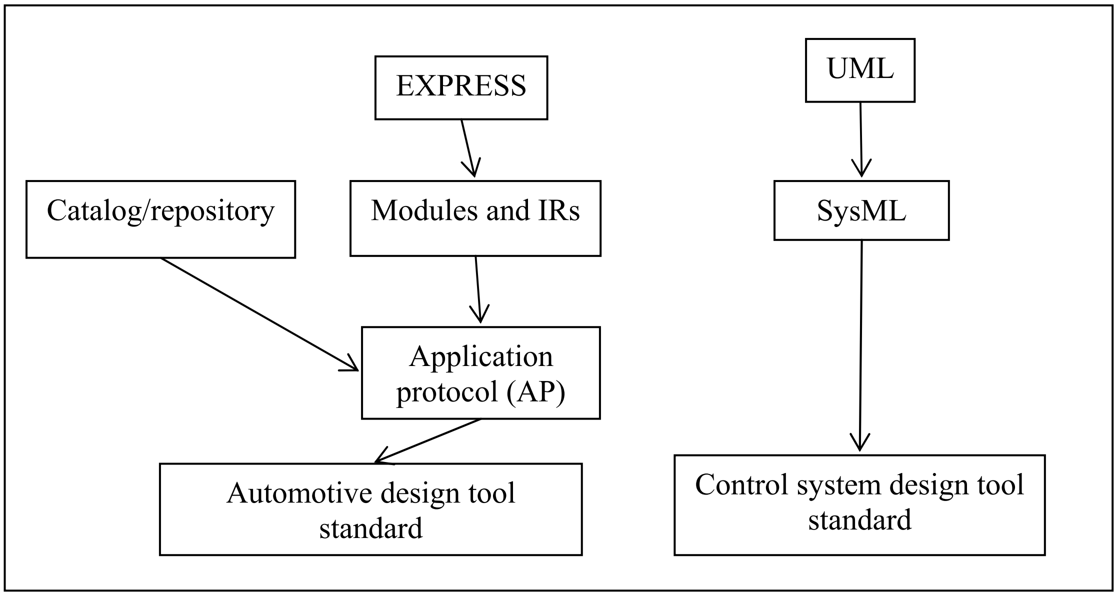

Figure 17: Examples of content standards

AP239 is dedicated to product support and is based on an extension to the STEP PDM Schema capability [85]. PLCS provides mechanisms to maintain the information needed to support complex assets (such as ships, aircraft, or engines). PLCS builds upon the functionality defined by other standards relevant to product support.

Product visualization standards

The U3D graphics standard is a simple format for interactive viewing and sharing of 3D data and is being standardized in ISO [131]. X3D is an XML-enabled 3D standard to enable real-time communication of 3D data [132]. JT is a CAD-neutral data format for product visualization, collaboration and data sharing [133]. JT Open is a library of Java classes supporting the client/server and Internet programming models. JT2Go is a JT format viewer. OpenGL (Open Graphics Library) is a low-level graphics library for 3D data visualization [134]. OpenML (Open Media Library) is a programming environment that supports the creation and playback of digital, audio, video and graphics [135].

Type Three: Architectural framework standards

To achieve interoperability between the standards within the PLM context, it is imperative that the different types of standards described in this section be reconciled and made convergent. In integrating these types of standards, it is necessary to take into consideration the architectural frameworks for creating integrated support systems. A number of architecture framework standards have been proposed, such as the Zachman Framework [136], the Department of Defense Architecture Framework (DODAF) [137] and the Federal Enterprise Architecture Framework (FEAF) [138]. These frameworks do not yet provide the full spectrum of viewpoints needed to address the overall interoperability concerns. Another interesting framework is the ISO RM-ODP Reference Model for Open Distributed Processing [139]. This model has been used as a framework for CORBA-based [140] distributed applications management, and defines five architectural viewpoints that address a wide range of interoperability concerns from policies and procedures to engineering solutions: the enterprise, information, computational, engineering, and technology viewpoints.

The Department of Defense (DoD) Architecture Framework (DODAF), Version 1.0, defines a common approach for DoD architecture description development, presentation, and integration. The Framework enables architecture descriptions to be compared and related across organizational boundaries, including multinational boundaries. DODAF is the implementation chosen by DoD to gain compliance with the Clinger-Cohen Act and United States Office of Management and Budget Circulars A-11 and A-130. All major DoD weapons and information technology system procurements are required to develop an enterprise architecture and document that architecture using a number of predefined views. DODAF was formerly named C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance). Other derivative frameworks based on DODAF include the NATO Architecture Framework (NAF) and Ministry of Defence (United Kingdom) Architecture Framework (MODAF).

Though DODAF is aimed at military systems, it has broad applicability across the private, public, and voluntary sectors involved around the world. It is especially suited to large systems with complex integration and interoperability challenges, and is apparently unique in its use of "operational views" detailing the external customer's operating domain in which the developing system will operate.

The Framework supports the development of interoperating and interacting architectures as referenced in DoD issuances. It defines three related views of architecture: Operational View (OV), Systems View (SV), and Technical Standards View (TV) as depicted in Figure 18**.** Each view is composed of sets of architecture data elements that are depicted via graphic, tabular, or textual products. The All-DoD Core Architecture Data Model (CADM) defines the entities and relationships for architecture data elements.

Like other Enterprise Architecture (EA) approaches, DODAF is organized around a shared repository to hold work products. The repository is defined by the Core Architecture Data Model (CADM -- essentially a common database schema) and the DoD Architecture Repository System (DARS). A key feature of DODAF is interoperability, which is organized as a series of levels, called Levels of Information System Interoperability (LISI). The developing system must not only meet its internal data needs but also those of the operational framework into which it is set.

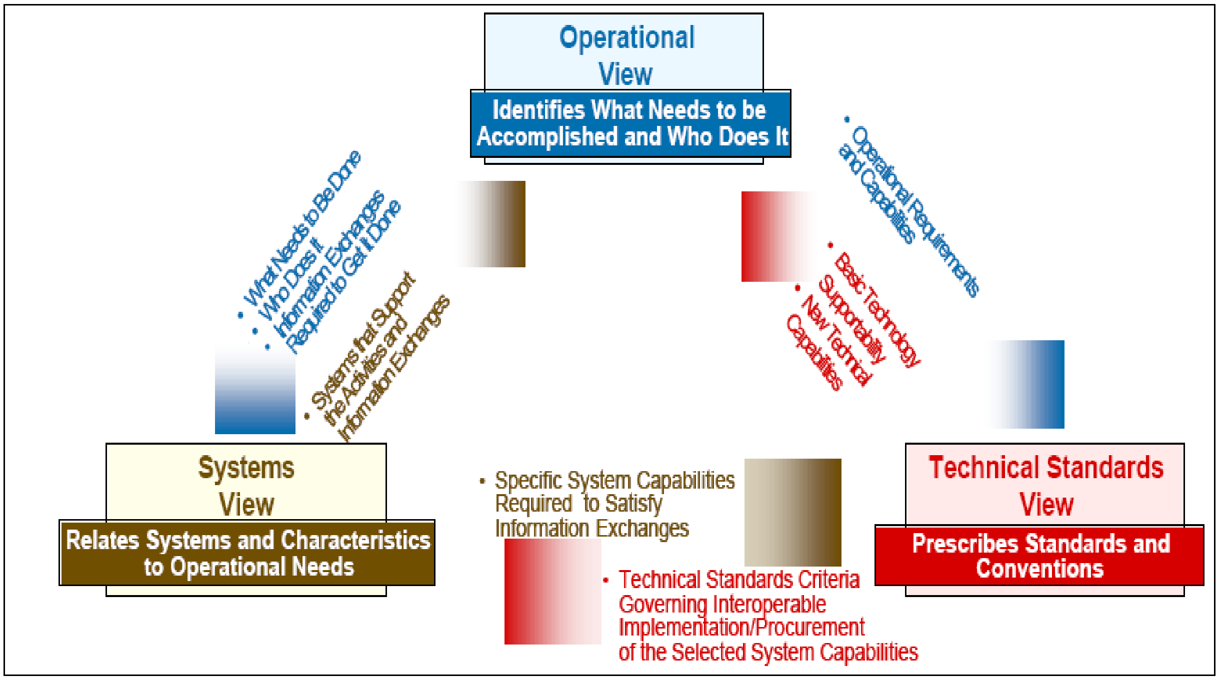

Figure 18: Linkages among views [137]

5.1 *Convergence of PLM support standards*

The importance of interoperability across the phases and functions in PLM among the multiplicity of languages dealing with the varied contents comprising the complete product description has been recognized by a number of institutions including NIST, the US Department of Defense (DoD), the European Ministries of Defense and, more recently, by the vendor and end-user communities [26; 27]. While there has been articulation of the need, the issue has not been yet fully addressed due to the divergence of interests on how interoperability should be achieved. The challenge is to create standards and protocols that allow legacy systems as well as future technological innovations to interoperate seamlessly.

Today's standards, particularly in the area of CAD, have produced direct improvement in productivity, especially in the manufacturing arena, by reducing transaction costs and even more so by increasing the richness of interactions between supplier and customer [29; 30]. The real cost of the lack of interoperability is difficult to measure and is often buried in day to day operations of individuals needing the information or needing to transmit the information.

It is clear from Figure 19 that there is no standard that provides full coverage of the PLM support spectrum. One can see that some standards, e.g., SysML and PSL cover some aspects of PLM with notable discontinuity in their scope. Please note that this figure is not intended to show the full set of important standards for PLM support, but to give examples of current standards and their coverage e.g., for STEP only a very limited subset of APs is shown. STEP+ denotes lifecycle functional coverage by existing ISO 10303 APs, including AP239.

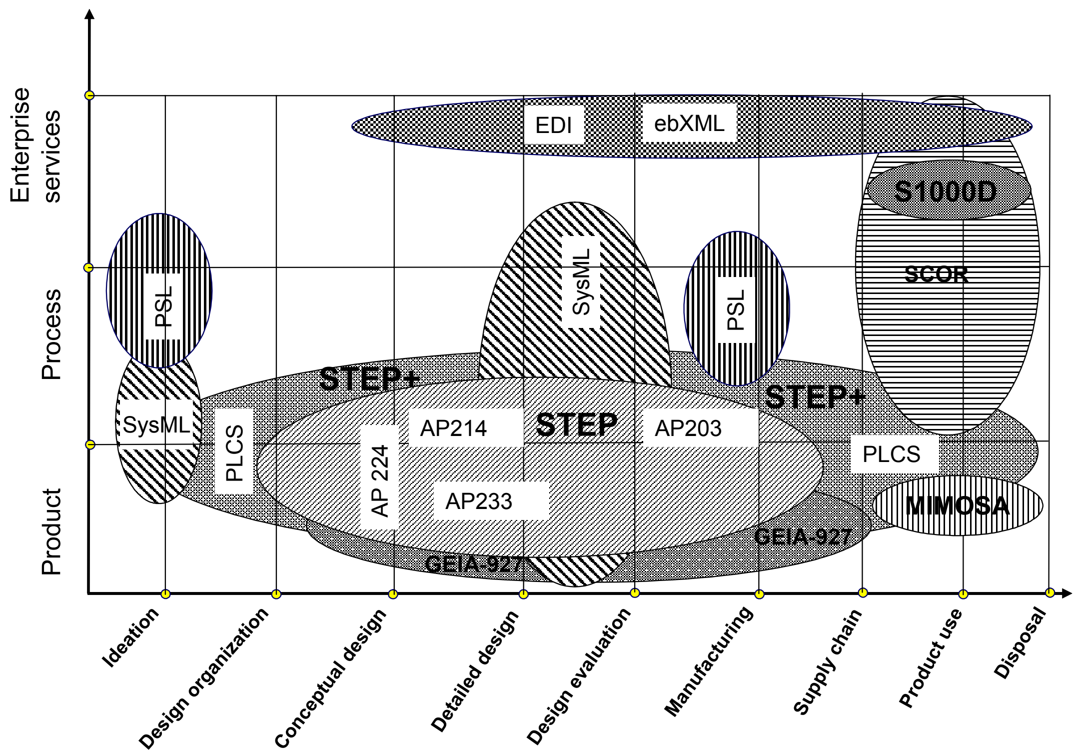

Figure 19: An example of current standards and their coverage

6. Implementation issues and strategies

In general, the use of internationally developed, industry-driven, industry-maintained standards allows the maximum freedom of choice for the AMC, and will drastically reduce expense across the lifecycle of the product. Information technology standards are a key enabler to manufacturers and participants in the lifecycle management of the product's data for bridging the gap between the multitude of enterprise systems and the asset management systems. This aspect is critical to the U.S. Army as most of its asset management systems and associated product data still lie within the ownership, or at least, physical domain of the OEM delivering the product and associated support. A movement toward the adoption and implementation of data exchange standards to fully support the product's lifecycle processes has been proven to be a good business practice as referenced earlier in this report. As the Army considers the use of such standards, the PEWG should factor into their recommendations that any given standard should ensure the U.S. Army has:

- Commercial, off-the-shelf, multi-vendor purchasing power.
- Intra-enterprise product data and process integration; automatic plug-and-play.
- Inter-enterprise product data and process integration; automatic plug-and-play.
- Cross-industry-domain integration, allowing the supply chain sub tiers to remain competitive in pricing to U.S. Army-specific customers.
- Remote, "same-view" online access to the product's data.
- Opportunities for data to be created once, used many times, and in many ways.

Historically, the Department of Defense has had a vested interest and proactive support in the use of international standards for data exchange, system integration, and more joint force cooperation for system readiness. Probably one of the most notable initiatives for joint service collaboration and commitment to international standards emerged from the Computer-aided Acquisition and Logistics Support (CALS) program. This program began in the fall of 1985, and actively pursued improved information digitization and data integration through the mid-to-late 1990s. While the US commitment to CALS as an initiative has since been folded into other initiatives, worldwide activities still fan the flame of CALS and its concept to adopt industry standards. Some of the DoD initiatives that have committed to using industry standards (Appendix D) were a direct result of the CALS initiative, while others have continued to spring from the momentum and interest started by CALS. The most landmark of edicts in breaking new ground for its time was Secretary of Defense Perry's June 29, 1994 memorandum stressing the minimization of development and use of military specifications and standards and maximizing the use of industry or commercial standards. While more than a decade has passed since his memorandum was released, many of the tenets of the memorandum continue to motivate DoD toward industry standards today [141].

6.1 *Challenges in standards development for PLM*

As the type and scope of the standards needed for PLM support becomes clearer, there is increased interest in the models that have emerged in the distributed internet world for standards development and software production. Specifically, it is increasingly clear that a combination of open source models and TCP/IP-like open standards approaches is needed [26; 142]. The Internet Engineering Task Force (IETF) [143] open standards approach ensured that the features incorporated were demonstrated to be useful not just for one organization but for all who are affected and interested enough to participate in the process. Open source models that have evolved with the rise of the internet have addressed the large scale distributed design of complex products. The primary reason for success of the open source model has been its ability to scale that transcends "Brooks' Law" [144]. According to Brooks' law, the propensity for errors increases geometrically when resources are added linearly. In the case of open source, this constraint on the use of resources is resolved through the voluntary nature of participation and task selection [26]. Further, the availability of the complete record of the decision-making process and of the results of testing and use allows for the design-use-maintenance cycle to be rather quick in turnaround. The major success of open source comes from the recognition of the scale and diversity of skills through modular design; minimizing costs of bad local decisions; and the ability to mobilize people of diverse skills [26].

The development of standards for PLM support requires many people with different skills and expertise to participate. These people cannot be assembled in one place -- virtual or real -- to create a centralized top-down set of standards. Standards are best created in an open process and within a voluntary participatory model. Earlier experiences with standards development in the distributed, connected world point to open standards and open source models as an alternative model of consensus building and production [27]. Who should be responsible for creating these communities is an open question. Many existing standards have been created by individuals or groups of individuals. Some of these efforts also involve regional economic development zones. A few of these organizations have been mentioned in the context of some of the standards we reviewed in Section 4.

There are enormous benefits due to network effects that can be realized socially by open approaches; this will continue to allow university, industry (small, medium, and large), and laboratories to draw out of the same well (ISO model), minimizing incompatibilities and increasing the ability to create a plug-and-play system. This approach will foster innovation at the modular level without requiring a drastic redesign of the overall system. Repeated drastic design changes for both standards and software lead to increased costs in the creation, training, maintenance and archiving of the information and knowledge created in the life of a product. The open source and open standards models seem to address these issues in the best manner given the scale and scope, and provided us with alternative models for standards development.

Maintenance and use require conformance to standards and at times certification of the same. Institutions such as NIST can play a major role in being the honest broker and archivist of the process of standards creation, maintenance, and evolution; and with follow-on validation and conformance and interoperability testing of implementations. To encourage this process, the Manufacturing Interoperability Program of the Manufacturing Engineering Laboratory at NIST is working on achieving convergence among standards. Beyond the convergence of the types of standards referred to in this paper, standards for other aspects such as traceability, validation, verification and other audit and archival functions will have to be considered in the support system for PLM [145]. A good example is the Open Archival Information System (OAIS) reference model which facilitates a much wider understanding of what is required to preserve and access information for the long term [146].

The current disparate standards with differing assumptions and purposes are not easily reconciled; neither can they be resolved economically by any single entity. The extraction of positive network externalities in the networked manufacturing economy can only be achieved by the free flow of ideas and the exchange of knowledge in a public or semi-public space to create new innovations in the new knowledge economy [147]. To exploit the efforts of a large number of researchers, practitioners, users, and students to continuously integrate their work into the larger vision of full PLM support, there is no choice but to develop a pragmatic mechanism for supporting the development of standards in an open environment where the participation of all parties concerned will become critical.

Any convergence of standards that might be necessary can only take place in an open environment given the complexity of the task ahead. This realization can be seen in the publications of information technology vendors such as IBM, end users such as DoD, and engineering consultants making a case for open standards for the information base required to support the underlying IT infrastructure to accommodate legacy and changing technologies [148-150].

7. Observations and recommendations

The product data exchange standards and best practices that were preliminarily investigated by NIST for this report are:

- ANSI/EIA 649, National Consensus Standard for Configuration Management
- EIA-836, Configuration Management Data Exchange and Interoperability
- ASD/AIA S1000D International Specification for Technical Publications Utilizing a Common Source Database
- ISO 10303, Industrial automation systems and integration -- Product data representation and exchange Application Protocols:

  - 203 *Configuration Controlled Design*
  - 214 *Core Data for Automotive Mechanical Design Processes*
  - 224 *Mechanical Product Definition for Process*
  - 233 *Systems Engineering Data Representation*
  - 239 *Product Life Cycle Support*
  - *240 Process Plans for Machined Parts*

- MIMOSA OpenO&M, Information standards

- GEIA-927, Common data schema for complex systems
- DoD Architecture framework, 9 February 2004:
  - Volume 1: Definitions and guidelines
  - Volume 2: Product descriptions

Based on our analysis of the list of standards selected for review, we have the following observations:

- Some of the standards are extensions of the others, e.g., EIA-836 complements the well-established ANSI/EIA-649 standard for configuration management and incorporates its principles.
- Some of the standards are built as an integration of others, e.g., GEIA-927 is an integration of ISO 15926, PAS20542, ISO 10303-AP212, and AP239; and more standards are currently being integrated into GEIA-927.
- A number of the same functionalities are supported by more than one standard, e.g., configuration management is included in ANSI/EIA-649, EIA-836, 10303-AP203, ISO 10303-214, and 10303-AP239. To compound this overlap, several standards are being developed within the United States, while similar development efforts are, or have occurred, in the international arena, e.g., GEIA-0007 and ISO 10303-239, EIA-836 and ISO 10303-203, and ANSI/EIA-649 with ISO 10007. (The latter is not covered in the scope of this report.) (See Table 1)
- EIA-836 appears to be a thorough and good start for managing configuration data within the Army, but it appears the funding of the work and the interest in the work is only by the government. Without much industry buy-in, such a project and direction in employing standardization will be an expensive approach for maintenance and enhancement by the Army.
- ISO 10303 appears to have the most breadth and depth of coverage for product lifecycle data. ISO 10303-239 (Product Lifecycle Support, PLCS) is currently the only international standard available that covers the entire lifecycle spectrum. NIST believes that PLCS has great potential to handle the Army's PLM requirements, but recommends the Army resolve certain challenges explained below) before firmly committing to its adoption.

GEIA standards efforts	ISO standards efforts
927 Common Data Schema	10303 Standard for The Exchange of Product Model Data (STEP)
0007 Logistics Data Implementation Model	AP239 Product Life Cycle Support – PLCS
859 Data Management	10032 Reference Model of Data Management
836 Data Standard for Configuration Management	AP203 Configuration –Controlled Design
649 Configuration Management	10007 Configuration Management

Table 1: Similar efforts by GEIA and ISO

Although in some cases, we can consider that standardization efforts complement each other, in most of the cases the standardization efforts are inefficiently repeated, creating a proliferation of standards. Such a volume of standards from which to choose is often a source of confusion for the users and project leaders or managers to decide which standard to use for a particular task. This problem is especially pressing and needs to be quickly addressed in the case of PLM where the diversity of data and its distribution in time and place require a large number of standards to be used and there are so many from which to choose.

This set of standards addresses data standards covering the various phases of the Defense Acquisition Management Framework (see Section 4.2 and Figure 2 for a brief presentation of the DoD 5000 directives and DAMF). These set of standards are consistent with DoDD-5000.1. DoDD-5000.1 does not elaborate on specific STEP APs and does not specify GEIA-927 (GEIA-927 is a later effort supported by DoD). GEIA-927 is an integrated multi-domain data schema for representing system product and process data. The data schema is the organization and interrelationships of system data essential for developing an advanced integrated environment. It remains to be seen what role GEIA-927 will play if the STEP application protocols are adopted more widely across the supporting industrial sectors (e.g., automotive, aerospace, electrical/electronic, construction, numerical control) and supporting software vendors. GEIA-927 is attempting to compensate for the lack of modular structure available across the existing STEP APs. It may become obsolete if industry and vendors implement the new STEP modularized application protocols. Most recently, ISO 10303 AP203ed2, AP236 (furniture industry) and AP239 are already internationally standardized as modularized APs.

ISO 10303-239 (AP239 or PLCS) defines an application-specific, but flexible and extensible, information model. The information model can be modified by specific industry and organizations through the use of Reference Data Libraries (RDL). The role of RDL is to complete the semantics of the PLCS model necessary for implementation in a specific industry. The benefit of AP239 is its integrated view. It has a large and generic information model that is larger in scope than most business processes require or most IT applications can manage; therefore, it allows better flexibility. To subset the information model to suit a specific business process, a DEX is developed. These DEXs are outside the scope of ISO 10303-239. A DEX provides a subset of the PLCS information model, along with usage guidance. A DEX can be used as a contract specification or for setting conformance but AP239 implementations can exist without using DEXs.

The OASIS Product Life Cycle Support Technical Committee is currently committing the resources to develop DEXs, and their supporting infrastructure using AP239. The OASIS Technical Committee will consider any data exchange specifications, capabilities, and reference data developed by outside projects for adoption by OASIS.

ISO 10303 represents a powerful capability for engineering product information and PLCS extends ISO 10303 into through-life support processes. Early PLCS implementations have already begun to validate the standard and its use. Even though PLCS may not solve all the problems of product data interoperability today, it is currently the only international standard available that covers the entire lifecycle spectrum. PLCS extends the functionality of ISO 10303 in many ways including mechanisms for schema evolution; both top-down and bottom-up (instance-based) information models, and semantics interoperability. There are, however, some caveats related to PLCS that NIST recommends the Army think through and resolve before committing organizationally to the use of ISO 10303-239:

- Different applications using the same data model but with different Reference Data will not interoperate until the two sets of Reference Data have been harmonized or mapped. NIST recommends the Army centrally defines and mandates the Reference Data for AMC.
- The ISO community has a good procedure for Reference Data management but no business model to support its implementation. NIST recommends the Army work with the ISO community to define a good business model to support its implementation.
- The DEXs, Capabilities, and Reference Data that are under OASIS development might face problems of nonstandardized modification and proliferation. The issues of maintenance and ownership for those under OASIS also need to be addressed. NIST recommends the Army investigate and understand more fully the ramifications and long-term effects regarding issues associated with maintenance and ownership.
- There could be potential intellectual property rights (IPR) issues related to these specifications. OASIS IPR policy (see OASIS.IPR.3.2. OASIS Specifications (c)) specifies Reasonable and Non-Discriminatory (RAND) terms for IPR. A careful study of potential RAND-related problems is critical as these could affect the future of data access and data integrity. While NIST has no direct recommendation on how to assess and resolve the potential problems associated with OASIS IPR, it is important for the Army to be aware of this potential barrier to the way the Army would like to do business.

Beyond our recommendations for the use of ISO 10303-239, NIST recommends the PEWG consider implementing other ISO 10303 application protocols if prototype testing under current projects as Army's AGILE and Lean Munitions successfully prove cost-effective. APs under these projects include AP203, AP214, AP224, and AP240. As the PEWG selects from the possible candidates to be implemented within the AMC's product lifecycle support, it is critical to the success of these selections that contractual requirements are clear, consistent, and pervasive in support of the standards selected; and that proprietary vendor solutions – equipment and software – are avoided.

In summary, the achievement of the Army's PLM objectives requires a clear understanding of all its supporting logistics' systems to ensure sound decision-making. As was observed by Herbert Simon in his essay, "The Architecture of Complexity" [151], and extending his observation to our present context, we agree that the complexity of the information exchange issue and the diversity of participants and their perspectives make it highly improbable that a single disciplinary perspective can accomplish the task of supporting PLM. For these reasons, and the associated short and long-term economic impact of "islands of isolation" decisions, we believe that much of the stable part of the information base supporting PLM should be developed within the framework of open standards.

Also in the course of this study, NIST had a preliminary introduction to the Army's SALE initiative. For the long-term success of this critical initiative (more than $60M in FY2006 alone), NIST recommends the use of a selected set of mature international standards become part of the SALE architecture and contract mandate. NIST was unable to access the business case study that was done, which supported adopting a proprietary software product as part of the SALE architecture; therefore, NIST recommends the Army have a clear understanding of the long-term ramifications of this proprietary decision by reviewing its business case for such decisions as analyzed and reported per DoDD 5000.1, (cf. Section 4).

Earlier in this report, in our discussion on good characteristics of a standard, we suggested one should look for standards that:

- Support fair trade and fair competition.
- Increase user, consumer, and government confidence.
- Facilitate interoperability.
- Stimulate innovation.

These are also considerations when assessing the long-term solutions, expense, and necessary resources for maintaining a fully integrated, tri-service logistics lifecycle support network. We also have the following recommendations for the Army. That it:

- Review its investments and pilot results for various STEP AP projects, and investigate further integration of these application protocol commitments with AP239 for full product lifecycle support. The Army has been investing in the development and piloting of several other ISO 10303 application protocols, including AP203 edition 2; and a "manufacturing" suite comprised of at least AP203, AP219, AP223, AP224, AP238, and AP240.
- Investigate and understand more fully the ramifications and long-term effects regarding issues associated with maintenance and ownership of existing OASIS DEX and Reference Data. If OASIS standardization in PLCS is determined the best viable solution, the Army should:
  - Assess the coverage by existing OASIS DEXs and reference data to meet the Army's needs.
  - Participate in the development of necessary DEXs and reference data sets within an international standards development forum.
- Promote the transfer of national standards into the international standards development arena. The Army has invested significant resources into developing national standards such as EIA-836, GEIA-927, and GEIA-0007. Adoption and use of these standards may improve if this work is incorporated into the international standards development efforts. For example, the business rules available in EIA-836 could possibly be turned

into a configuration management DEX within OASIS. Similarly, the business rules being developed in GEIA-0007 could be turned into a logistics support analysis DEX.
- Ensure standards-based product lifecycle support by vendors and users by developing a template of contractual language that consistently and expressly calls out the recommended standards of choice and commits the Army to a standardized solution as the only way to do business.
- Act upon Under Secretary of Defense Krieg's recommendation in his memorandum of June 23, 2005, "Standard for the Exchange of Product Model Data (STEP) --- ISO 10303" to review and implement STEP as the Army's interoperability standard.

As defined in Section 1, Background, the objective of this report was twofold. To provide to the U.S. Army Materiel Command through its PEWG:

- An introduction and review of standards and related technologies that might support the Army's lifecycle management of products and services necessary to maintain the mission-readiness of its troops.
- Recommendations that will assist the Army in its selection of product lifecycle support standards.

To this end, our investigative study focused primarily on the Army's use of a selected set of standards and best practices in product data representation, and in the exchange of product data between various divisions within US Army and their OEMs. NIST discussed how the Army meets its requirements for materiel and logistics support, primarily focusing on the lifecycle requirements of a product. A complete list of those with whom we had contacted is included under Acknowledgements.

8. Proposed next steps

The time allowed for this report did not permit a uniform in-depth study of the standards investigated in this report, nor of the full suite of prospective PLM-related standards. NIST proposes in this section, as a follow-up to this report, several additional short and long-term possible joint efforts with the Army, which include providing a more in-depth assessment of a larger suite of candidate PLM standards, identifying the gaps, and producing a formal process that will assist the Army in its selection of necessary standards. As part of this extended assessment, NIST would include reviews of the linkage or overlaps between PLCS and S1000D, and PLCS and MIMOSA.

- As mentioned earlier, the ISO community has a good procedure for reference data management but no business model to support its implementation. NIST recommends that the Army work with the ISO community to define a good business model to support its implementation. Such a collaborative activity could be conducted using Army resources or Army-sponsored representatives.
- Develop strategies for the creation of common and discrete ontologies that best facilitate the interoperability and fluidity of information flow between the Army, its OEMs, and other allied countries.

While this study focused primarily on product data standards called out in several DoD missives, there are many other and sometimes, more mature standards identified in the typology of standards (Type 0 through 3) as discussed earlier. Appendix C provides a sampling of standards to illustrate what might be used in populating a typology. NIST recommends the Army take initial steps to assess standards in the lower levels of the typology, and begin implementing their use; start with the fundamental foundations offered by Type 0 standards. This could eliminate the need and resources currently invested in developing primarily Army or government-unique standards such as EIA-836 or GEIA-927.

The incompatibilities and gaps that exist among current standards arise at different typology levels of the necessary data exchange process supporting the Army's logistics demands. These incompatibilities require further research and can be studied using the typology defined in [16], and introduced in Section 5.

In addition to the recommendations above, the following are other areas of research and development NIST believes may be of interest to the Army, particularly for product lifecycle management of its product and process data.

- A reference model for the Army's product lifecycle information ecosystem

  A key requisite to a manufacturer leveraging strategies for competitive advantage is a common product description that is shared among all stakeholders throughout the lifecycle of the product. Detailed product information cannot be kept isolated within the boundaries of any one single entity within the extended networked enterprise. This information must now be shared in a collaborative and secure manner across the global enterprise and its extended value chain.

  The challenges of the product-engineering environment are to support the creation, exchange, archiving, and management of information about product, process, people, and services within and across the networked and extended enterprise covering the entire product lifecycle spectrum. It is critical to the success of companies and their suppliers that this sharing is done correctly, efficiently, and inexpensively. To achieve this we need a reference model as a framework for understanding significant relationships among the entities, and for the development of consistent standards or specifications supporting this environment. This reference model would be based on the reference model for Open Archival Information System (OAIS), which consists of a small number of unifying concepts. OAIS can be used as a basis for education and explaining standards to a non-specialist.

- A methodology to create test beds for evaluating information standards and their implementations

  The lack of complete interoperability is a pervasive problem in today's information systems and the cost of managing systems under these conditions is a major economic drain in most industries. Support of interoperability requires developing standards through which different systems can communicate with each other. However, multiple systems intended to interoperate will have to be tested for conformance, implementation, and interoperability among each other. These tests will have to encompass syntactic, content, and semantic aspects of exchange between the systems. NIST has prior experience in developing test beds and testing services for some of these aspects for specific standards such as ebXML, STEP, SQL, XML, and other information technology measurement and testing activities at NIST. While there has been considerable experience with developing test beds, testing methodologies, and test suites, there has not been a systematic synthesis of these experiences into a methodology. A joint NIST and Army research effort to synthesize a methodology for test beds based on prior experiences at NIST, and to develop a reference test bed architecture would be very useful to the Army and to US industries in general. The test bed architecture could be designed to address all levels of interoperability covering syntax, content, semantics, and visualization. We would apply the architecture derived to create an exemplar for the Product Lifecycle Management (PLM) support system. The potential outcomes could be to:

- Ensure the manufacturing industry end-users and software vendors conform to exchange standards.
- Create an industry/vendor neutral private entity to verify, validate, and certify vendor implementations of standards, with help from NIST leadership, and hence create opportunities for vendors to provide additional services.
- Create a generalized architecture and test models and regimes for test bed design and implementation in various domains.
- Allow vendors to commercialize tools for standards integration and system interoperability testing to ensure integration of legacy tools.

• Long term knowledge retention for digital technical product documentation

Data has always been a critical asset to manufacturing. Increasingly, data is in digital form with no corresponding analog equivalent. For example, 3D digital models have become the preferred method for specifying designs in the transportation sector. With product life cycles often far longer (i.e., aircraft fifty years) than the expected lifetime of a manufacturing software application used to interpret the data (approximately three years), or of the technologies used to store and retrieve the data (approximately ten years), searching for archived information is routinely problematic.

Data access, retrieval, and reuse is necessary for such information-based activities as initial manufacturing, design reuse, liability and legal issues, incident investigation, and regulatory and contractual compliance. Current practices include converting the 3D models to 2D, and archiving the result on microfiche; migrating data off storage systems before they become obsolete and/or unreliable; and maintaining legacy hardware and software for the sole purpose of accessing old data. These practices are expensive, labor-intensive, and still result in a loss of information over time.

Recognizing the importance of electronic records for its mission of preserving "essential evidence," the National Archives and Records Administration (NARA) launched a major new initiative, the Electronic Records Archives (ERA) initiative, in 1998. The recommendations of the Consultative Committee for Space Data Systems (CCSDS) established a common framework of terms and concepts which comprises the Open Archival Information System (OAIS), later adopted as the ISO 14721:2003 standard. Other efforts have also undertaken to address the needs for long term knowledge retention in specific areas such as manufacturing, health care, life sciences and legal and military applications. The importance of digital preservation is clearly emphasized by these efforts and more specifically the Digital Preservation Project of US Library of Congress [152].

In all these efforts, standards play a crucial role. In the area of engineering informatics, NIST's Knowledge Retention project and the Long Term Data Retention (LTDR) project [153] dealing with digital technical product documentation, such as 3D-CAD and PDM data, studied the applicability of international standards such as ISO 14721:2003 and ISO 10303. This research effort will concentrate on representation of *form*, *function*, and *behavior* of complex engineering designs to maximize long-term information access, retrieval, and reuse.

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Organization	Name	Primary Type of Interaction (meeting, teleconference, written)
AM General	Mike Peters	Teleconference
AMCOM	Gayle Booker	Web Conference
AMCOM	Jerry Austin, Steve Gaver, Glenn Williams, Steven Ross	Written
AMCON/CIO/G6	Patrick Smith, Jerry Austin	Meeting
AMRDEC	Deborah Cornelius, Carla Crawford, Ray Morgan, Russ Miller, Mike Campe, W. Odis Nickoles (AMREC detail)	Meeting
AMRDEC	Mellisa Barnett, Ray Morgan, Carla Crawford, Mike Campe	Written
AMSAA	Tom Schneider, Gordon Ney, Dave Collum, Art Heyderman, Willie Feli,Eric Bakk	Web Conference
ARDEC	John Hummel, Art Heyderman	Web Conference
ARDEC	Neil Stern, Fred Johnson, Mark Napolitano	Meeting
ARDEC	Joe Mokey, Brenda Pettenger, Dave Robinson	Teleconfernce
Boeing, C-17	Reginald Gates	Teleconference, Written
ECBC	Willie Felix	Web Conference
EDMS PMO	John Montgomery	Meeting

Organization	Name	Primary Type of Interaction (meeting, teleconference, written)
Enterprise Integration, Inc.	John Hunter, Martin Malis	Meeting
Ford	Gahl Berkooz	Meeting
General Dynamics Land Systems	Carol Tierney	Meeting
LCMC IMMC	Louis R. Washington	Meeting
LOGSA	Lou Sciaroni,	Meeting
LOGSA	John Colsen	Teleconference
TACOM	Dennis Dunlap	Written
TACOM-IBO	Eric Bakken	Web Conference
TARDEC	Raj Iyer	Meeting

10. Disclaimer

Mention of commercial products or services in this paper does not imply approval or endorsement by NIST nor does it imply that such products or services are necessarily the best available for the purpose.

11. References

1. "DoD 4140.1-R Supply Chain Materiel Management Regulation, Office of the Deputy Under Secretary for Logistics and Materiel Readiness Section C7.4," US Department of Defense, May 2003.
2. Army Materiel Command. http://www.amc.army.mil/G3/org/e/esfaq.htm . 7-13-2006.
3. Single Enterprise Concept Sets "SALE" Under New Contracts. Army Logistician. http://www.findarticles.com/p/articles/mi_m0PAI/is_4_37/ai_n15648706 . 2005.
4. Interoperability Cost Analysis of the U.S. Automotive Supply Chain. http://www.nist.gov/director/prog-ofc/report99-1.pdf . 1999. Research Triangle Institute, NIST Planning Report .
5. AMC web site. http://www.amc.army.mil/ . 2006. Army Materiel Command.
6. Defense Update, International Online Defense Magazine, Issue 3. http://www.defense-update.com/products/f/fcs.htm . 2005.
7. Iyer, R. G., and Gulledge, T., "Product Lifecycle Management for the US Army Weapon Systems Acquisition," Inderscience Publishers, PLM: Emerging solutions and challenges for Global Networked Enterprise, ISBN 0-907776-18-3,2005, pp. 553-564.
8. Interoperability week @ NIST. http://www.mel.nist.gov/div826/msid/sima/interopweek . 2006.
9. Acquisition Reform. http://www.dod.mil/execsec/adr95/acq_.html . 2006. US department of Defense (DoD).
10. GSC: Global Standards Collaboration. www.itu.int/ITU-T/gsc/index.html . 2006.
11. Saunders, M., "International Standards and Innovation - What are the Linkages?," NIST Sigma Xi Lecture Series, 2006.
12. CSA International. http://www.csa-international.org/consumers/why_standards_matter/ . 2006.

13. NTTAA: National Technology Transfer and Advancement Act. http://standards.gov/standards_gov/index.cfm?do=documents.NTTAA . 3-7-1996.
14. Office of Management and Budget Circular A-119. http://standards.gov/standards_gov/index.cfm?do=documents.A119 . 2006.
15. Allen, R. H. and Sriram, R. D., "The Role of Standards in Innovation," *Technological Forecasting and Social Change*, Vol. 64, 2000, pp. 171-181.
16. Subrahmainain, E., Sudarsan, R., Bouras, A., Fenves, S. J., Foufou, S., and Sriram, R. D., "The role of standards in product lifecycle management support," National Institute of Standards and Technology, NISTIR 7289, 2006.
17. "Global Standards: Building Blocks for the Future, TCT-512," U.S. Congress, Office of Technology Assessment, U.S. Government Printing Office, Washington, DC, Mar. 1992.
18. NTTAA: National Technology Transfer and Advancement Act. http://standards.gov/standards_gov/index.cfm?do=documents.NTTAA . 2006.
19. White, W. J.. Measuring Benefits from the National Technology Transfer and Advancement Act. http://ts.nist.gov/ts/htdocs/210/nttaa/pubs/MeasuringBenefits_Aug04Finalrpt.pdf RTI Project Number 08628. 2004.
20. United States Standards Strategy. http://public.ansi.org/ansionline/Documents/Standards%20Activities/NSSC/USSS-2005%20-%20FINAL.pdf . 2005. ANSI.
21. Cargill, C. F., *Information Technology Standardization Theory, Process, and Organizations*, Digital Press, Digital Equipment Corporation1989.
22. "Report of the process action team on military specifications and standard. http://www.acq.osd.mil/ . 1994. OUSDA&T: Office of the Under Secretary of Defense for Acquisition, Technology, & Logistics.
23. Defense Logistics Agency. http://www.dsp.dla.mil/ . 2006.
24. Remarks by Dr. William Jeffrey, Director, National Institute of Standards and Technology, National Technology Transfer Act Standards Luncheon, Washington, D.C.. 3-6-2006.
25. Conversation with Gahl Berkooz, PhD, Ford, Tech Leader, Systems Engineering & Production Creation Complex Reduction. 2006.
26. Weber, S., *The Success of Open Source*, Harvard University Press, Cambridge, MA2004.
27. Krechmer, K., "Open Standards requirements," *The International Journal of IT Standards and Standardization Research*, Vol. 14, No. 1, 2006.
28. US Product Data Association. https://www.uspro.org/ . 2006.
29. Robertson, D. and Allen, T. J., "CAD system use and engineering performance," *IEEE Transactions on Engineering Management*, Vol. 40, No. 3, 1993, pp. 274-282.
30. Liker, J. K., *The Toyota Way: 14 Management Principles from the world's greatest manufacturer*, Mc Graw Hill2004.
31. The Defense Acquisition System. http://akss.dau.mil/dag/DoD5000.asp?view=document&doc=1 . 5-12-2003.
32. Defense Acquisition University. http://www.dau.mil/index.asp . 2006. DAU web site.
33. Kemmerer, S., "STEP: The Grand Experience, (Editor)," NIST Special Publication 939, National Institute of Standards and Technology, Gaithersburg, MD 20899, USA, 1999.
34. ISO 10303-11: 1994, Industrial automation systems and integration -- Product data representation and exchange -- Part 11. Description methods: the EXPRESS language reference manual.

35. Product Life Cycle Support (PLCS), Frequently Asked Questions. http://xml.coverpages.org/PLCSInc-FAQv2-20030804.pdf . 4-8-2003.
36. Gallaher, M., O'Connor, A., and Phelps, T., "Economic Impact Assessment of the International Standard for the Exchange of Product Model Data (STEP) in Transportation Equipment Industries," National Institute of Standards and Technology, Department of Commerce, USA, 2002.
37. STEP Success Stories. http://pdesinc.aticorp.org/success_stories.html . 2006. PDES, Inc.
38. ISO/DIS 10303-219, Industrial system-Product data representation and exchange - Part 219, Dimensional inspection information exchange. International Organization for Standardization (ISO), Geneva, Switzerland.
39. ISO 10303-232, Industrial automation systems and integration -- Product data representation and exchange -- Part 232, Application Protocol: Technical data packaging core information and exchange. 2002. International Organization for Standardization (ISO), Geneva, Switzerland.
40. Feeney, A. B., "The STEP Modular Architecture," *Journal for Computing and Information Science in Engineering*, Vol. 2, No. 2, 2002, pp. 132-135.
41. PDES, Inc. http://www.pdesinc.com/ . 2006.
42. CAx Implementor Forum. http://www.cax-if.org/ . 2006.
43. ProSTEP iViP Verein. http://www.prostep.org/en/ . 2006.
44. Loffredo, D.. Fundamentals of STEP Implementation. www.steptools.com/library/fundimpl.pdf . 2000. Website STEP tools, Inc., New York.
45. ISO 10303 STEP Application handbook Version 2. http://www.isg-scra.org/STEP/STEPHandbook.html . 12-21-2001. SCRA.
46. CAD System Translators. http://pdesinc.aticorp.org/vendor/CAD_vendor.html . 2006. PDES, Inc.
47. STEP ISO 10303. http://www.steptools.com/library/standard/ . 2006. STEP Tools, Inc.
48. Developed APs and Modules: AP203. http://pdesinc.aticorp.org/aps_modules.html#assemblies . 2006. PDES, Inc.
49. STEP: Will It Finally Hit Stride? http://www.autofieldguide.com/articles/109902.html . 1999.
50. ISO 10303-203: 1994, Product Data Representation and exchange - AP 203: Configuration controlled 3D design of mechanical parts and assemblies. International Organization for Standardization (ISO), Geneva, Switzerland.
51. Briggs, D., and Hendrix, T.. AP203 Edition 2, Configuration Controlled 3D Design of Mechanical Parts and Assemblies. http://www.isd.mel.nist.gov/projects/metrology_interoperability/imis/presentations/Hendrix.pdf . 3-28-0006. Boeing Technology.
52. kassel, B., and Mays, J. L.. ISO 10303 AP 214 and DoD. www.nsrp.org/panels/systems/downloads/STEP_3D_Model_Mays.pdf . 2006.
53. Memorandum of Common Understanding and Cooperation on Standardized CA-Product Data. http://pdesinc.aticorp.org/mous/automotive.html . 2006.
54. Developed APs and Modules: AP214. http://pdesinc.aticorp.org/aps_modules.html#ap214 . 2006. PDES, Inc.
55. Feltes, M., Kornmueller, M., Oster, K., Hug, H., Weinmann, M., and Schreinert, S.. How DaimlerChrysler uses one STEPping stone to exchange bills of material. http://www.iso.ch/iso/en/commcentre/isobulletin/articles/2003/pdf/step03-05.pdf . 2003. DaimlerChrysler AG.

56. EPMT provides long-term 3D archiving software for the Eurofighter project. http://www.epmtech.jotne.com/newsletter/ew106/eurofighter.html . 2006.
57. Developed APs and Modules: AP224. http://isg.scra.org/products/step_ap224.html . 2006. PDES, Inc.
58. STEP & ISG on the SCRA website. http://www.isg-scra.org/STEP/STEP_AP224.html . 2006.
59. Sharma, R. and Gao, J. X., "A progressive design and manufacturing evaluation system incorporating STEP AP224," *Computers in Industry*, Vol. 47, No. 2, 2002, pp. 155-167.
60. ISO/CD 10303-223, Industrial system—Product data representation and exchange—Part 223, Exchange of design and manufacturing product information for casting parts. International Organization for Standardization (ISO), Geneva, Switzerland.
61. ISO/DIS 10303-238, Industrial system-Product data representation and exchange - Part 238, Application interpreted model for computerized numeric controllers. International Organization for Standardization (ISO), Geneva, Switzerland.
62. An Overview of AP233 STEP's Systems Engineering Standard, Jim U'Ren, Presentation available online. syseng.nist.gov/aerospace-workshop/slides/Tuesday/uren1.ppt. 2003.
63. STEP AP233, Eurostep web site. http://ap233.eurostep.com . 2006.
64. Price, D.. Creating an AP233 Systems Engineering Scripting Language in Ruby. conferences.esa.int/pde2006/presentations/pde2006_price_ruby-for-ap233.ppt . 2006.
65. ISO 10303-233, Industrial automation systems and integration -- Part 233: Systems engineering data representation. 2006. International Organization for Standardization (ISO), Geneva, Switzerland.
66. Bailey, I.. Eurostep Technology White Paper, DODAF and AP233. www.eurostep.com/files/DODAF%20and%20AP233%20White%20Paper.pdf . 2003.
67. UGS TeamCenter. http://www.ugs.com/products/teamcenter/ . 2006.
68. Telelogic DOORS. http://www.telelogic.com/corp/products/doors/doors/index.cfm . 2006.
69. Eurostep. Share-A-Space. http://www.share-a-space.com . 2006.
70. ThreeSL, Cradle 5 requirements mangement. http://www.threesl.com:8080/pages/requirements-management-home.php . 2006.
71. PTC: Product Lifecycle Management (PLM) Software Solutions. www.ptc.com . 2006.
72. EDS Slate web site. http://www.bitpipe.com/detail/PROD/1017064915_186.html . 2006.
73. ThreeSL, Cradle 5 requirements mangement. http://www.threesl.com:8080/pages/requirements-management-home.php . 2006.
74. Vitech Corporation. http://www.vtcorp.com/ . 2006.
75. IBM Rational RequisitePro. http://www-306.ibm.com/software/awdtools/reqpro/ . 2006.
76. ILogix StateMate-Embedded Systems Design Software. http://www.ilogix.com/sublevel.aspx?id=74 . 2006.
77. Aonix-Software through Pictures. www.aonix.com/stp.html . 2006.
78. The Open Systems Joint Task Force. http://www.acq.osd.mil/osjtf/overview.html . 2006.
79. The International Council on Systems Engineering (INCOSE). www.incose.org . 2006.
80. BAE systems. http://www.baesystems.com/ . 2006.
81. NASA-National Aeronautics and Space Administration. http://www.nasa.gov/home/index.html?skipIntro=1 . 2006.

82. U'ren, J.. Implementations of the STEP Systems Engineering Standard (AP233). http://conferences.esa.int/pde2006/presentations/pde2006_uren_ap233-implementations.ppt . 8-28-2006.
83. U'ren, J.. AP233 Implementations. conferences.esa.int/pde2006/presentations/pde2006_uren_ap233-implementations-2006-04-28.xls . 4-27-2006.
84. Product Life Cycle Support. http://www.plcs-resources.org/#Background+to+PLCS+Inc . 2006. eurostep.
85. The STEP PDM Schema Home Page. http://www.pdm-if.org/pdm_schema/ . 2006.
86. OASIS: Organization for the Advancement of Structured Information Standards. www.oasis-open.org . 2006.
87. DEXLib. http://plcs.eurostep.com/dexlib/dex_index.htm . 2006.
88. Web Ontology Language (OWL). http://www.w3.org/2004/OWL/ . 2005.
89. Gibson, M.. UK MOD Implementations of PLCS and Lessons Learned ILS and Engineering Policy, Technical Enabling Services, UK MOD, Presentation given at DoD PLCS Meeting, Arlington, VA. www.acq.osd.mil/dpap/UID/attachments/wawf-uid-rfid/3-plcs-meeting-arlington-20060216.ppt . 2-15-2006.
90. ISO 10303-240, Industrial automation systems and integration -- Product data representation and exchange -- Part 240: Application protocol: Process plans for machined products. 2005. International Organization for Standardization (ISO), Geneva, Switzerland.
91. SCRA. The STEP Manufacturing Suite, White paper V3. http://www.isg-scra.org/STEP/files/STEP_MfgSuiteWhitePaper.pdf . 3-5-2004.
92. Government Electronics & Information Technology Association. http://www.geia.org/index.asp?sid=13 . 2006.
93. GEIA 927 Overview. http://63.249.145.5/sstc/G47/GEIA-927/index.htm . 2006.
94. Colson, J.. GEIA-927 Standard Common Data Schema for Complex Systems. http://www.ndia.org/Content/ContentGroups/Divisions1/Systems_Engineering/PDFs18/Modeling_Committee_PDFs/Colson_John.pdf . 2006.
95. ISO 15926-1: Industrial automation systems and integration -- Integration of life-cycle data for process plants including oil and gas production facilities -- Part 1: Overview and fundamental principles. ISO . 2004. Geneva, Switzerland, International Standards Organization.
96. ISO TC 184/SC4. ISO/WD PAS 20542: Industrial automation systems and integration - Product data representation and exchange - Systems engineering data representation. 2001. ISO, Geneva, Switzerland.
97. ISO. ISO 10303:212. Industrial automation systems and integration -- Product data representation and exchange -- Part 212: Application protocol: Electrotechnical design and installation. 2001. ISO, Geneva, Switzerland.
98. STEP AP239: Product Life Cycle Support (PLCS). http://www.oasis-open.org/committees/tc_home.php?wg_abbrev=plcs . 2006.
99. CMBoK - Configuration Management Body of Knowledge. http://www.cmcrossroads.com/cgi-bin/cmwiki/view/CM/CMBoK . 2006. CM Crossroads.
100. ebXML. http://www.ebxml.org/ . 2005. ebXML.
101. Integrated Defense Acquisition, Technology & Logistics Life Cycle Management Framework Chart, Ver. 5.2. http://akss.dau.mil/ifc/ . 2005. Defense Acquisition University.

102. InSync Product Overview (continued). http://www.isscorp.com/html/insync_overview_continued.html . 2006.
103. PTC Develops New PLM Solution For The Aerospace & Defense Industry. Press Releases. http://www.ptc.com/appserver/wcms/standards/textsub.jsp?&im_dbkey=25838&icg_dbkey=21 . 2006.
104. Extensible Markup Language (XML). http://www.w3.org/XML/ . 2005.
105. CMBoK - Configuration Management Body of Knowledge. http://www.cmcrossroads.com/cgi-bin/cmwiki/view/CM/CMBoK . 2006.
106. EIA, "EIA-836: Configuration Management Data Exchange and Interoperability. Draft Version 1.2," Jan. 2004.
107. ASME, *Dimensioning and Tolerancing Y14.5M*, ASME1994.
108. ISO 1101:1983, Technical drawings -- Geometrical tolerancing -- Tolerancing of form, orientation, location and run-out -- Generalities, definitions, symbols, indications on drawings. International Organization for Standardization, Geneva, Switzerland.
109. ASME Y14.41: Digital Product Definition Data Practices. 8-1-2006. ASME.
110. Condition Based Operations for Manufacturing, MIMOSA OpenO&M. www.mimosa.org/papers/OpenO&M%20Whitepaper-CBO%20for%20Manufacturing-Final.pdf . 10-6-2004. Manufacturing Joint Working Group.
111. ISA: Instrument Society of America. http://www.isa.org/ . 2006.
112. OPC: open connectivity via open standards. http://www.opcfoundation.org/ . 2006.
113. Hoske, M. T.. http://www.manufacturing.net . 8-1-2006. Control Engineering Magazine.
114. Case Study: eRTIS Project and use of MIMOSA and Generic Web Services. http://www.mimosa.org/papers/Case%20Study-BP%20Refining%20Selection%20of%20O&M%20Information%20Standards.ppt#277,12,Interfaces . 10-23-2004. BP Refining eRTIS Project.
115. ISO 8879:1986 Information processing -- Text and office systems -- Standard Generalized Markup Language (SGML). 1986. International Organization for Standardization (ISO), Geneva, Switzerland.
116. ANSI/ISO 8632.1-4:1992 Computer Graphics Metafile. 1994. International Organization for Standardization & American National Standards Institute.
117. S1000D - International specification for technical specification. http://www.s1000d.org/ . 1-5-2005.
118. S1000D: Five reasons why. http://www.dclab.com/s1000d_reasons.asp . 2006. *Mikhail Vaysbukh, Data Conversion Laboratory*.
119. Raytheon Missile Systems expands its use of iLog with acquisition of site license. http://www.lbs-ltd.com/LBSWeb/News/NewsDetails.aspx?Ar=Article&NewsID=50 . 2006.
120. Robinson, M., Hennessey, and M.. The Implementation of AECMA 1000D. http://www.aecma.com/Presentation_Download/downloads/The_Implementation_of_AECMA_1000D_M_Robinson.pdf . 2006. LBS & General Dynamics Canada.
121. Subrahmanian, E., Sudarsan, R., Fenves, S. J., Foufou, S., and Sriram, R. D., "Challenges in Supporting Product Design and Manufacturing in a Networked Economy: A PLM Perspective," Inderscience Publishers, PLM: Emerging solutions and challenges for Global Networked Enterprise, ISBN 0-907776-18-3,2005, pp. 495-506.
122. RDF- Resource Description Framework. www.w3.org/RDF/ . 2006.
123. KIF-Knowledge Interchange Format. http://logic.stanford.edu/kif/kif.html . 2006.

124. ISO 10303-11: 1994, Industrial automation systems and integration -- Product data representation and exchange -- Part 11. Description methods: the EXPRESS language reference manual.
125. Schenck, D., and Wilson, P. R., *Information modeling: the EXPRESS way*, Oxford University Press, New York,1994.
126. Booch, G., Rumbaugh, J., and Jacobson, I., *The United Modeling Language User Guide*, Addison-Wesley1997.
127. OMG. UML 2.0 OCL Specification. http://www.omg.org/cgi-bin/doc?ptc/03-10-14 . 2004.
128. Process Specification language (PSL) . http://www.nist.gov/psl . 2006.
129. Bock, C., "Systems Engineering in the Product Lifecycle," *International Journal of Product Development, Special Issue on Product Lifecycle Management*, 2004.
130. ISO/DIS 10303-214:2000, Product data representation and exchange: Integrated application resource: Application protocol: Core data for automotive mechanical design processes. International Organization for Standardization (ISO), Geneva, Switzerland.
131. Lubell, J., Peak, S. S., Srinivasan, V., and Waterbury, S. C., "STEP, XML, AND UML: Complementary Technologies," Vol. CIE-2004-141, Proceedings of DETC 2004: ASME 2004 Design Engineering Technical Conferences and Computers and Information in Engineering Conference September 28–October 2, 2004, Salt Lake City, Utah USA,2004.
132. Web3D: Open Standards for Real-Time 3D Communication. http://www.web3d.org/ . 2005.
133. Wang, M. Y. and Wang, X., "A level-set based variational method for design and optimization of heterogeneous objects," *Computer-Aided Design*, Vol. 37, No. 3, 2005, pp. 321-337.
134. OpenGL - The Industry Standard for High Performance Graphics. http://www.opengl.org/ . 2006.
135. OpenML - The Standard for Dynamic Media Authoring. http://www.khronos.org/openml/ . 2006.
136. Sowa, J. F. and Zachman, J. A., "Extending and Formalizing the Framework for Information Systems Architecture," *IBM Systems Journal*, Vol. 31, No. 3, 1992, pp. 590-616.
137. DoD Architecture Framework Working Group, DoD Architecture Framework Version 1.0, Volume I: Definitions and Guidelines. http://www.defenselink.mil/nii/doc/DoDAF_v1_Volume_I.pdf . 2004. US department of defense.
138. A Practical Guide to Federal Enterprise Architecture. http://www.cio.gov/archive/bpeaguide.pdf . 2001.
139. RM-ODP: The Reference Model for Open Distributed Processing. http://www.rm-odp.net/ . 2005.
140. CORBA. http://www.cs.wustl.edu/~schmidt/corba-overview.html . 2006.
141. The Standardization newsletter, No 46. http://www.dsp.dla.mil/newsletters/archive/news9407.pdf . 1994. US department of defense.
142. Galloway, A. R., *Protocol, how control exists after decentralization*, The MIT Press2001.
143. The Internet Engineering Task Force. http://www.ietf.org . 2006.
144. Brooks, F. P., *The Mythical Man-Month: Essays on Software Engineering, 20th Anniversary Edition*, Addison-Wesley Professional, Boston, MA, USA2005.

145. Denno, P. and Thurman, T., "Requirements on Information Technology for Product Lifecycle Management," *International Journal of Product Development - Special Issue on PLM*, Vol. 5, No. 1, 2005.
146. CCSDS 650.0-B-1: Reference Model for an Open Archival Information System (OAIS). Blue Book. Issue 1. ISO 14721:2003. http://public.ccsds.org/publications/archive/650x0b1.pdf . 2005. Consultative Committee for Space Data Systems.
147. David, P. A. and Foray, D., "Economic Fundamentals of the Knowledge Society, Policy Futures In Education," *An e-Journal : Special Issue: .Education and the Knowledge Economy*, Vol. 1, No. 1, 2003.
148. C4ISR Architecture Working Group, "Levels of Information Systems Interoperability (LISI): C4ISR Architecture Working Group Final Report," 1998.
149. Mick, R.. Defining and Measuring Interoperability. ARC Insights, Insight 2004-43 . 2004.
150. Srinivasan, V.. Open Up PLM Systems. Design News . 2004.
151. Simon, H. A., "Architecture of complexity," *Proceedings of the American Philosophical Society*, Vol. 106, 1962, pp. 467-482.
152. The National Digital Information Infrastructure and Preservation Program. www.digitalpreservation.gov . 2006.
153. Long Term Data Retention (LTDR). http://pdesinc.aticorp.org/long_term_data_retention_pilot.html . 2006. PDES, inc.
154. Iyer, R.. PLM for the US Army, Presentation at 7th NASA-ESA Workshop on Product Data Exchange. http://www.marc.gatech.edu/events/pde2005/presentations/ . 4-18-2005.
155. Rentz, R., "STEP Program Summary 2005," South Carolina Research Authority Integration Systems Group, Nov. 2005.
156. SCRA. http://scra.org/04_rr.shtml . 2006.
157. Mokey, J.. Teleconference. 4-12-2006. ARDEC, Picatinny Arsenal, NJ.

Appendix A: Product lifecycle and the supply chain management: An investigative study

To understand clearly the status of PLM support and the role of standards in the related activities of US Army, we developed this questionnaire and discussed it during our site visits and interviews at various US Army Research Centers.

NIST is investigating the full cross-functional process scope of Product Lifecycle Management (PLM) to better drive development of appropriate interoperability standards. As companies increasingly adopt outsourcing and globalization practices, they are focused on product development, sales and marketing and supply chain coordination. PLM becomes the critical mechanism to provide competitive advantage by bridging the gap between these functional silos to enable rapid and effective product launch, sustainment and disposal.

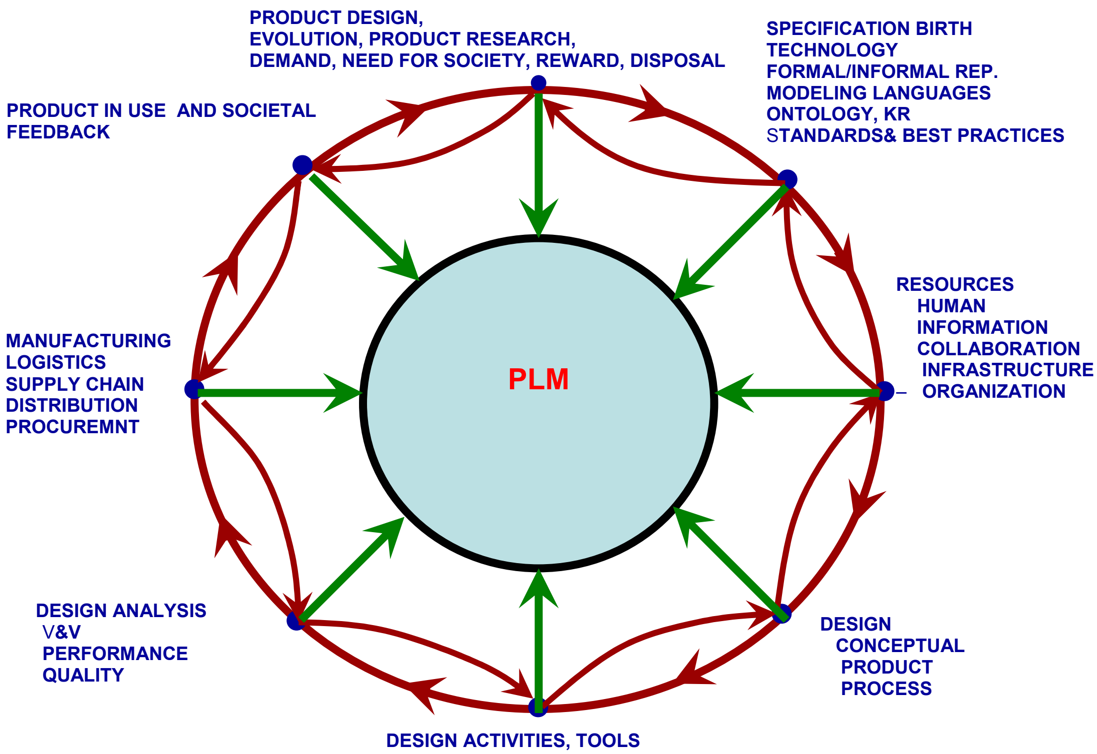

Figure 20: Epicycles nature of PLM

However, the overall scope of processes comprising PLM, the specific needs across industries, and the priorities are not well understood. Also, it is believed that the available tools are limited in their ability to holistically support PLM in its entirety.

We would greatly appreciate if you would provide your input to this study by responding to the questions that follow. All individual responses will be kept confidential. Only summary results will be published. Also, we will be glad to provide you with the summary results and the overall results of our study.

This questionnaire is divided into two parts. Part one deals with Product Data Exchange and Standards. To deliver a quantum improvement in OEM and supplier productivity, the Manufacturing Engineering Laboratory of the National Institute of Standards and Technology (NIST) and a private army contractor are conducting this study in the area of standards required for Product Lifecycle Management (PLM) on behalf of the United States Army Product Data and Engineering Working Group (PEWG). The US Army is interested in those aspects of PLM most critical to US industry and the US Army, in particular relating to development, manufacturing and sustainment of complex products. The purpose of these questions is to help the Army identify applicable data exchange standards. Part Two deals with current state of PLM challenges and requirements for supply chain integration issues. Specifically we are seeking to determine:

- Current state of PLM challenges and requirements, including supply chain integration issues.
- Identification of technology gaps, and critical development and interoperability needs.
- Industry view of critical development areas in processes and technologies.

GLOSSARY

BOM	Bill Of Materials
CAD	Computer Aided Design
COGS	Cost of Goods Sold
CTO	Configure To Order
DfX	Design for X, such as Design for Manufacturing, Design for Six Sigma
EAI	Enterprise Application Integration
ECO	Engineering Change Order
EII	Enterprise Information Integration
EOL	End Of Life
ETL	Extract, Transform, Load
ETO	Engineer to Order
IT	Information Technology
MTO	Make To Order
MTS	Make To Stock
NPI	New Product Introduction
OTD	On-Time Delivery
PDM	Product Data Management
PLM	Product Lifecycle Management
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference

PART ONE: PRODUCT DATA EXCHANGE AND STANDARDS

The investigative study consists of **12** sections:

RESPONDENT/ORGANIZATION INFORMATION

Name

Title

Name of Organization

Job responsibility/Organizational level

Phone Number

E-mail

Mailing Address

Is the information provided in this study specific to the entire organization?

Yes ☐ No ☐

If no, please indicate what percentage of your organizations entire product data exchange that is associated with the response given in the following questions.

%

PLM DEFINITION

What is the best definition of Product Lifecycle Management as used in your company?

A vision or a business strategy for creating, sharing, managing information about product, process, people and services within and across the extended and networked enterprise covering the entire lifecycle spectrum of the product. PLM in some companies is essentially the integrated product development function. In others it is used in the context of software solutions. As the importance and scope of the challenge gains increased recognition, definitions range from enabling capabilities such as information management to a complete cross-functional activity.

☐ Same as Product Development

☐ A cross-functional activity that is responsible for all processes from concept to disposal

☐ Management of product related information that is needed by different parts of the organization

☐ An IT solution

☐ Other, please specify

IMPORTANCE AND VALUE
What would you say is the importance of PLM to your company at this time?

☐ One of the most important issues for current and future success

☐ Important, but other issues take priority at this time

☐ Not so important

EXCHANGE OF PRODUCT DATA
In general terms, please explain why Product Data is exchanged?

What type of product data is exchanged in different lifecycle phases (Design, Prototype, Manufacturing, Maintenance and Retirement/Recycle) and how is it exchanged?

		Exchanged with			Method for exchanging product data				
					Informal		Formal		
Product Data Types	**Lifecycle Phase**	Supplier	Customer	Internal	Phone/fax	Electronic format	Electronic format (proprietary protocol)	Electronic (standard based)	**Frequency (files transferred per month)**
Product requirements, functions and behavior (non geometric)		☐	☐	☐	☐	☐	☐	☐	
Geometrical representation of product (CAD)		☐	☐	☐	☐	☐	☐	☐	
BOM information		☐	☐	☐	☐	☐	☐	☐	
Manufacturing Process		☐	☐	☐	☐	☐	☐	☐	
Build Order Info / Order Management		☐	☐	☐	☐	☐	☐	☐	

		Exchanged with			Method for exchanging product data				
Change Management		☐	☐	☐	☐	☐	☐	☐	
Repair and Service BOM		☐	☐	☐	☐	☐	☐	☐	
Environmental Regulatory		☐	☐	☐	☐	☐	☐	☐	
Other (please describe):		☐	☐	☐	☐	☐	☐	☐	

Additional comments:

APPLYING STANDARDS TO ENABLE THE EXCHANGE OF PRODUCT DATA

If you are using standards for exchanging product data, please specify what standards are applied and what data they are used for. Also, please add the version of the standard. (Include standards and de facto formats such as: IGES, EIA, SET, VDA-FS, EDIF, POSC, DXF, S1000D and STEP. What application protocols are used?).

Why do you apply the standards for exchanging data?

What translation method is used (Standard-based, Point-to-point proprietary interface)?

How significant would the financial impact be if international standards or open standards-based-transfer protocols were available for automatically and seamlessly sharing the following types of information with customers and suppliers?

	Negative Impact				Positive Impact		
Type of activity	**Significant negative financial impact**	**Considerable negative financial impact**	**Small negative financial impact**	**No financial impact**	**Small positive financial impact**	**Considerable positive financial impact**	**Significant positive financial impact**
Authoring Tool (CAD)	☐	☐	☐	☐	☐	☐	☐
Authoring Tool (CAM)	☐	☐	☐	☐	☐	☐	☐
Authoring Tool (PDM)	☐	☐	☐	☐	☐	☐	☐
BOM Processor	☐	☐	☐	☐	☐	☐	☐
Configuration Management	☐	☐	☐	☐	☐	☐	☐
Data Model	☐	☐	☐	☐	☐	☐	☐

	Negative Impact				Positive Impact		
Type of activity	Significant negative financial impact	Considerable negative financial impact	Small negative financial impact	No financial impact	Small positive financial impact	Considerable positive financial impact	Significant positive financial impact
Database Management	☐	☐	☐	☐	☐	☐	☐
Data Integration	☐	☐	☐	☐	☐	☐	☐
Systems Integration	☐	☐	☐	☐	☐	☐	☐
Workflow for Process Planning	☐	☐	☐	☐	☐	☐	☐
Program Management	☐	☐	☐	☐	☐	☐	☐
Training Manuals	☐	☐	☐	☐	☐	☐	☐
Simulation	☐	☐	☐	☐	☐	☐	☐
User Interface	☐	☐	☐	☐	☐	☐	☐
Visualization	☐	☐	☐	☐	☐	☐	☐
Web-Enabled Networking	☐	☐	☐	☐	☐	☐	☐
Supply Chain and Logistics (Provisioning)	☐	☐	☐	☐	☐	☐	☐
Supply Chain and Logistics (Cataloging)	☐	☐	☐	☐	☐	☐	☐
Maintenance	☐	☐	☐	☐	☐	☐	☐
Prognostics / Diagnostics	☐	☐	☐	☐	☐	☐	☐
Readiness	☐	☐	☐	☐	☐	☐	☐
Recycling / Disposal	☐	☐	☐	☐	☐	☐	☐
Other: (please specify)	☐	☐	☐	☐	☐	☐	☐

What problems (e.g. lack of interoperability, overlapping/contradictory standards, and gaps between standards) have you encountered when applying standards for exchanging data?

CURRENT APPLICATION CAPABILITIES

Does your current application (CAD/PDM/PLM/ERP) allow you to export any type of information to be exchanged?

Yes ☐ No ☐

What type of IT tools constitutes your PLM system and what are their roles:

Type of activity	Toolset Name and Version	Role
Authoring Tool (CAD)		
Authoring Tool (CAM)		
Authoring Tool (PDM)		

Type of activity	Toolset Name and Version	Role
BOM Processor		
Configuration Management		
Data Model		
Database Management		
Data Integration		
Systems Integration		
Workflow for Process Planning		
Program Management		
Training Manuals		
Simulation		
User Interface		
Visualization		
Web-Enabled Networking		
Supply Chain and Logistics (Provisioning)		
Supply Chain and Logistics (Cataloging)		
Maintenance		
Prognostics / Diagnostics		
Readiness		
Recycling / Disposal		
Other: (please specify)		

What capabilities do the IT systems of your organization have with respect to product requirements, functions, and behaviors?

	Yes	No	Don't know	Unimportant capability	Important capability	Very important capability
Can your IT systems automatically generate a BOM for a product from a representation of product requirements, functions, or behavior?	☐	☐	☐	☐	☐	☐
Can your IT systems see all requirements, functions, and behaviors affected by a swap of components?	☐	☐	☐	☐	☐	☐

How flexible are the capabilities of your organization to share each of the following types of information with customers?

Product Data Type	**Low flexibility:** plant information systems are integrated with the information systems of a single customer	**Medium flexibility:** plants share information w/ customers based on a proprietary electronic protocol set up individually with each customer	**High flexibility:** plants share information with customers automatically using a generic, standards based transfer protocol	**High (manual) flexibility:** plants share information with customers through manual processes
Product requirements, functions and behavior (non geometric)	☐	☐	☐	☐
Geometrical representation of product CAD)	☐	☐	☐	☐
BOM information	☐	☐	☐	☐
Manufacturing process information	☐	☐	☐	☐
Build order information / order mgmt.	☐	☐	☐	☐
Change Management information	☐	☐	☐	☐
Repair and service BOM information	☐	☐	☐	☐
Environmental regulatory information	☐	☐	☐	☐

Different software products generate output for similar or related information using different XML forms (use different XML tags for the same information). Is there a need to map between XML streams (mapping meta schemas) when sharing data between software created by different vendors?

				How important is the XML output?			Can you change the meta schema used to generate XML?		Can you read an XML file?		Are the XML input and output complete?	
Product Data Type	**No**	**Don't know**	**Yes (if Yes, please fill in the columns to the right)**	**Low importance**	**Medium importance**	**High importance**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
Product requirements, functions and behavior (non geometric)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Geometrical representation of product (CAD)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
BOM information	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Manufacturing process information	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Build order information / order management	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Change Management information	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Repair and service BOM information	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Environmental regulatory information	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

What software products do you presently use to create, store, and support Logistics Support Analysis Record (LSAR) information?

What software products do you presently use to create, store, and support Interactive Electronic Technical Manuals (IETM)?

What Data Standard/Specification (e.g. S1000D) do you use for IETM publications?

Should it become a requirement of the Army, do you have the capability to handle/transmit all IETM publications in the S1000D data exchange format once the specifications are provided?

Yes ☐ No ☐

If you are an Original Equipment Manufacturer (OEM), do you provide digital publications, hard copy, or aperture cards to the client or are they strictly used for in-house purposes? If yes, please specify which.

REPRESENTATION OF INFORMATION

How is the information represented?

Product Data Type	Spreadsheet or other generic tool	Document Management System	Custom application	Commercial off-the-shelf application (COTS)
Product requirements, functions and behavior (non geometric)	☐	☐	☐	☐
Geometrical representation of product (CAD)	☐	☐	☐	☐
BOM information	☐	☐	☐	☐
Manufacturing process information	☐	☐	☐	☐
Build order information / order management	☐	☐	☐	☐
Change Management information	☐	☐	☐	☐
Repair and service BOM information	☐	☐	☐	☐
Environmental regulatory information	☐	☐	☐	☐

Please add other existing representation forms:

How do you represent product requirements, functions, and behaviors (non-geometric)?

	Information not represented	Information modeling tool that tracks functional relationships between entities	Text Document	Don't know
What means are used to represent product requirements?	☐	☐	☐	☐
What means are used to represent product functions?	☐	☐	☐	☐
What means are used to represent product behavior?	☐	☐	☐	☐
Other:	☐	☐	☐	☐

If you are using or planning to use visual information modeling languages (for example UML) and ontologies for product modeling? (Ontology is defined as: A formal explicit specification of shared concepts), please describe the application?

FUTURE CAPABILITIES

Is your organization interested in representing and exchanging other information than current capabilities allow for at this time?

Yes ☐ **No** ☐

If yes, please specify what other information?

At what level of detail?

Please describe any future requirements to systems and applications. What are the key benefits in relation to data exchange?

Please list standards for enabling product data exchange that you would consider applying in the future and for what aspect of PLM.

Additional Comments (For Part One)

Please add any additional comments:

PART 2: PRODUCT LIFECYCLE AND THE SUPPLY CHAIN MANAGEMENT: A STUDY OF INDUSTRY PRACTICE

PLM-SCM INTEGRATION – IMPORTANCE AND VALUE

How many years have you been involved in PLM or SCM related functions?

☐< 2 Years ☐2-5 Years ☐5-10 Years ☐10-20 Years ☐> 20 Years

Would you be interested in participating in a 1 hour phone conversation to discuss our findings and provide additional insight?

Yes ☐ No ☐

Are you interested in receiving the final report of our study?

Yes ☐ No ☐

Would you be interested in participating in a workshop to discuss future directions to advance knowledge, practices and technologies in PLM-SCM integration?

Yes ☐ No ☐

What would be the value of better integration between PLM and SCM activities?

From being ready to take advantage of higher than expected demand for new products, keeping procurement/manufacturing/fulfillment costs low during the entire lifecycle, and minimizing the markdown and inventory obsolescence costs during end-of-life stage, our hypothesis is that the potential impact on all financial drivers is significant.

- Increase in revenue ☐ 1% ☐ 5% ☐ 10% >10% ☐ N/A
- Increase in margin ☐ 1% ☐ 5% ☐ 10% >10% ☐ N/A
- Lower development costs ☐ 1% ☐ 5% ☐ 10% >10% ☐ N/A
- Lower supply chain costs ☐ 1% ☐ 5% ☐ 10% >10% ☐ N/A
- Lower procurement costs ☐ 1% ☐ 5% ☐ 10% >10% ☐ N/A
- Lower inventory write-offs ☐ 1% ☐ 5% ☐ 10% >10% ☐ N/A
- Higher asset utilization ☐ 1% ☐ 5% ☐ 10% >10% ☐ N/A

What key issues are driving or will drive the need for better PLM-SCM integration within your company?

Companies today are faced with a variety of internal and external pressures that increase the complexity and variability in the product development and supply chain activities. We hypothesize that better PLM-SCM integration will be the most critical approach to handle these pressures and continue to gain business value

- ☐ Off-shoring to low-cost regions
- ☐ Outsourcing to contract manufacturing
- ☐ Regulations and compliance
- ☐ Increased competition from low-cost manufacturers
- ☐ Rapid product commoditization
- ☐ Financial issues (revenue/margin/cost/writeoffs)
- ☐ Supply chain operational performance (OTD, turns)

What metrics are used for Product Lifecycle Management? Which parts of the organization are measured on these metrics?

The following metrics are those that are in common use in most companies. Because PLM is a cross-functional activity, it impacts and is impacted by a variety of metrics, depending on the product lifecycle stage. Standard metrics are based on the SCOR definition. For others, a basic definition is provided.

	Metrics	Sales and Marketing	Product Development	Supply Chain	Procurement
New Product Introduction (NPI) Metrics	Time to Market				
	Product Development Cost				
	Initial Promotion Cost (cost of promoting the new products to gain market recognition)				
	Commoditization Rate (number of weeks or months after introduction when competitive products appear on the market and the premium margin opportunity is eroded)				
	Number of ECOs				
	New Component Percentage (ratio of new components to all components in the product)				
	New Supplier Percentage (ratio of new suppliers needed versus all suppliers used for the product)				
	Stockout Percentage (percentage of time product is unavailable)				
	Stabilization Period (number				

	Metrics	Sales and Marketing	Product Development	Supply Chain	Procurement
	of weeks or months when product reaches mature stage, defined as a combination of demand stabilization and engineering change stabilization)				
Stable Lifecycle Metrics	Forecast Accuracy				
	Inventory Turns				
	OTD Performance				
	Logistics Cost				
End of Life (EOL) Metrics	Excess and Obsolescence Costs				
	Markdown Cost				
	Lifecycle Period (total number of weeks or months from product introduction to disposal)				
	Disposal Cost (cost associated with returns and disposal of product to meet compliance requirements)				

What are typical values for the following metrics?

An aggregate estimate of metrics based on common experience is sufficient.

	Average	Range
Time to Market		
Forecast Accuracy		
Delivery Performance		
Average Product Lifecycle Period		
Inventory Obsolescence Cost as a percent of COGS		
Average Gross Margin over Lifecycle		

PROCESS

What supply chain capabilities and constraints are explicitly considered during the product design process?

During the design process, common practices for evaluating manufacturing, procurement and supply chain readiness usually involve concepts such as Concurrent Engineering and DfX. Increasingly, there is focus on design reuse, including component and supplier reuse. We hypothesize that effective PLM will require detailed understanding and reuse of existing supply chain capabilities and constraints.

	Conceptual Design	Detailed Design	Prototyping	Testing
Approved Parts List				
Approved Vendor List				
Manufacturing Capability and Constraints				
Logistics Capability and Constraints				
Available Capacity				
Available Inventory				

What processes are used to evaluate the supply chain readiness during product development?

As supply chains become more complex with increasing use of partners through outsourcing, preparing a supply chain for a new product can be involved and time consuming. We hypothesize that not only the PLM-SCM integration should be closed-loop to ensure that detailed supply chain readiness is assessed and required capabilities developed to keep up with the increasing pace of product development and shortening product lifecycles.

☐ New Supplier/Component Qualification

☐ Supply Risk Analysis (the potential need to establish new inventory points, transportation routes or production capabilities to meet design requirements)

☐ Manufacturing Strategy Analysis (MTS, MTO, CTO, ETO)

☐ Supply Bottleneck Analysis (identification of capacity and material constraints and corresponding impact on product launch plans)

☐ Obsolescence Analysis (impact on existing inventory)

☐ Up/down Volume Flex Analysis (internal and external capacity analysis to cope with demand variability during product introduction)

During product launch, what information is used to make trade-offs between market opportunity and supply chain costs?

The trade-off involves determining product launch timing that optimizes the overall margin. Earlier introduction provides greater price premium, while increasing costs of preparing the supply chain quickly, and markdown and write-off costs for products that are likely to be cannibalized.

☐ Demand (Volume and Price) Elasticity

☐ Inventory Markdown and Write-off Costs

☐ Supply Ramp Cost

In which SCM processes are product lifecycle issues currently considered?

- ☐ Supply Chain Design
- ☐ Strategic Sourcing
- ☐ Customer Collaboration
- ☐ Program Management
- ☐ Demand Planning
- ☐ Inventory Planning
- ☐ Demand Supply Balancing
- ☐ Supplier Collaboration
- ☐ Factory Planning
- ☐ Distribution Planning
- ☐ Transportation Planning
- ☐ Warehouse Management
- ☐ Production Scheduling
- ☐ Transportation Management
- ☐ Service Parts Management
- ☐ Returns Management

Is the supply chain managed differently during the different stages of a product's lifecycle?

Supply chains employ business rules to account for variations in product characteristics. However, we hypothesize that these rules are established on an ad-hoc basis, without explicitly considering lifecycle issues.

- ☐ Lower performance targets (longer lead times, lower service levels) during NPI/EOL stages versus higher targets during mature stage
- ☐ ETO/CTO during NPI/EOL stages versus MTS during mature stage
- ☐ Single inventory storage during NPI/EOL versus distributed inventory management during mature stage
- ☐ In-house manufacturing during NPI/EOL versus contract manufacturing during mature stage

ORGANIZATION

Which business function has primary responsibility for PLM?

- ☐ Product Development
- ☐ Marketing
- ☐ Product Line or Business Unit
- ☐ Supply Chain
- ☐ Procurement
- ☐ IT
- ☐ Not currently defined

Is there an explicitly defined role for coordinating product lifecycle issues between the various functions?

- ☐ Yes, resides in one of the functional areas. Please specify: Product Development, Marketing, Supply Chain, Procurement
- ☐ Yes, is a separate cross-functional role
- ☐ No, role does not exist. Coordination is ad-hoc

TECHNOLOGY AND DATA

Which commercial solutions, if any, are used to enable the following processes?

- ☐ SCM
- ☐ EAI
- ☐ ETL
- ☐ EII
- ☐ Data Warehousing
- ☐ Enterprise Reporting
- ☐ Master Data Management

How is PLM-SCM integration enabled?

- ☐ Manual processes
- ☐ MS Excel and other unstructured tools
- ☐ In middleware such as EAI/ETL
- ☐ Within SCM system with data imported from PLM system

What product lifecycle information is used in SCM processes?

- ☐ Design concept
- ☐ Unreleased BOM
- ☐ Component effectivity dates
- ☐ Design alternatives
- ☐ Engineering change orders
- ☐ Other (Specify)

What is the frequency of update of information from PLM to SCM?

- ☐ Event-based as new designs are created
- ☐ Weekly
- ☐ Monthly
- ☐ Quarterly
- ☐ Combination, weekly for ECOs, monthly for demand elasticities and new requirements, quarterly for new design concepts
- ☐ Other (Specify)

Appendix B: Army-Related Projects Employing PLM Standards

A sampling of projects specific to the Army

The whole idea for the Army's PLM strategy is to be proactive, not reactive. To this end, there have been several projects identified and pilot trials done. The following list is not intended to be exhaustive, but to give an overview of how the Army and DoD are addressing the integration of ISO 10303 into their product lifecycle process.

HMMWV data exchange with AM General

AM General, the Army's contractor for the HMMWV (High Mobility Multi-Purpose Wheel Vehicle), used Teamcenter, UGS PDM software. AM General maintains the vehicle's engineering CAD master database in a 3D Unigraphics format. Since the Army does not have any UG capabilities, it is accepting pdf files for the drawings on CD media, importing the data into the Army's Windchill PDM system. A schematic diagram of the data exchange between AM General and TACOM is shown in Figure 21. Duplicating the data in an asynchronous fashion adversely impacts data integrity as version control and updates are managed by AM General, and not getting to the Army at the same time. TARDEC and AM General have begun to use ISO 10303-214, Conformance Class 6, PDM Schema for exchange with 10303-28 XML file formats. The Army is not doing any CAD translation of the information, only PDM translation; hence, still having two sources for product data. Federation, another participating software vendor, adapted its software to the PDM schema that is now being used to broker the exchange. Federation has an adaptor (extracts, converts) and a server (web-server broker). Using the Federation Servers allows automatic product data update notification to approved users (Army). Recently, AM General has migrated out of Teamcenter to SAP PLM.

Measured Impact from Change: *By progressing from pdf format/CD transport to web-service-brokered product data exchange TARDEC anticipates measurable impact and cost-savings. With the current process it takes several days to receive the data, upload the data, and make the necessary changes to validate the data. This time can be cut down to a few hours when the proposed piloted solution is put into production.*

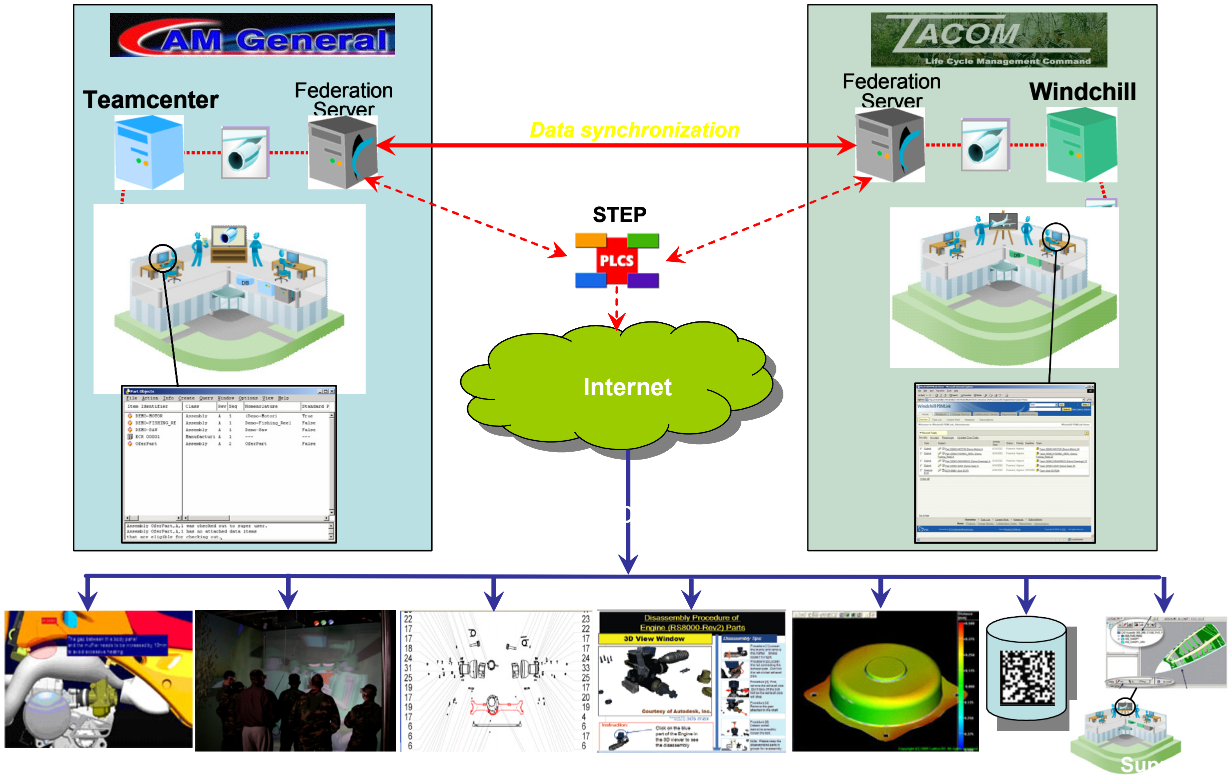

Figure 21: Data Exchange between AM General & TACOM [154].

Bradley data exchange with BAE

Another STEP-based implementation at TARDEC involves the Bradley Fighting Vehicle. TARDEC is currently implementing a pilot project to show how data can be automatically exchanged between the OEM for the Bradley, BAE Systems, and TACOM (Figure 22). The Bradley configuration data is stored in a database called CMSTAT and it also serves as the master repository for the Bradley product data. TACOM would like for this data to be pushed to TACOM's Windchill using the STEP PDM Schema, to enable various TACOM production and procurement functions. In this project, the two systems – CMSTAT and Windchill are not federated, but a push approach has been adopted because BAE Systems has not segregated the data among its various proprietary programs from the Government data. BAE is also in the process of moving to a PDM, Windchill, as required by the Army's Future Combat Systems contract. The developed STEP functionality could also help BAE migrate their data to Windchill.

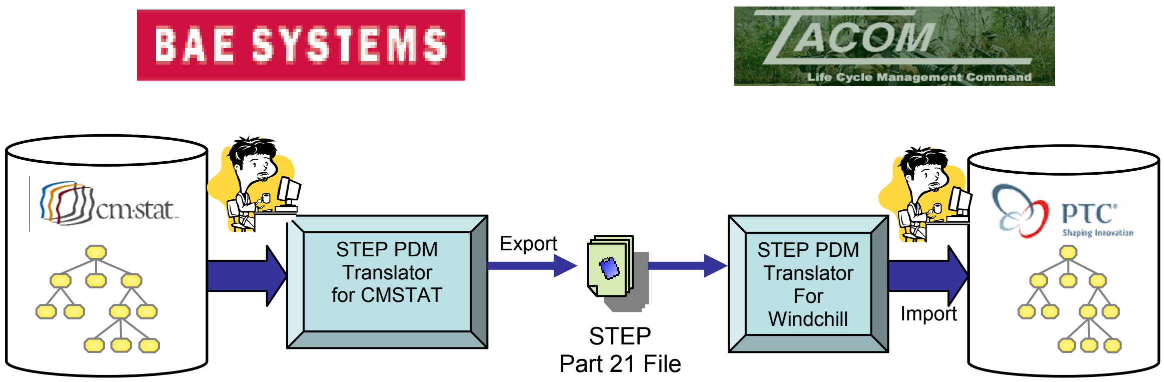

Figure 22: Data exchange between BAE Systems and TACOM

Abrams UID Pilot with GDLS

The Abrams Tank project has 200 tanks coming in for RESET/RECAP[15]. TACOM is currently marking many of the components within the Abrams tank using UID. General Dynamics Land Systems (GDLS) is responsible primarily for the components' marking for this project, and is using an Oracle PLM system to track the data. The Army is working with General Dynamics to set up a process to access the BOM information using ISO 10303-239. The same standard will also be used to transmit the UID embedded item information to the DOD UID Registry. Items being chosen for tagging must be great than $5K and mission critical (if item fails, the system fails). Once tagged, each tank's UID can point to all the unique information, maintenance records, metadata, schedules, etc., in an RFID-readable way.

U.S. Army National Automotive Center (NAC), N-STEP

Considered the flagship initiative for Army's piloting and use of ISO 10303 is the National Automotive Center STEP-Enabled Production of components program, or N-STEP. Started in FY2002, the intent of the N-STEP project was to improve the machined part supply to the Army's ground combat systems. Initial efforts went into supporting the development of the ISO application protocols among international partners (historically AP224, and more recently AP240). *Pilot demonstrations conducted showed a 40-55% process planning lead time reduction for machined parts and assemblies [155].* With the deployment of SCRA-developed technology and processes completed, the focus now is on the full-scale production of parts and assemblies, enhancement of SCRA's STEP-enabling software tools, and the commercialization of those tools so that a broader spectrum of DoD's partners and suppliers can benefit from them [156].

LEAN munitions

ARDEC is leveraging the work previously accomplished under N-STEP to conduct its own spare parts delivery initiative. The Lean Munitions program started in FY2003, plans to put into production a 3-D "Lean Munitions" design and manufacturing lifecycle support system by

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[15] RECAP activity strips and replaces everything in the vehicle and sets the vehicle's odometer back to zero. RESET is about 80/20% ratio, bringing the vehicle back to 80% of its original performance.

applying some functionality from STEP APs 203, 224, and 240 to enable more timely and cost effective production of machined parts and assemblies needed for the Army's munitions and armaments systems. To date, most of the exchange has focused on 2D Autocad and ProEngineer exchange [157]. *With delivery time reductions of up to 55% already being realized, ARDEC envisions an annual cost savings of as much as $35M upon program completion [156].*

TACOM/Army Ground systems integrated lean enterprise (AGILE)

Started in 2005, AGILE is to establish the infrastructure and processes to enable STEP-based product data exchange between TACOM's organic industrial sites for more efficient RECAP and RESET activities. The program is currently being executed at Rock Island Arsenal, Anniston Army Depot, and Watervliet Arsenal. The program intends to develop a common set of processes and data standards to enable sharing of work load among TACOM's various depots and arsenals in support of surge requirements. AGILE has also successfully integrated two STEP APs – AP224 and AP238 to enable a seamless flow of data between CAD/ CAM systems. The output data will then be sent to NC machines for automated manufacturing. AGILE has processed 117 operational production parts through the system concentrating on complex parts that stretch the system, especially at Watrevliet. Another focus of AGILE is to apply AP223 to develop cast parts.

Electronic Logistics Information Trading Exchange (ELITE)

The Electronics Logistics Information Trading Exchange (ELITE) effort interconnects military services with private industry to share maintenance actions performed on aircraft and aircraft components. Currently, this data is shared in a proprietary format between a single manufacturer, Sikorsky Aircraft, and a single Army recipient system. ELITE expands the current effort in several key areas:

- PLCS-based Data Exchange (DEX) format is being exploited as the standard canonical data exchange format
- Additional service systems that conduct or track aircraft maintenance actions are participating
- Expanded uses of the data beyond maintenance actions are being considered

The ELITE effort expands the current data flow to transform the maintenance action data into PLCS-compliant DEX format prior to transmission. The Aviation DEX defines the structure of the PLCS compliant transactions. In addition to exploitation of a standard format, ELITE also expands the number of participants. The Navy Aviation Maintenance system, will also participate in data sharing.

Some tri-Service initiatives

CALS

The Continuous Acquisition and Lifecycle Support[16] (CALS) had it tri-service beginning in 1985. In a response to a NIST report evaluating and recommending various international data exchange standards, the Office of the Secretary of Defense kicked off, what became a multi-decade initiative. Building international military involvement and momentum over the last two decades, it is still alive as a multi-national initiative today. CALS encompasses a host of interrelated activities such as business process improvement, enterprise integration and information technology standardization. As an umbrella tri-service program, there were several programs contributing to the piloting and implementation of international standards, such as JEDMICS and RAMP mentioned below.

JEDMICS

The Joint Engineering Data Management Information and Control System (JEDMICS is the DOD standard engineering data management and repository system. A total of twenty-two Army, Navy, Air Force, Marine Corps and Defense Logistics Agency sites currently use JEDMICS to manage over 80 million engineering drawings for more than 36,000 users. Additionally, several external logistic systems depend on the JEDMICS application interface to obtain engineering drawing data. JEDMICS capabilities support DOD logistics business functions, such as maintenance, repair, procurement, and re-engineering by providing worldwide, on-demand access to digital engineering drawings and associated data.

The JEDMICS provides the means to efficiently convert, store, protect, process, locate, receive and output data previously contained on aperture cards and paper. Large engineering drawings and related text are scanned and stored on network-accessible digital media, providing online access at distributed workstations. The JEDMICS application also provides the capability to accept data directly from various other digital media processes. Quoted from [159].

Rapid acquisition of manufactured parts (RAMP)

Started in the late 1980s, and led by the Naval Air Systems Command, RAMP focused on the manufacturing system is to produce and deliver quality mechanical parts or printed wiring assemblies within an average of 27 days of receiving an order. Using the concepts of functional equivalence, modularity, standardized communications, and reduction of administrative lead times, the manufacturing runs proved concepts of large capability manufacturing (e.g., 15,000 parts), ordered in very small lot sizes (e.g., 4). Quoted from [160].

Anniston Army Depot in Anniston, AL cited its experience with RAMP as a "Best Practice"[17]. In 1995, ANAD successfully completed the installation of the RAMP system, and started producing parts. *Since the installation, the system has been used successfully and has reduced the average in-shop production time to less than 30 days with no increase in personnel.*

RAMP lasted for twelve years, with over $250M investment, with legacy implementations at over 35 installations across the United States, United Kingdom, and Japan. Manufacturing execution systems continue to operate at several DoD industrial facilities [155]. One pilot

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[16] Those involved from industry preferred to refer to CALS as, "Commerce at Light Speed."
[17] This best practice, "Flexible Computer Integrated Manufacturing/Rapid Acquisition of Manufactured Parts," is described at http://www.bmpcoe.org/bestpractices/internal/anad/anad_3.html .

project, conducted by Focus: HOPE Center for Advanced Technologies, demonstrated the feasibility and practicality of using STEP-based (AP203, AP224) Technical Data Packages (TDPs) when acquiring spare parts. "The data collected were from a 17-part sample: three from the Naval ICP - Philadelphia, nine from the Defense Logistics Agency, and five from the Tank - automotive and Armaments Command. *An analysis of the data revealed: Focus: HOPE experienced from 30% to 42 % savings in the time required to prepare a bid using the bid module and GPPE software suites. An additional 25 % to 40 % savings were realized in micro level process planning utilizing the STEP files and the GPPE macro level process planning output. The RAMP-validated STEP files were observed to be 100% accurate.* The use of STEP eliminated the time necessary to prepare a solid model prior to commencing micro level process planning. As a result of the accurate solid model, significant time was saved on the shop floor as compared to conventional operations. These savings were evident because the usual manufacturing problems experienced due to the typical Computer Aided Design (CAD) modeling errors were eliminated." Quoted from [161].

Appendix C: Product lifecycle-related integration standards

The proposed typology primarily reflects the content to be communicated and implies the appropriate expressiveness and language choices for each type of content. Within each type, individual standards may be classified as to origin, intent, development process and, to some extent, scope. Type Zero is represented by standards for implementation languages, and is not exemplified in table format here. These standardized languages include programming, scripting, assembly level, and other computable languages used to implement the Type One, Type Two, and Type Three standards. Examples of Type Zero include: Basic, FORTRAN, C, C++, Java, C#, Prolog, Perl, Tcl/Tk, OpenGL.

Type One: Information Modeling Standards

Type One standards are for semantically rich modeling languages, and are based on different forms of logic.

Acronym	Standard	Functional Description	Web URL
CL	Common Logic	a language designed for use in the interchange of knowledge among disparate computer systems. It will be a logically comprehensive language with a declarative semantics, and it will provide for the representation of knowledge about knowledge. The standard will be divided into three parts. Part 1 (Knowledge Interchange Format and Conceptual Graphs) specifies the semantics of a language that extends first-order logic, together with two semantically equivalent syntaxes – the Knowledge Interchange Format (KIF) and Conceptual Graphs (CG). Part 2 (Sorted Language) is an expansion of the language of Part 1 that specifies the syntax and semantics of a sorted logic. Part 3 (Metalanguage) is an expansion of the language of Part 1 that formalizes the syntax and semantics of the meta-theory of first-order logic.	http://cl.tamu.edu/#cl
CWM	Common	standardizes a basis for data modeling commonality	http://www.omg.org/technology/cw

Acronym	Standard	Functional Description	Web URL
	Warehouse Metamodel	within an enterprise, across databases and data stores. Building on a foundation metamodel, it adds metamodels for relational, record, and multidimensional data; transformations, OLAP, and data mining; and warehouse functions including process and operation. CWM maps to existing schemas, supporting automated schema generation and database loading. This makes it the basis for data mining and OLAP across the enterprise.	m/
CycL		CycL is a formal language whose syntax derives from first-order logic. It was created and used by Doug Lenat's Cyc Artificial Intelligence project. Ramanathan V. Guha was instrumental in the design of the language. There is a close variant of CycL known as MELD. The original version of CycL was a frame language, but the modern version is not. Rather, it is based on classical first-order logic, with extensions for modal operators and higher order quantification. CycL is used to represent the knowledge stored in the Cyc Knowledge Base, available from Cycorp. The source code written in CycL released with the OpenCyc system is licensed as open source, to increase its usefulness in supporting the semantic web.	http://en.wikipedia.org/wiki/CycL
DL	Description Logic	Description logics are a family o knowledge representation languages which can be used to represent the terminological knowledge of an application domain in a structured and formally well-understood way. The name *description logic* refers, on the one hand, to concept descriptions used to describe a domain and, on the other hand to the logic-based semantics which can be given by a translation into first-order predicate logic. Description	http://en.wikipedia.org/wiki/Description_logic

Acronym	Standard	Functional Description	Web URL
		logic was designed as an extension to frames and semantic networks, which were not equipped with a formal logic-based semantics. Description logic was given its current name in the 1980s. Previous to this it was called (chronologically): *terminological systems*, and *concept languages*. Today description logic has become a cornerstone of the Semantic Web for its use in the design of ontologies.	
EXPRESS	Information Modeling Language	ISO 10303-11: 1994, Industrial automation systems and integration -- Product data representation and exchange -- Part 11: Description methods: The EXPRESS language reference manual. Consists of language elements which allow an unambiguous data definition and specification of constraints on the data defined and by which aspects of product data can be specified. Deals with data types and constraints on instances of the data types. Also defines a graphical representation (EXPRESS-G) for a subset of the constructs in the EXPRESS language. EXPRESS is not a programming language.	http://www.iso.org/
FOL	First Order Logic	First-order predicate calculus (FOPC) or first-order logic (FOL) is a system of mathematical logic, extending propositional logic (equivalently, sentential logic) and in turn extended by second-order logic. First-order logic has sufficient expressive power for the formalization of virtually all of mathematics.	http://en.wikipedia.org/wiki/First-order_predicate_calculus
KIF	Knowledge Interchange Format	A language designed for use in the interchange of knowledge among disparate computer systems (created by different programmers, at different times, in different languages, and so forth). KIF is *not* intended as a primary language for interaction with human users (though it can	http://logic.stanford.edu/kif/kif.html

Acronym	Standard	Functional Description	Web URL
		be used for this purpose). Different computer systems can interact with their users in whatever forms are most appropriate to their applications (for example Prolog, conceptual graphs, natural language, and so forth). Nor is KIF intended as an internal representation for knowledge *within* computer systems or within closely related sets of computer systems (though the language can be used for this purpose as well). Typically, when a computer system reads a knowledge base in KIF, it converts the data into its own internal form (specialized pointer structures, arrays, etc.). All computation is done using these internal forms. When the computer system needs to communicate with another computer system, it maps its internal data structures into KIF.	
ODF	Open Document Format, short for the OASIS Open Document Format for Office Applications	is an open document file format for saving and exchanging editable office documents such as text documents (including memos, reports, and books), spreadsheets, charts, and presentations. This standard was developed by the OASIS industry consortium, based upon the XML-based file format originally created by OpenOffice.org.	http://en.wikipedia.org/wiki/OpenDocument
OWL	Ontology Web Language	is a *Web* Ontology language. Where earlier languages have been used to develop tools and ontologies for specific user communities (particularly in the sciences and in company-specific e-commerce applications), they were not defined to be compatible with the architecture of the World Wide Web in general, and the Semantic Web in particular. OWL uses both URIs for naming and the description framework for the Web provided by RDF to add the	http://www.w3.org/2004/OWL/

Acronym	Standard	Functional Description	Web URL
		following capabilities to ontologies: • Ability to be distributed across many systems • Scalability to Web needs Compatibility with Web standards for accessibility and internationalization • Openess and extensiblility. OWL builds on RDF and RDF Schema and adds more vocabulary for describing properties and classes: among others, relations between classes (e.g., disjointness), cardinality (e.g., "exactly one"), equality, richer typing of properties, characteristics of properties (e.g., symmetry), and enumerated classes. There are three sublanguages of OWL, known as OWL DL (description language), OWL Lite, and OWL Full.	
PSL	Process Specification Language	defines a neutral representation for manufacturing processes. Process data is used throughout the lifecycle of a product, from early indications of manufacturing process flagged during design, through process planning, validation, production scheduling and control. In addition, the notion of process also underlies the entire manufacturing cycle, coordinating the workflow within engineering and shop floor manufacturing. The goal of PSL is to create a process representation that is common to all manufacturing applications, generic enough to be decoupled from any given application, and robust enough to be able to represent the necessary process information for any given application. This representation would facilitate communication between the various applications because they would all "speak the same language."	http://www.nist.gov/psl
RDF	Resource	integrates a variety of applications from library catalogs	http://www.w3.org/RDF/

Acronym	Standard	Functional Description	Web URL
	Description Framework	and world-wide directories to syndication and aggregation of news, software, and content to personal collections of music, photos, and events using XML as an interchange syntax. The RDF specifications provide a lightweight ontology system to support the exchange of knowledge on the Web.	
SOAP	Simple Object Access Protocol	Version 1.2 provides the definition of the XML-based information, which can be used for exchanging structured and typed information between peers in a decentralized, distributed environment.	http://www.w3.org/2000/xp/Group/
SUO-KIF	Standard Upper Ontology Knowledge Interchange Format	Standard Upper Ontology Knowledge Interchange Format (SUO-KIF) is a language designed for use in the authoring and interchange of knowledge. SUO-KIF has declarative semantics. It is possible to understand the meaning of expressions in the language without appeal to an interpreter for manipulating those expressions.	http://suo.ieee.org/SUO/KIF/index.html http://www.ontologyportal.org/
SysML	Systems Engineering Modeling Language	is directed towards the specific domain of systems engineering. SysML is derived from the basic UML to cover the requirements, structure, behavior, parametrics, and the relation of structure to behavior (allocation)	http://www.sysml.org/
U3D	Universal 3 Dimensional	A graphics standard that is a simple format for interactive viewing and sharing of 3D data	http://www.answers.com/topic/u3d
UML	Unified Modeling Language	standardizes representation of object oriented analysis and design. A graphical language, its dozen diagram types include Use Case and Activity diagrams for requirements gathering, Class and Object diagrams for design, and Package and Subsystem diagrams for deployment. UML lets architects and analysts visualize, specify, construct, and document applications in a standard way.	http://www.uml.org/

Acronym	Standard	Functional Description	Web URL
XML	Extensible Markup Language	is a simple, very flexible text format derived from SGML (ISO 8879). Originally designed to meet the challenges of large-scale electronic publishing, XML is also playing an increasingly important role in the exchange of a wide variety of data on the Web and elsewhere.	http://www.w3.org/XML/
XML Schema		XML Schemas express shared vocabularies and allow machines to carry out rules made by people. They provide a means for defining the structure, content, and semantics of XML documents.	http://www.w3.org/XML/Schema

Type Two: Content standards - domains of discourse

Content standards pertain to information models specifically defined for particular domains using generic information modeling language (Type One) or an extension of one.

Acronym	Standard	Functional Description	Web URL
AECMA 2000M	International Specification for Materiel Management Integrated Data Processing for Military Equipment	Developed by the aerospace industry (European Association of Aerospace Industries) and its defense customers to provide common business processes and electronic communications for the logistic support of complex systems from initial procurement through their entire lifecycle.	http://ww.aecma.org/Publications/Spec2000/s2000m.htm
AECMA S1000D	International Specification for Technical Publications Utilizing a	for the procurement and production of technical publications. Whilst the title restricts its use to technical publications, it has been found through application that the principles of the specification can be applied to non-technical publications.	http://www.s1000d.org/

Acronym	Standard	Functional Description	Web URL
	Common Source Database	This specification has been initially developed by the AeroSpace and Defence Industries Association of Europe (ASD) --former European Association for Aerospace Industries (AECMA). The current edition has been jointly produced by ASD and the Aerospace Industries Association of America (AIA), who form the Technical Publications Specification Maintenance Group (TPSMG) to establish standards for documentation agreed by the participating nations.	
BPML	Business Process Modeling Language	A meta-language for the modeling of business processes	http://www.oasis-open.org/cover/bpml.html
CML	Chemical markup language	Is a new approach to managing molecular information. It has an extensible scope as it covers disciplines from macromolecular sequences to inorganic molecules and quantum chemistry. CML is new in bringing the power of XML to the management of chemical information. In simple terms it is "HTML for Molecules," but there is a great deal more to it than that. CML and associated tools allows for the conversion of current files without semantic loss into structured documents, including chemical publications, and provides for the precise location of information within files.	http://cml.sourceforge.net/
ebXML	Electronic Business using eXtensible Markup Language	Is a modular suite of specifications that enables enterprises of any size and in any geographical location to conduct business over the Internet. Using ebXML, companies now have a standard method to exchange business messages, conduct trading relationships, communicate data in common terms and define and register business processes. ebXML was started in 1999	www.ebxml.org

Acronym	Standard	Functional Description	Web URL
		as an initiative of OASIS and the United Nations/ECE agency CEFACT.	
GEIA – 927	Government Electronics and Information technology Association 927: Common Data Schema for Complex Systems	Is being developed to achieve an unprecedented degree of interoperability among IT systems for complex engineer-to-order systems, products and processes over their lifecycle. It specifies the data concepts to be exchanged to share product information pertaining to a complex system from the viewpoints of multiple disciplines. It supports the exchange of data across the entire lifecycle for the product from the concept stage through disposal.	http://63.249.145.5/sstc/G47/GEIA-927/index.htm
IGES	Initial Graphics Exchange Specification	Defines a neutral data format that allows for the digital exchange of information among computer-aided design (CAD) systems. CAD systems are in use today in increasing numbers for applications in all phases of the design, analysis, manufacture and testing of products. Since it is common practice for a designer to use one supplier's CAD system and for the contractor and subcontractors use different systems, there is a need for the ability to exchange data digitally among all CAD systems. IGES provides a neutral definition and format for the exchange of specific data. Using IGES, a user can exchange product data models in the form of wire frame or solid representations as well as surface representations. Applications supported by IGES include traditional engineering drawings as well as models for analysis and/or various manufacturing functions. In addition to the general specification, IGES includes application protocols in which the standard is interpreted to meet discipline	https://www.uspro.org/

Acronym	Standard	Functional Description	Web URL
		specific requirements.	
IPC-2570 series	Shop Floor Communications (PDX) - IPC-257x	PDX is the Product Data eXchange standard for the e-supply chain. It is a multi-part standard, represented by the IPC 2570 series of specifications. The PDX standardization effort is focused on the problem of communicating product content information between Original Equipment Manufacturers, Electronics Manufacturing Services providers and component suppliers. The standard is based on XML because this provides a simple way to encode structured data into a format that is both human and machine-readable. PDX provides a way to describe product content (Bill of Materials (BOM), Approved Manufacturer Lists (AML), Drawings, etc.), Engineering Change Requests (ECR), Engineering Change Orders (ECO) and deviations.	http://webstds.ipc.org/2571/2571.htm
MatML	Materials Markup Language	An XML language developed especially for the interchange of materials information. It addresses the problems of interpretation and interoperability for materials property data exchanged via the World Wide Web	http://www.oasis-open.org/cover/matML.html
MML	MOKA Modelling Language	Provides for the representation of meta classes and relations between them as MOKA's main formal knowledge structuring facility.	http://www.kbe.coventry.ac.uk/moka/meta.htm
OAGIS	Open Applications Group Integration Specification	Is an effort to provide a canonical business language for information integration. It uses XML as the common alphabet for defining business messages, and for identifying business processes (scenarios) that allow businesses and business applications to communicate.	http://www.ibm.com/developerworks/xml/library/x-oagis/
PDML	Product Data	being developed as part of the Product Data	http://www.PDML.org/pdmlintro.ht

Acronym	Standard	Functional Description	Web URL
	Markup Language	Interoperability (PDI) project	ml
PDX	Product Data eXchange	Please see IPC-2570 series above.	http://webstds.ipc.org/2571/2571.htm
PLCS	Product Life Cycle Support	ISO 10303-239: 2005, Industrial automation systems and integration -- Product data representation and exchange -- Part 239: Application protocol: Product life cycle support. Seeks to provide a mechanism to maintain the information needed to support complex products and systems such as ships, aircraft, engines, or oil platforms, in line with the changing product over its complete life cycle from concept through design and manufacture to operation and disposal. AP239 also addresses the information requirements needed to define and deliver life cycle support for complex assets.	http://www.iso.org/ http://www.oasis-open.org/committees/tc_home.php?wg_abbrev=plcs
PLM XML	Product Lifecycle Management eXtensible Markup Language	A set of XML schemas serving as a transport protocol. an emerging UGS format for facilitating product lifecycle interoperability using XML, it is open and based on standard W3C XML schemas. Representing a variety of product data both explicitly and via references, PLM XML provides a lightweight, extensible, and flexible mechanism for transporting high-content product data over the Internet, and aims to form the basis of a rich interoperability pipeline connecting UGS PLM Solutions products and third party adopter applications.	http://www.plmxml.org
STEP	STandard for Exchange of Product model data	ISO 10303 objective is to provide a means of describing product data throughout the lifecycle of a product that is independent from any particular computer system. The nature of this description makes it suitable not only for neutral file exchange, but also as a basis for implementing	http://www.tc184-sc4.org/SC4%5FOpen/SC4%5FWork%5FProducts%5FDocuments/STEP%5F%2810303%29/

Acronym	Standard	Functional Description	Web URL
		product databases and for archiving data. In practice, the standard is implemented within computer software associated with particular engineering applications and so its use and function will be transparent to a user. The descriptions are information models that capture the semantics of an industrial requirement and provide standardized structures within which data values can be understood by a computer implementation.	
STEP PDM Schema	Standard for the Exchange of Product model data (STEP) Product Data Management (PDM)	Iis a reference information model for a central, common subset of the data being managed within a PDM system. It represents a set of common requirements and data structures from a range of STEP Application Protocols all generally within the domains of design and development of discrete electro/mechanical parts and assemblies. It is not a specification for the functionality of the complete scope of all PDM system functionality. Important interfaces exist with functionality needed for comprehensive PDM services that exist in STEP but are not within the common scope of the core PDM schema.	http://www.pdm-if.org/pdm_schema/
STEPml	STEP markup Language	A library of XML specifications based on the content models from the STEP standard	http://www.stepml.org/
UBL	Universal Business Language	The product of an international effort to define a royalty-free library of standard electronic XML business documents such as purchase orders and invoices. Developed in an open OASIS Technical Committee with participation from a variety of industry data standards organizations, UBL is designed to plug directly into existing business, legal, auditing, and records management practices, eliminating the re-keying of data	http://www.oasis-open.org/committees/tc_home.php?wg_abbrev=ubl

Acronym	Standard	Functional Description	Web URL
		in existing fax- and paper-based supply chains and providing an entry point into electronic commerce.	
U3D	Universal 3 Dimensional	A graphics standard that is a simple format for interactive viewing and sharing of 3D data	http://www.answers.com/topic/u3d
X3D		XML-enabled 3D standard to enable real-time communication of 3D data	

Type Three: Architecture Frameworks Standards

In integrating these Types of standards, it is necessary to consider the architectural frameworks for creating integrated support systems, Type Three category of standards.

Acronym	Standard	Functional Description	Web url
DoDAF	Department of Defense Architecture Framework	DoD Architecture Framework Working Group, DoD ArchitectureFramework, Version 1.0, Volume I: Definitions and Guidelines , 2004	http://www.defenselink.mil/nii/doc/DoDAF_v1_Volume_I.pdf
FEAF	Federal Enterprise Architecture Framework	Was established in 1999 by the Chief Information Officers (CIO) in response to this mandate. The purpose of the FEAF is to facilitate shared development of common processes and information among Federal Agencies and other government agencies. The FEAF, like other frameworks, is essentially a guide for collecting common architecture information and building a repository to store this information.	http://www.cio.gov/archive/fedarch1.pdf
MDA	Model-Driven Architecture	MDA supports applications over their entire lifecycle from Analysis and Design, through implementation and	http://www.omg.org/mda/

Acronym	Standard	Functional Description	Web url
		deployment, to maintenance and evolution. Based on UML models which remain stable as the technological landscape changes around them, MDA-based development maximizes software ROI as it integrates applications across the enterprise, and one enterprise with another.	
MODAF	Ministry of Defence (UK) Architectural Framework	Defines a standardized way of modeling an enterprise. The purpose of MODAF is to ensure a consistent approach when developing enterprise architectures.	http://www.modaf.com/
NAF	NATO Architecture Framework	Part of the NATO C3 Technical Architecture (NC3TA), which provides the architectural building blocks in a functional, standards, and product-related form and their relationships necessary to develop the technical and system views of an architecture.	http://nc3ta.nc3a.nato.int/website/home_volumes.asp?menuid=15http://nc3ta.nc3a.nato.int/website/home_volumes.asp?menuid=15
OSA-EAI	Open System Architecture for Enterprise Application Integration (OSA-EAI)	Is MIMOSA's XML-based system specification for the integration of asset management information. A standard by which data flows from the monitored assets to the Enterprise Asset Management system.	http://www.mimosa.org/osaeai30.htm
RM-ODP	Reference Model for Open Distributed Processing	An ISO/IEC 10746 standard, the model describes an architecture within which support of distribution, interworking, interoperability and portability can be integrated. The RM-ODP framework defines ODP concerns using five "viewpoints" (abstractions), namely enterprise, information, computational, engineering, and technology.	http://www.dstc.edu.au/Research/Projects/ODP/ref_model.html
SCOR	Supply Chain Operations	The supply chain council, supported by over 650 member organizations (both academia and industry)	http://www.eng.uc.edu/icams/publications/2005b.pdf ,

Acronym	Standard	Functional Description	Web url
	Reference	worldwide, has developed the supply chain operations reference (SCOR) model. The SCOR model is a process reference model, which is intended to be an industrial standard that enables next-generation supply chain management. It contains a standard description of management processes, a framework of relationships among the standard processes, standard metrics to measure process performance, management practices that produce best-in-class performance, and a standard alignment to software features and functionality.	http://www.supply.chain.org/
VCOR	Value Chain Operational Reference Model	Aims at providing a unified and universal approach to organizational analysis and help in consolidating enterprise processes	http://www.value-chain.org
Zachman Framework		Draws upon the discipline of classical architecture to establish a common vocabulary and set of perspectives, a framework, for defining and describing today's complex enterprise systems. Enterprise Architecture provides the blueprint, or architecture, for the organization's information infrastructure.	http://www.zifa.com

Standards Development Organizations or Communities of Practice (beyond ANSI and ISO)[18]

Acronym	Organization Name	Scope of Development	Web url

[18] A much more thorough list of standards development organizations for well beyond product data-related activities, can be found at the Standards Engineering Society website: http://www.ses-standards.org/displaycommon.cfm?an=9 .

Acronym	Organization Name	Scope of Development	Web url
ASME	American Society of Mechanical Engineers	Founded in 1880 as the American Society of Mechanical Engineers, today's ASME is a 120,000-member professional organization focused on technical, educational and research issues of the engineering and technology community. ASME conducts one of the world's largest technical publishing operations, holds numerous technical conferences worldwide, and offers hundreds of professional development courses each year. ASME sets internationally recognized industrial and manufacturing codes and standards that enhance public safety.	http://www.asme.org/
CIDX	Chemical Industry Data Exchange	a non-profit organization dedicated to improving the ease, speed and cost of securely conducting business electronically in the Chemical Industry. CIDX is a membership-based organization serving the chemical industry, focused on the development of eBusiness standards, called Chem eStandards.	http://www.cidx.org/
FIATECH	Fully Integrated and	A consortium whose vision is a	http://www.fiatech.org/

Acronym	Organization Name	Scope of Development	Web url
	Automated Technology	future state where capital projects are executed in a highly automated and seamlessly integrated environment across all phases and processes of the capital project lifecycle.	
GEIA	Government Electronics and Information Technology Association	Promotes the interests of the U.S. electronics, communications and information technology industries with regard to government markets, requirements, and technical standards.	http://www.geia.org/
IEEE	Institute of Electrical and Electronics Engineers Inc.	The IEEE, a non-profit organization, is the world's leading professional association for the advancement of technology. IEEE has about 900 active IEEE standards and more than 400 in development.	http://www.ieee.org/portal/site
JT Open		JT Open is a community of software users and software vendors committed to the widespread adoption of a single, open and preferred 3D visualization platform based on JT technology. "JT" is Engineering Animation Inc's DirectModel (.jt) file format.	http://www.jtopen.com/
MIMOSA	Machinery Information Management Open Systems	A not-for-profit trade association dedicated to developing and	http://www.mimosa.org/

Acronym	Organization Name	Scope of Development	Web url
	Alliance	encouraging the adoption of open information standards for Operations and Maintenance in manufacturing, fleet, and facility environments. MIMOSA's open standards enable collaborative asset lifecycle management in both commercial and military applications.	
NEMA	National Electrical Manufacturing Association	A trade association in the U.S. representing the interests of electro industry manufacturers of products used in the generation, transmission and distribution, control, and end-use of electricity.	http://www.nema.org/
OAG	Open Applications Group	A not-for-profit open standards group building process-based XML standards for both B2B and A2A integration. The Open Applications Group was formed in late 1994 as the first post-EDI organization focusing on improving the state of application integration.	http://www.openapplications.org/
OASIS	Organization for the Advancement of Structured Information Standards	A not-for-profit, international consortium that drives the development, convergence, and adoption of e-business standards. Founded in 1993, OASIS has more than 3,500 participants representing over 600 organizations and	http://www.oasis-open.org/

Acronym	Organization Name	Scope of Development	Web url
		individual members in 100 countries.	
OMA	Open Mobile Alliance	An alliance to facilitate global user adoption of mobile data services by specifying market driven mobile service enablers that ensure service interoperability across devices, geographies, service providers, operators, and networks, while allowing businesses to compete through innovation and differentiation. Maintaining an open organization is key to OMA's vision for broad industry participation and adoption.Any interested party may join OMA and contribute to the technical specifications, and any entity (both members and non-members) may build applications and services in accordance with OMA's open specifications and interfaces under the same conditions.	http://www.openmobilealliance.org/
OMG	Object Management Group	Open, not-for-profit consortium that produces and maintains computer industry specifications for interoperable enterprise applications.	http://www.omg.org/
RosettaNet		A subsidiary of GS1 US (parent organization GS1 US™, formerly	http://www.rosettanet.org/

Acronym	Organization Name	Scope of Development	Web url
		the Uniform Code Council, Inc.®), is a non-profit organization dedicated to the collaborative development and rapid deployment of open, e-business process standards that align processes within global trading networks. RosettaNet standards and services provide a common language for e-business transactions and the foundation for integrating critical processes among partners within the global supply chain. Founded in 1998 in the heart of Silicon Valley, RosettaNet has affiliates in Europe, Asia, and Australia.	
STAR	Standards for Technology in Automotive Retail	A non-profit, auto industry-wide initiative to create voluntary IT standards for how manufacturers, dealers, and customers communicate with each other.	http://www.starstandards.org/
Supply Chain Council		A global, not-for-profit trade association open to all types of organizations. It sponsors and supports educational programs including conferences, retreats, benchmarking studies, and development of the Supply-Chain Operations Reference-model (SCOR), the process reference	http://www.supply-chain.org/

Acronym	Organization Name	Scope of Development	Web url
		model designed to improve users' efficiency and productivity.	
W3C	World Wide Web Consortium	An international consortium where Member organizations, a full-time staff, and the public work together to develop Web standards. W3C primarily pursues its mission through the creation of Web standards and guidelines.	http://www.w3.org

Appendix D: DOD policies, procedures, and guidelines on the use of national and international standards associated with defense product lifecycle management

In our recent research of Department of Defense and Army-specific memoranda, directives, instructions, military standards, and military specifications, we found a plethora of existing guidelines, policies, or procedures for encouraging the use of, requiring the use of, and hoping for the use of industry-developed standards. The memoranda, letters, and documents that follow provide a sampling of the Department of Defense and Army's commitment to use commercial standards, products, and services wherever possible. In addition to some of these overarching declarations of support below, there are several other documents that have influenced history and warrant mention, but are too voluminous to include more than a reference here:

These are:

- The DOD 5000 series found online: http://akss.dau.mil/dag/DoD5000.asp?view=framework
    - DoDD 5000.1, the Defense Acquisition Handbook
    - DoDI, 5000.2, Operation of the Defense Acquisition System
    - DoDI, 5000.2, Defense Acquisition Guidebook
- MIL-DTL-31000C, Detail Specification Technical Data Package
- DoD 4140.1-R, DoD Supply Chain Materiel Management Regulation

The rest of the documents included below are in historical order. This report would be remiss if it did not acknowledge the historical precedence set by Secretary Perry, in his June 29, 1994 memorandum, entitled, "Specification & Standards -- A New Way of Doing Business." His memorandum revolutionized the way the whole of Defense DoD thought about, and conducted, weapon system and service support. Secretary Perry's modification to the June 29th memorandum, and example follow-up tri-service policies and procedures continue to prescribe the spirit of the memorandum.

- William J. Perry, Secretary of Defense Memorandum, 29 June, 1994, "Specification & Standards -- A New Way of Doing Business"[19]
- Andrew D. Certo, Chief Standardization Program Division, 18 March 1997, "Guidance on Development and Adoption of Non-Government Standards (NGS)"
- Richard V. Reynolds, Joint Logistics Commanders, Joint Aeronautical Commanders' Group, 2 May 2002, "Strategy for Product Data Throughout the Life Cycle"
- Stenbit, John P., DoD/CIO, "The Department of Defense Architecture Framework (DoDAF), February 9 2004
- Defense Adoption Notice of MIMOSA OSA-EAI-2004, December 20, 2004.
- John J. Young, Jr., Assistant Secretary of the Navy, Research and Development and Acquisition, "DON Policy on Digital Product/Technical Data," October 23, 2004.
- Stevenson, Mitchell H., "Army Materiel Command (AMC) Logistics Modernization Program Data Implementation Policy, 4 April 2005.

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[19] This memorandum and several others were found at: http://www.amc.army.mil/amc/rda/milspec/policyguidance.html .

- Ronald J. Davis, Jr., Headquarters, US Army Materiel Command, “Army Standardization Improvement Policy, Memo 95-1 and 95-1 change 1, ‘Waivers for Use of Specifications and Standards’,” 19 April 2005
- Kenneth J. Krieg, Under Secretary of Defense for Acquisition, Technology and Logistics, Jun 23, 2005, “Standard for the Exchange of Product Model Data (STEP) – ISO 10303

THE SECRETARY OF DEFENSE
WASHINGTON, DC 20301-1000
29 Jun 94

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
CHAIRMAN OF THE JOINT CHIEFS OF STAFF
UNDER SECRETARIES OF DEFENSE
COMPTROLLER
ASSISTANT SECRETARY OF DEFENSE (COMMAND, CONTROL, COMMUNICATIONS, AND INTELLIGENCE)
GENERAL COUNSEL
INSPECTOR GENERAL
DIRECTOR OF OPERATIONAL TEST AND EVALUATION
DIRECTORS OF THE DEFENSE AGENCIES
COMMANDER-IN-CHIEF, U.S. SPECIAL OPERATIONS COMMAND

SUBJECT: Specifications & Standards - A New Way of Doing Business

To meet future needs, the Department of Defense must increase access to commercial state-of-the-art technology and must facilitate the adoption by its suppliers of business processes characteristic of world class suppliers. In addition, integration of commercial and military development and manufacturing facilitates the development of dual-use processes and products and contributes to an expanded industrial base that is capable of meeting defense needs at lower costs.

I have repeatedly stated that moving to greater use of performance and commercial specifications and standards is one of the most important actions that DoD must take to ensure we are able to meet our military, economic, and policy objectives in the future. Moreover, the Vice President's National Performance Review recommends that agencies avoid government-unique requirements and rely more on the commercial marketplace.

To accomplish this objective, the Deputy Under Secretary of Defense (Acquisition Reform) chartered a Process Action Team to develop a strategy and a specific plan of action to decrease reliance, to the maximum extent practicable, on military specifications and standards. The Process Action Team report, "Blueprint for Change," identifies the tasks necessary to achieve this objective. I wholeheartedly accept the Team's report and approve the report's primary recommendation to use performance and commercial specifications and standards in lieu of military specifications and standards, unless no practical alternative exists to meet the user's needs. I also accept the report of the Industry Review Panel on Specifications and Standards and direct the Under Secretary of Defense (Acquisition and Technology) to appropriately implement the Panel's recommendations.

I direct the addressees to take immediate action to implement the Team's recommendations and assign the Under Secretary of Defense (Acquisition and Technology) overall implementation responsibility. I direct the Under Secretary of Defense (Acquisition and Technology) to immediately arrange for reprogramming the funds needed in FY94 and FY95 to efficiently implement the recommendations. I direct the Secretaries of the

Military Departments and the Directors of the Defense Agencies to program funding for FY96 and beyond in accordance with the Defense Planning Guidance.

Policy Changes

Listed below are a number of the most critical changes to current policy that are needed to implement the Process Action Team's recommendations. These changes are effective immediately. However, it is not my intent to disrupt on-going solicitations or contract negotiations. Therefore, the Component Acquisition Executive (as defined in Part 15 of DoD Instruction 5000.2), or a designee, may waive the implementation of these changes for on-going solicitations or contracts during the next 180 days following the date of this memorandum. The Under Secretary of Defense (Acquisition and Technology) shall implement these policy changes in DoD Instruction 5000.2, the Defense Federal Acquisition Regulation Supplement (DFARS), and any other instructions, manuals, regulations, or policy documents, as appropriate.

Military Specifications and Standards: Performance specifications shall be used when purchasing new systems, major modifications, upgrades to current systems, and non-developmental and commercial items, for programs in any acquisition category. If it is not practicable to use a performance specification, a non-government standard shall be used. Since there will be cases when military specifications are needed to define an exact design solution because there is no acceptable non-governmental standard or because the use of a performance specification or non-government standard is not cost effective, the use of military specifications and standards is authorized as a last resort, with an appropriate waiver.

Waivers for the use of military specifications and standards must be approved by the Milestone Decision Authority (as defined in Part 2 of DoD Instruction 5000.2). In the case of acquisition category ID programs, waivers may be granted by the Component Acquisition Executive, or a designee. The Director, Naval Nuclear Propulsion shall determine the specifications and standards to be used for naval nuclear propulsion plants in accordance with Pub. L. 98-525 (42 U.S.C. §7158 note). Waivers for reprocurement of items already in the inventory are not required. Waivers may be made on a "class" or items basis for a period of time not to exceed two years.

Innovative Contract Management: The Under Secretary of Defense (Acquisition and Technology) shall develop, within 60 days of the date of this memorandum, Defense Federal Acquisition Regulation Supplement (DFARS) language to encourage contractors to propose non-government standards and industry-wide practices that meet the intent of the military specifications and standards. The Under Secretary will make this language effective 180 days after the date of this memorandum. This language will be developed for inclusion in both requests for proposal and in on-going contracts. These standards and practices shall be considered as alternatives to those military specifications and standards cited in all new contracts expected to have a value of $100,000 or more, and in existing contracts of $500,000 or more having a substantial contract effort remaining to be performed.

Pending completion of the language, I encourage the Secretaries of the Military

Departments and the Directors of the Defense Agencies to exercise their existing authority to use solicitation and contract clause language such as the language proposed in the Process Action Team's report. Government contracting officers shall expedite the processing of proposed alternatives to military specifications and standards and are encouraged to use the Value Engineering no-cost settlement method (permitted by FAR 48.104-3) in existing contracts.

Program Use of Specifications and Standards: Use of specifications and standards listed in DoD Instruction 5000.2 is not mandatory for Program Managers. These specifications and standards are tools available to the Program Manager, who shall view them as guidance, as stated in Section 6-Q of DoD Instruction 5000.2.

Tiering of Specification and Standards: During production, those system specifications, subsystem specifications and equipment/product specifications (through and including the first-tier reference in the equipment/product specifications) cited in the contract shall be mandatory for use. Lower tier references will be for guidance only, and will not be contractually binding unless they are directly cited in the contract. Specifications and standards listed on engineering drawings are to be considered as first-tier references. Approval of exceptions to this policy may only be made by the Head of the Departmental or Agency Standards Improvement Office and the Director, Naval Nuclear Propulsion for specifications and drawings used in nuclear propulsion plants in accordance with Pub. L. 98-525 (42 U.S.C. §7158 Note).

New Directions

Management and Manufacturing Specifications and Standards: Program Managers shall use management and manufacturing specifications and standards for guidance only. The Under Secretary of Defense (Acquisition and Technology) shall develop a plan for canceling these specifications and standards, inactivating them for new designs, transferring the specifications and standards to non-government standards, converting them to performance-based specifications, or justifying their retention as military specifications and standards. The plan shall begin with the ten management and manufacturing standards identified in the Report of the Industry Review Panel on Specifications and Standards and shall require completion of the appropriate action, to the maximum extent practicable, within two years.

Configuration Control: To the extent practicable, the Government should maintain configuration control of the functional and performance requirements only, giving-contractors responsibility for the detailed design.

Obsolete Specifications: The "Department of Defense Index of Specifications and Standards" and the "Acquisition Management System and Data Requirements Control List" contain outdated military specifications and standards and data requirements that should not be used for new development efforts. The Under Secretary of Defense (Acquisition and Technology) shall develop a procedure for identifying and removing these obsolete requirements.

Use of Non-Government Standards: I encourage the Under Secretary of Defense

(Acquisition and Technology) to form partnerships with industry associations to develop non-government standards for replacement of military standards where practicable. The Under Secretary shall adopt and list in the "Department of Defense Index of Specifications and Standards" (DoDISS) non-government standards currently being used by DoD. The Under Secretary shall also establish teams to review the federal supply classes and standardization areas to identify candidates for conversion or replacement.

Reducing Oversight: I direct the Secretaries of the Military Departments and the Directors of the Defense Agencies to reduce direct Government oversight by substituting process controls and non-government standards in place of development and/or production testing and inspection and military-unique quality assurance systems.

Cultural Changes

Challenge Acquisition Requirements: Program Managers and acquisition decision makers at all levels shall challenge requirements because the problem of unique military systems does not begin with the standards. The problem is rooted in the requirements determination phase of the acquisition cycle.

Enhance Pollution Controls: The Secretaries of the Military Departments and the Directors of the Defense Agencies shall establish and execute an aggressive program to identify and reduce or eliminate toxic pollutants procured or generated through the use of specifications and standards.

Education and Training: The Under Secretary of Defense (Acquisition and Technology) shall ensure that training and education programs throughout the Department are revised to incorporate specifications and standards reform.

Program Reviews: Milestone Decision Authority (MDA) review of programs at all levels shall include consideration of the extent streamlining, both in the contract and in the oversight process, is being pursued. The MDA (i.e., the Component Acquisition Executive or his/her designee, for all but ACAT 1D programs) will be responsible for ensuring that progress is being made with respect to programs under his/her cognizance.

Standards Improvement Executives: The Under Secretary the Secretaries of the Military Departments, and the Director of the Defense Logistics Agency shall appoint Standards Improvement Executives within 30 days. The Standards Improvement Executives shall assume the responsibilities of the current Standardization Executives, support those carrying out acquisition reform, direct implementation of the military specifications and standards reform program, and participate on the Defense Standards Improvement Council. The Defense Standards Improvement Council shall be the primary coordinating body for the specification and standards program within the Department of Defense and shall report directly to the Assistant Secretary of Defense (Economic Security). The Council shall coordinate with the Deputy Under Secretary of Defense (Acquisition Reform) regarding specification and standards reform matters, and shall provide periodic progress reports to the Acquisition Reform Senior Steering Group, who will monitor overall implementation progress.

Management Commitment

This Process Action Team tackled one of the most difficult issues we will face in reforming the acquisition process. I would like to commend the team, composed of representatives from all of the Military Departments and appropriate Defense Agencies, and its leader, Mr. Darold Griffin, for a job well done. In addition, I would like to thank the Army, and in particular, Army Materiel Command, for its administrative support of the team.

The Process Action Team's report and the policies contained in this memorandum are not a total solution to the problems inherent in the use of military specifications and standards; however, they are a solid beginning that will increase the use of performance and commercial specifications and standards. Your leadership and good judgment will be critical to successful implementation of this reform. I encourage you and your leadership teams to be active participants in establishing the environment essential for implementing this cultural change.

This memorandum is intended only to improve the internal management of the Department of Defense and does not create any right or benefit, substantive or procedural, enforceable at law or equity by a party against the Department of Defense or its officers and employees.

/signed/

William J. Perry

ACQUISITION AND TECHNOLOGY

MARCH 18 1997

OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON DC 20301-3000
OASD(IA&I)AP
Standardization Program Division
5203 Leesburg Pike, Suite 1403
Falls Church, Virginia 22041-3466

MEMORANDUM FOR DOD STANDARDIZATION MANAGEMENT ACTIVITIES

SUBJECT: **Guidance on Development and Adoption of Non-Government Standards (NGS)**

The heightened emphasis within the Department of Defense on the use of commercial items, practices, and processes, has resulted in extensive efforts to replace military and federal specifications and standards with NGS. Since our reform efforts began in June 1994, we have adopted an additional 1700 NGS, and have replaced or are in the process of replacing hundreds of military specifications and standards with these documents. We commend and encourage such efforts.

We must keep in mind, however, that our goal is not to develop and use NGS for the sake of avoiding government specifications and standards. Our goal is to increase our access to commercial products and practices, and NGS are one way to achieve that goal.

There is a very simple acid test for determining whether a government specification or standard is a good candidate to become a non-government standard. Will the resultant standard be used by the commercial sector? If the answer is yes, then it is a good candidate. If the answer is no, then the DoD still has many alternatives to non-government standards, including DoD performance specifications and commercial item descriptions. Any effort to develop a NGS that is not for a commercial product or does not specify a process or practice that truly will be used industry wide is discouraged. DoD should not participate in such efforts, nor should the NGS be adopted. In those instances where industry elects to develop a NGS for a canceled government document, the DoD must ensure a valid internal need exists for the NGS before a decision is made to adopt the document.

Some NGS developing organizations have offered to cover sheet existing government specifications and standards in order to shift document maintenance responsibility in a rapid manner. This is acceptable, and the NGS may be adopted, if all of the following conditions apply:

The government document is currently being used as the commercial industry standard. It is reformatted as a NGS with a new document identifier. Dual document identifiers which retain the military document number are not acceptable (e.g., NAS/MS 12345). However, it is acceptable for the NGS to retain the military Part Identification Number (PIN). It does not duplicate another NGS, which has already been adopted by the DoD.

One of the proposed schemes for cover-sheet adoption by a NGS organization would require DoD personnel to sign the cover sheet acknowledging the new ownership. Preparing activities should not sign such cover sheets. Also, while there is pressure to develop NGS rapidly as replacement documents, DoD personnel should not request NGS developing organizations to circumvent their due processes for establishing standards development efforts.

We hope you find this guidance useful, but if you require further clarification or an exception to this guidance, please contact your Departmental Standardization Office (DepSO).

//signed//
Andrew D. Certo
Chief Standardization Program Division
cc: DepSOs

JOINT LOGISTICS COMMANDERS
JOINT AERONAUTICAL COMMANDERS' GROUP
DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AERONAUTICAL SYSTEMS CENTER (AFMC)
1865 FOURTH STREET, ROOM 208
WRIGHT-PATTERSON AIR FORCE BASE OHIO 45433-7126

[illegible] MAY 200[illegible]

MEMORANDUM FOR THE AIR FORCE ACQUISITION EXECUTIVE
NAVY ACQUISITION EXECUTIVE
ARMY ACQUISITION EXECUTIVE

SUBJECT: Strategy for Product Data throughout the Life Cycle

1. Last year, we evaluated the benefits of standardizing on common product data exchange requirements. In particular, we were interested in standards that would allow engineering data developed under one automated design tool to be read and manipulated by design teams using different automated tools. We determined the existing ISO 10303 (STandard for Exchange of Product model data – STEP) met our military aeronautical requirements and that it was widely used by the commercial aerospace community. As a result, we have approved the use of STEP throughout our commands. Since STEP is a standard with many applications beyond aerospace (e.g., it is required in Navy shipbuilding), we encourage you to consider its use in other sectors.

2. Our implementation approach will be to use STEP in new aerospace system designs and major modifications to existing systems unless either the cognizant PEO or Systems Commander approves a waiver. The services have agreed and hence its use should be considered mandatory. Where a business case supports this, we are also encouraging the use of STEP for legacy systems.

3. The use of STEP will give us the greatest flexibility to take advantage of new computer design and support tools, but the real benefit to our services will be seen in reduced cost and cycle time, and in improved supportability. I would be pleased to arrange a briefing on STEP and our intended implementation, if you would like.

4. My point of contact for this subject is Mr. James Arnold, ASC/ENSM, DSN 785-9883, email: James.Arnold@wpafb.af.mil.

RICHARD V. REYNOLDS
Lieutenant General, USAF
JACG Chairman

Attachment:
ISO 10303 Point Paper

Defense Contract Mgmt Agency
6350 Walker Lane
Alexandria VA 22310

Naval Air Systems Command
47123 Buse Rd, Unit IPT, Suite 354
Patuxent River MD 20670-1547

Headquarters US Marine Corps
Dept of Aviation, 2 Navy Annex
Washington DC 20380-1775

Department of the Army
US Army Aviation & Missile Command
Redstone Arsenal AL 35898-5000

United States Coast Guard
USCG Headquarters
2100 Second St. SW
Washington DC 20593-0001

Defense Logistics Agency
Defense Supply Center - Richmond
8000 Jefferson Davis Highway
Richmond VA 23297-5100

National Aeronautics and
Space Administration
300 E Street S.W.
Washington DC [illegible]

Federal Aviation Administration
800 Independence Ave, SW
Washington DC 20591

OFFICE OF THE SECRETARY OF DEFENSE
WASHINGTON, DC 20301

FEB 9 2004

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
CHAIRMAN OF THE JOINT CHIEFS OF STAFF
UNDER SECRETARIES OF DEFENSE
COMBATANT COMMANDERS
ASSISTANT SECRETARIES OF DEFENSE
GENERAL COUNSEL OF THE DEPARTMENT OF DEFENSE
INSPECTOR GENERAL OF THE DEPARTMENT OF DEFENSE
DIRECTOR, OPERATIONAL TEST AND EVALUATION
DIRECTOR, ADMINISTRATION AND MANAGEMENT
DIRECTOR, PROGRAM ANALYSIS AND EVALUATION
DIRECTOR OF NET ASSESSMENT
DIRECTOR, FORCE TRANSFORMATION
DIRECTORS OF DEFENSE AGENCIES

SUBJECT: The Department of Defense Architecture Framework (DoDAF)

The DoD Architecture Framework (DoDAF) Version 1.0 is approved for immediate use. All architectures developed or approved subsequent to December 1, 2003, shall be in compliance with this framework. Architectures developed prior to this date shall be converted upon issuance of their next version update.

The DoDAF supersedes the C4ISR Architecture Framework, Version 2.0, dated December 18, 1997. The DoDAF and its key components described here apply to all architectures developed by and for the Office of Secretary of Defense (OSD), the Military Departments, the Chairman of the Joint Chiefs of Staff (CJCS), Combatant Commands, the Office of the Inspector General of the Department of Defense (DoD), the Defense Agencies, DoD Field Activities, and all other organizational entities within the DoD. DoDAF Version 1.0 is available at http:// www.defenselink.mil/nii.

Through several DoD Directives and related issuances, the DoD has established policy and procedures that direct the use of integrated architectures to support Capital Planning and Investment, Joint Capabilities Integration and Capabilities System (JCIDS), the Acquisition System, and interoperability between and among information technology (IT) and National Security Systems (NSS). In addition, the information Technology Management Reform Act (ITMRA)/Clinger Cohen Act (CCA) of 1996 mandates that the Chief Information Officer (CIO) of each Executive Agency is responsible for "developing, maintaining, and facilitating the implementation of a sound and integrated information technology for the executive agency."

The DoDAF Version 1.0 defines a common approach for DoD architecture description, development, presentation, and integration for both warfighting operations and business processes. The DoDAF is intended to ensure that architecture descriptions can be compared and related across organizational and mission area boundaries, including Joint multi-national boundaries and DoD warfighting and business domains. The DoDAF is based upon a common architecture data model, the Core Architecture Data Model (CADM), and instantiated in the DoD Architecture Repository System (DARS), which provides a common virtual space for DoD IT related architectures.

The established value of the Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) Architecture Framework is combined with both Federal and DoD policies to evolve the DoDAF. The Architecture Framework Working Group, composed of representatives of the Joint Staff, Military Services, and other DoD components, accomplished this evolution.

The DoDAF is partitioned into two volumes and a deskbook:

Volume I provides definitions, guidelines, and related background material.
Volume II describes each architecture product.
The Deskbook provides supplementary "how to" information relating to architectures.

John P Stenbit

John P. Stenbit
Department of Defense
Chief Information Officer

ADOPTION NOTICE

MIMOSA OSA-EAI-2004, MIMOSA Open Systems Architecture for Enterprise Application Integration (OSA-EAI) Standards, was adopted on 20 December 2004 for use by the Department of Defense (DoD). Proposed changes by DoD activities must be submitted to the DoD Adopting Activity: Department of the Army, Aviation and Missile Research, Development, and Engineering Center, Research, Development, and Engineering Command, Attn: AMSRD-AMR-SE-TD-ST-DM/ST, 5400 Fowler Road, Redstone Arsenal, AL 35898-5000. The private sector and other government agencies may obtain copies from http://www.mimosa.org.

Custodians:
Army – MI
Navy - AS
Marine – MC

Adopting Activity:
Army – AV

(Project IPSC-0085)

Review Activities:
Army – TM
Navy – CG, CH, EC, SA, TD

AMSC N/A

AREA: IPSC

DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

THE ASSISTANT SECRETARY OF THE NAVY
Research Development and Acquisition
1000 Navy Pentagon
Washington DC 20350-1000

OCT 2 3 2004

MEMORANDUM FOR DISTRIBUTION

Subj: DON POLICY ON DIGITAL PRODUCT/TECHNICAL DATA

Ref: (a) DEPSECDEF Memorandum, "Policy for the Transition to a Digital Environment for Acquisition Programs", 2 July 1999
(b) USD (A&T) Management Reform Memorandum #2, "Moving to a Paper-free Contracting Process by January 1, 2000", 21 May 97 w/Addendum, 29 July 1997
(c) USD (A&T) Memorandum, "Guidance for the Transition to a Digital Environment for Acquisition Programs", 15 July 1997
(d) USD A&T Memorandum, "Transition to a Digital Environment for Acquisition Programs (Paperless Program Office)", 15 April 1999
(e) SECNAVINST 5000.36, Department of the Navy Data Management and Interoperability, 1 November 2001
(f) GENADMIN/CNO Washington DC/032300ZAPR2001, "Implementing the Web Enabled Navy"
(g) Web-Enabled Navy Logistics Integration (WEN-L) Plan, June 2001
(h) NAVAIR ltr Ser AIR-3.3/005, "Digital File Formats Required for Technical Data Repository and Distribution Management", 1 May 2003
(i) DoD Directive 5230.24, Distribution Statements on Technical Documents, 18 March 1987
(j) SECNAVINST 5000.2B, "Implementation of Mandatory Procedures for Major and Non-major Defense Acquisition Programs and Major and Non-major Information Technology Acquisition Programs", 6 December 1996
(k) DOD Directive 5000.1, "The Defense Acquisition System", 12 May 2003
(l) DoD Memorandum on the DoD Information Technology Standards Registry (DISR), 15 July 2004; DoD CIO, USD AT&L, and JS
(m) Joint Aeronautical Commanders Group, Strategy for Product Data Throughout the Life Cycle, 8 May 2002
(n) DISA DIICOE, Version 3.1, Baseline Specifications, 29 April 1997
(o) Global Information Grid, Overarching Policy, DoD Directive 8100.1, 19 Sept 2002
(p) ASN RDA Memorandum on Summary of FORCEnet EXCOM, 19 February 2004, ASN RDA
(q) SECNAVINST 4105.1A, Independent Logistics Assessment (ILA) and Certification Requirements
(r) DON Independent Logistic Assessment Handbook, NAVSO P-3692, December 2003

This memorandum updates existing DoN Policy for Digital Product/Technical Data. New business practices relying on the use of digital methodologies and products have generated significant cost savings, reduced process cycle times and expanded capability for interoperability. References (a) through (d) set corporate goals for digital operations within the Department of Defense (DoD). Reference (e) defines the Department of the Navy (DoN) requirements for management, interoperability, authoritative sources and technical change authority of DoN data. Reference (f) established Task Force Web to implement Navy web enablement. Reference (g) describes the Navy's strategy for Web-Enabled Navy Logistics (WEN-L) for digital data. This memorandum better aligns current policy with references (e), (f) and (g) as well as with major command objectives in reference (h). These references express goals for an interoperable digital logistics product/technical data environment to improve warfighter support and reduce the life cycle system management cost of DoN systems.

To achieve the goals and benefits of digital operations and WEN-L, Program Executive Officers (PEOs), Direct Reporting Program Managers (DRPMs), Systems Command (SYSCOM) Commanders and Program Managers (PMs) shall establish an Integrated Digital Data Environment (IDDE) encompassing their entire organization. PEOs, DRPMs, SYSCOMs and PMs will procure all product/technical data in attachment (1) digital formats and ensure product model data meets ISO/STEP requirements specified in attachment (1). Procuring activities shall:

1. For contracts awarded after 1 January 2005, plan, procure and accept delivery of product/technical data only in digital formats specified by attachment (1). In cases where the acquisition strategy requires access only to technical data (such as Performance Based Logistics (PBL) contracts), procuring activities must ensure product/technical data is developed in accordance with attachment (1);

2. For contracts awarded prior to 1 January 2005 as well as existing contracts, establish and submit plans to ASN (RD&A) - (DASN Logistics) outlining timelines to modify contracts to require delivery of (or access to) digital data in accordance with attachment (1) formats. These plans shall be submitted by 31 December 2004, and address the timing of necessary contract modifications to ensure only digital data be delivered to the government after 31 December 2005. If initial planning and analysis indicate it would be cost prohibitive to modify existing contracts, a detailed BCA shall be conducted to document all costs associated with the decision. Should the BCA indicate it would not be cost effective to convert existing data, a waiver letter shall be prepared and forwarded to ASN (RD&A) - (DASN Logistics) for approval. The original BCA shall be retained by the program office;

3. For legacy data, prepare abbreviated BCAs to assess the cost effectiveness of converting existing hard copy data or data not in compliance with the digital formats specified in attachment (1). The results of the BCAs should be reported to ASN (RD&A) - (DASN Logistics) no later than 28 February 2005 and a copy of the

analysis retained by the Program Office. Programs having BCAs indicating conversion of legacy data would be cost effective should prepare and submit conversion schedules and plans no later than 31 December 2005.

4. Provide for appropriate protection of digital data and ensure that all product/technical data is properly marked (meta-data) for distribution in accordance with reference (i); and

5. Apply business and process analyses to IDDE digital improvements.

Attachment (1) provides specific guidance on the acquisition, conversion and access to digital product/technical data. This guidance enables the DoN to comply with paragraph 3.3.4.5 of reference (j) and paragraphs E1.10 and E1.13 of reference (k). Infrastructure, standards and tools will be compliant with the DoD Information Technology Standards Registry (DISR), reference (l) (formerly the DOD Joint Technical Architecture); the Joint Aeronautical Commanders Group Strategy for Product Data Throughout the Life Cycle, reference (m); when required, the Defense Information Infrastructure Common Operating Environment, reference (n); the DoD Global Information Grid, reference (o), and with the FORCEnet architecture and standards resulting from reference (p).

This policy does not prohibit the reproduction of digital data in hardcopy formats where needed to meet specific needs, as in the use of large schematics or foldout drawings. This policy also does not apply to the acquisition of proprietary data that is available only in hardcopy. (See Sections 5 and 7 of attachment (1))

For all Acquisition Category (ACAT) programs, compliance with this policy will be assessed prior to major milestone reviews and throughout the acquisition process as required by references (q) and (r).

This above policy is effective immediately and will be incorporated in subsequent revisions to SECNAVINST 5000.2 series.

Additional information or questions relating to this policy should be directed to my action officer within DASN Logistics, Mr. Chuck Silva, at (703) 697-4063 or e-mail charles.silva1@navy.mil.

John J. Young, Jr.
Assistant Secretary of the Navy
Research Development and Acquisition

Attachment:
1. Guidance on Acquisition & Conversion of Product/Technical Data to Digital Form, Rev 1

Subj: DON POLICY ON DIGITAL LOGISTICS PRODUCT/TECHNICAL DATA

DISTRIBUTION:

SNDL	A1J	ASSTSECNAV RDA WASHINGTON DC
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	A6	CMC WASHINGTON DC (MC-L, LPS-1, only)
	A2A	DON CIO WASHINGTON DC
	Director Navy Staff	
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	PEO (Joint Strike Fighter)	
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	21A1	COMLANTFLT
	21A2	COMPACFLT
	21A3	COMEURFLT

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	FKP4	COMNAVSURFWARCEN WASHINGTON DC (less FKP4A, FKP4E)
	C80	COMNAVAIRWARCENAD PATUXENT RIVER MA
	FKP4E	NAVSURFWARCEN WASHINGTON DC
	FA2	COMNAVNETWARCOM NORFOLK VA

GUIDANCE ON ACQUISITION AND CONVERSION OF PRODUCT / TECHNICAL DATA TO DIGITAL FORM

(Revision 1)

POC:

Joseph Garner

GarnerFJ@nswccd.navy.mil

Naval Surface Warfare Center, Carderock Division

Issued By: **Office of Deputy Chief of Naval Operations for Fleet Readiness and Logistics Logistics Planning and Innovation Division (N40)**

POC: Quentin Hays, N401F, quentin.hays@navy.mil
Matt Weden, N401H, matt.weden@navy.mil

Attachment (1)

Table of Contents

PREFACE

This document is a revision to the document first published in November 1999. The revisions reflect both the evolution of the Department of Navy planned uses and architectures for product and technical data, as well as, the evolution and maturation of the digital data format specifications and standards and related software implementation tools. The principal revisions are:

- Increased emphasis on Extensible Markup Language (XML) as the markup language of choice for technical publications
- Increased emphasis on Web CGM as format for 2D vector data
- Inclusion of Scalable Vector Graphics (SVG) as a choice for 2D vector data
- Stronger endorsement of the Adobe Systems' Portable Data Format (PDF) as an economical conversion format
- Updates to references and web-sites

This guidance was developed by the Technical Information Systems Department, Code 205, at the Naval Surface Warfare Center, Carderock Division, in Bethesda, MD, working in support of the Logistics Planning and Innovation Division (N40) of the Office of Deputy Chief of Naval Operations for Fleet Readiness and Logistics (N4/N4B). Implementation assistance may be obtained from NSWC Carderock Division through contacts listed on **http://navycals.dt.navy.mil**.

Acknowledgements

This guidance document is the work of the following technical data experts at the Technical Information Systems Division of the Naval Surface Warfare Center, Carderock Division: Joseph Garner, Donald Gignac, Eric Jorgensen, John Junod, Lori Westbrook, and Harry Whittaker who are grateful to many Navy technical data developers, managers, and users for their advice and comments.

1. INTRODUCTION

This document provides Department of the Navy (DON) programs and activities specific guidance on how to specify digital data formats for both the acquisition of new technical data and also the conversion of legacy data to digital forms that support the migration toward an integrated digital data environment (IDDE). The digital data formats set forth below apply to any data developed by programs or activities that must be distributed or used outside of the program or activity or used within the DON infrastructure programs and systems. The guidance considers both existing technologies and existing data standards and specifications for identifying the desired digital formats. These acquisition and conversion efforts and these digital formats support the goal of the DON's digital data policy to achieve an integrated digital data environment for product and technical data and support the DON strategy to exploit World Wide Web (WWW) and Internet technology to access, distribute, and use this data. The data standards referenced are the best available for the data types identified and comply and agree with the DON Information Technology Standards Guidance. Where applicable, international and national standards are preferred over military standards in line with DoD 4120.24-M, "DoD Standardization Program (DSP) Policies and Procedures" (3/9/2000) and to achieve interoperability among Services and allies in joint operations. The latest versions of all standards are to be assumed unless otherwise specifically identified within the guidance. As the standards and related digital technologies mature, and as DON requirements and strategies evolve, this guidance will change, clarify, and expand.

This guidance document focuses on product and technical data that takes the form of engineering data, schematics, drawings, and technical manuals because digital formats for these forms are supported by published commercial and Government performance standards and common DON conventions and practices. These standards-based digital forms for product and technical data provide the foundation for interoperability that will be required to achieve the sharing and integration of technical and training data discussed in Section 6. Many other components of acquisition and life cycle support data, such as provisioning, configuration management, software/firmware and supply support, are not addressed because neither suitable standards nor DON consensus exist on the treatment of these forms of digital data. When the DON agrees on these standards and conventions, they will be incorporated within this document.

This guidance to help program managers make informed decisions in the acquisition of this digital data is provided by the Naval Surface Warfare Center Carderock Division in conjunction with the Navy Logistics Planning and Innovation Office (N40), (**http://navycals.dt.navy.mil/calsdata/**). New programs are encouraged to develop a Digital Data Concept of Operations as part of the acquisition process (for assistance, consult Integrated Digital Data Concept of Operations GENORATOR (**http://ric.crane.navy.mil/toolimpl.htm**)). This concept of operations should address the configuration status accounting of the data, the types of digital data to be acquired, and how it is to be stored, managed, distributed, used, viewed within the DON community and its associated information technology infrastructure. Program managers must specify all data acquisition and conversion efforts will obtain data in formats that will operate effectively in all user environments, such as, for example, on the Navy Marine Corps Intranet.

The data formats and conventions to be used for the digital product and technical data covered by this guidance are summarized in the sections below. For quick reference, the formats and data standards recommended within this document are summarized in tables contained in Appendix A. Appendix B is a guide to World Wide Web (WWW) resources providing additional information for implementation of digital technical data.

2. ACCESS CONTROL FOR DIGITAL DOCUMENTS

All documents, whether created digitally or subsequently digitized from paper or aperture cards, must be properly marked for access control, including as applicable: the document's security classification, export control status, no-foreign-access status, distribution statement, and data rights limitations. Security and access control requirements and procedures apply to digital data just as they do to paper or other hard copy documents. Digital technologies and formats for encryption and secure transfer of data will be addressed in future versions of this guidance document when DON agrees upon suitable standards and conventions. The formats and conventions identified in this Guidance have been selected to guarantee that the digital data is created, received, maintained, and distributed in common, neutral formats that will allow DON to minimize and simplify DON corporate investments in managing, viewing, and application software.

3. SPECIFICATIONS FOR DRAWINGS AND ENGINEERING DATA

This section deals with formats for two and three-dimensional engineering product data including models, drawings, schematics, and illustrations and also geospatial data deliverables for installations and facilities. Included are Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), and Computer Aided Engineering (CAE) product data for weapon systems and platforms as well as architecture, engineering, and construction data for facilities.

For all cases, the format selected for digital drawing and engineering data should be based on its intended use, how and where it is to be stored and accessed, and the media by which the data is delivered.

3.1 Product Data and CAD Data

Product data, engineering design and manufacturing data (CAD/CAM/CAE), 3-D vector data, and product model data should be delivered in a data definition format for neutral file exchange in accordance with the **Standard for the Exchange of Product Model Data STEP (ISO 10303)**.

STEP should be used for product and CAD data in those areas for which a STEP application protocol (AP) is defined.

Current approved APs that are recommended for use are:

AP202: Associative draughting (ISO 10303-202:1996): Supports exchange of computer-interpretable drawing information and associated 2 and 3-D product geometry and definition data.

AP203: Configuration controlled 3D designs of mechanical parts and assemblies (ISO 10303-203:1994): Defines exchange of configuration controlled-design information and 3D geometrically bounded wireframe and/or surface models exchange.

AP207: Sheet metal die planning and design (ISO 10303-207:1999): Supports exchange of information to enable the manufacturing/stamping of sheet metal parts using dies.

AP209: Composite and metallic structural analysis and related design (ISO 10303-209:2001): Enables exchange of composite and metallic structural product definition including their shape, their associated finite element analysis (FEA) model and analysis results, and material properties.

AP210: Electronic assembly, interconnect and packaging design (ISO 10303-210:2001): Specifies the information requirements for exchange of the design of electrical printed circuit assemblies.

AP212: Electrotechnical design and installation (ISO 10303-212:2001): Specifies information requirements for the exchange of design information of electrotechnical plant, industrial, and ship systems.

AP214: Core data for automotive mechanical design processes (ISO 10303-214:2001): Provides exchange of information between various applications, which support the development process of a vehicle.

AP215: Ship arrangement (ISO 10303-215:2004): Describes exchange of three-dimensional product definition data and its configuration status information for Naval and commercial ship arrangements.

AP216: Ship moulded forms (ISO 10303-216:2003): Provides for exchange of ship moulded form definitions, geometric representations, and related hydrostatic properties.

AP218: Ship structures (ISO 10303-218:2004): Specifies the use of the integrated resources necessary for the scope and information requirements for the exchange of product definition data and its configuration and approval status information for ship structural systems such as plates, stiffeners, and welding.

AP224: Mechanical product definition for process planning using machining features (ISO 10303-224:2001): Specifies the information needed to exchange product data necessary for manufacturing single mechanical parts and assemblies.

AP225: Building elements using explicit shape representation (ISO 10303-225:1999): Supports exchange of building element shape, property, and spatial arrangement information requirements for buildings.

AP227: Plant spatial configuration (ISO 10303-227:2001): Specifies the use of the integrated resources necessary for the exchange of spatial configuration and manufacturing information of process plant and ship piping. The next edition will support HVAC, mechanical systems, and cable trays.

AP232: Technical data packaging core information and exchange (ISO 10303-232:2002): Enables exchange of product information so that configuration controlled exchanges can be achieved among Product Data Management (PDM) systems.

AP232 supports bundling of multiple STEP files and formats and any other documents and formats agreed to by the exchange partners.

Information about the STEP standard, what application protocols exist, and their status may be obtained from the "STEP on a Page" web site maintained by the National Institutes of Standards and Technology (NIST) at http://www.mel.nist.gov/sc5/soap/. The Shipbuilding Team (T 23) within the STEP standard work group (TC 184/SC 4/WG 3) of ISO is maintaining and developing STEP APs for shipbuilding. Information on ship APs may be obtained from the T 23 web site (http://www.usashipbuilding.com/niddesc/t23.html).

3.2 Computer Aided Drafting and Design (CADD) Data for Naval Facilities and Installations

CADD drawings used for the planning, design, construction, operations, maintenance, and demolition of Department of the Navy facilities and installations should be delivered in conformance with the US National CAD Standard. The American Institute of Architects, the Construction Specification Institute (CSI), and the CADD/GIS Technology Center developed this standard under the auspices of the National Institute of Building Sciences (NIBS) for Facilities, Infrastructure and Environment (hereinafter referred to as CADD/GIS Technology Center) with support from the United States Coast Guard. The standard can be ordered on-line from http://www.nationalcadstandard.org. Drawings should be prepared for bid solicitation in accordance with the NAVFAC Electronic Design Deliverable Manual of Policies and Procedures, http://www.efdlant.navfac.navy.mil/downl/lantops_04/ebs/LantDiv_EBS_Manual.pdf.

3.3 Digital Geospatial Data Deliverables for Naval Installations

Digital geospatial data used for the planning and management of DON facilities, land and associated environmental planning and management purposes shall be acquired and managed in conformance with the latest version of the following standards and policies:

- ***Spatial Data Standards for Facilities, Infrastructure, and Environment (SDSFIE)*** (previously named ***Tri-Service Spatial Data Standards)***, ANSI/NCIT Standard 353, developed by the CADD/GIS Technology Center, http://tsc.wes.army.mil/products/TSSDS-TSFMS/tssds/html/. The standards are harmonized with and extend the Federal Geographic Data Committee (FGDC) standards at http://www.fgdc.gov required by Executive Order 12906 of 11 April 1994, "Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure".

- ***FGDC Content Standard for Digital Geospatial Metadata*** (CSDGM). This FGDC metadata standard shall be used to document Navy facilities, land and associated environmental planning and management geospatial data. The metadata shall be made electronically accessible to the National Spatial Data Clearinghouse (http://www fgdc.gov/clearinghouse/clearinghouse.html) by submission to the CADD/GIS Technology Center node (http://tsc.wes.army.mil/products/metadata/) of the Clearinghouse.

- ***NAVFAC Guidelines for Installation Mapping and Geospatial Data*** (http://www.foundationknowledge.com). This guideline, which is a companion document to the CADD/GIS Technology Center's ***Guidelines for Installation Mapping and Geospatial Data*** (http://tsc.wes.army.mil/downloadtracking/DownloadData.asp?PID=107), shall be used for acquiring facilities, installation, and environmental mapping and geospatial data.

3.4 2-D Drawings, Illustrations, and Schematics

Two dimensional drawings, illustrations, and schematics, not intended for Computer Aided Design (CAD) applications, may be delivered in several different formats. The choice of recommended format should be governed by the nature of the image, the intended use of the image, the software tools used to create the image, and the hardware and software available to users for viewing the image. Two-dimensional drawings, illustrations and schematics intended for static (vice animated) image presentations are usually delivered in either a raster (bit-map) or vector format. The raster formats are recommended for the simple capture of existing drawings not already in an acceptable vector format and also half-tone images, and photographs. Vector formats are preferred for all new 2-D drawings, schematics, and illustrations to be delivered to the Government. Acceptable raster and vector formats and their relative advantages are discussed in the following sections. Images required for use in CAD environments should be delivered in engineering CAD formats.

3.4.1 2-D Raster Image Formats

Acceptable raster image formats include commonly used commercial standards (TIFF, BMP, JPEG, and PNG) and two military formats (Types 1 and 4 in MIL-PRF-28002). Each is best suited for different types of images and image presentation effects. Raster formats, in general, are best suited for static images with no requirement for navigation (hot-spotting, hyper-linking) within the image, and no need to attach metadata or added information to text or graphic elements within the image.

3.4.1.1 Commercial Raster Formats

There are four commonly used and acceptable raster formats:

- **TIFF** (Tiled Image File Format) is a commonly supported industry standard format for the representation and compression of bit-map renditions of images. TIFF is best suited for black and white images. (**http://partners.adobe.com/asn/developer/pdfs/tn/TIFF6.pdf**)

- **BMP** (Bit Map Picture) (**http://www.dcs.ed.ac.uk/home/mxr/gfx/2d/BMP.txt**) is a commonly supported raster format, often used in place of TIFF, and most suitable for monochrome images. Both TIFF and BMP provide high image fidelity (i.e., very accurate rendition of the original image consistent with the precision allowed by the selected scan density, or "dots per inch", of the conversion process).

- **JPEG** (Joint Photographic Experts Group) (**http://www.jpeg.org/**) is an international standard for color image (and halftone photograph) sampling and compression. JPEG allows selectable compression ratios that achieve smaller files sizes at the expense of image fidelity (a so-called "lossy" compression of the image). JPEG is a good choice for photographic images and is suitable for applications requiring conveyance of only a visual image.

- **PNG** (Portable Network Graphics) (**http://www.w3.org/Graphics/PNG/**) is a royalty-free replacement to the royalty-required Graphic Interchange File (GIF) format. It was also designed to replace TIFF. Unlike BMP, it can handle both grayscale and color images. Unlike JPEG, it has a lossless compression. However, PNG should not be used for photographic images where JPEG is superior for that application. Web Browsers natively support PNG (**http://www.libpng.org/pub/png/pngstatus.html#browsers**).

3.4.1.2 Military Raster Formats

MIL-PRF-28002C, Raster Graphics Representation in Binary Format, 30 September 1997, specifies two acceptable raster formats. The preferred raster formats in MIL-PRF-28002 are either the Joint Engineering Data Management Information and Control System **(JEDMICS) C4 (CALS Type 4)** compressed image format, or the **CCITT Group 4 (CALS Type 1)** compressed format specified therein. DON acquisition and conversion efforts should not use the ODA/ODIF format (CALS Type 2) included within MIL-PRF-28002. The C4 format is recommended for engineering drawings to be easily accommodated within JEDMICS.

3.4.2 2-D Vector Images Not Intended for CAD

Vector formats are preferred for all new 2-D drawings, schematics, and illustrations delivered to the Government. The preferred vector formats for products that are not intended for computer-aided design (CAD) applications are the Computer Graphic Metafile (**CGM**) and Scalable Vector Graphics (**SVG**). Each of these formats is based on international and World Wide Web standards. Each has advantages depending on the type of image desired and the current and future functionality intended, or anticipated, for, and within, the images. CGM is ideal for static vector images and provides options for including hot spotting, linking and other WWW navigation functionality within the image itself. SVG is better suited for animation than is CGM. SVG also supports image-filtering (e.g., flashing, blurring, lighting, etc.) effects for the World Wide Web and has an XML-encoded format. The merits of these two formats are further discussed in the following two sections. Programs and activities should pay careful attention to the degrees of functionality available in each and to the impact on user viewing environments. Programs should also consider whether or not the data will be viewed over the web or on an NMCI machine.

3.4.2.1 CGM for Vector Graphics

Vector graphic images for 2-D drawings, schematics, and illustrations should be delivered to the Government in CGM in accordance with the international specification, ISO/IEC 8632, and either the implementation profile specified by **WebCGM** recommendation, REC-WebCGM-19990121, or the profile specified in MIL-PRF-28003.

3.4.2.1.1 WebCGM

WebCGM, published by the World Wide Web Consortium (W3C), (http://www.w3.org/Graphics/WebCGM) is a CGM implementation profile designed to support interoperability of CGM, Version 4 applications in web presentation and viewing environments. WebCGM will support WWW navigation, hot spotting, and hyper-linking among graphic components and text elements. WebCGM has been developed by CGM Open (www.cgmopen.org) and through the collaboration of the major CGM software tool developers. These tool developers support WebCGM in their newer product releases. WebCGM also supports Versions 1, 2, 3 of CGM and, at that level, is compatible with the profiles specified for these in MIL-PRF-28003 CGM.

3.4.2.1.2 MIL-PRF-28003 (CGM)

The military specification, MIL-PRF-28003, defines an implementation profile for Versions 1, 2, and 3 of CGM and also cites the WebCGM profile. Versions 1, 2, and 3 of CGM define progressively larger sets of graphic primitives with which to build progressively more complex vector graphic images. The CGM Versions 1, 2, and 3 do not support navigation and hyper-linking within the CGM image; however, MIL-PRF-28003 images can be presented and viewed on the WWW with appropriate CGM viewer tools.

3.4.2.2 SVG for Vector Graphics

Vector graphics requiring animation, gradients, or XML as the foundation should use SVG in accordance with Recommendation 1.0 of the World Wide Web Consortium (W3C) (**http://www.w3.org/TR/2001/REC-SVG-20010904/**). SVG is presently supported by a number of implementations (**http://www.w3.org/Graphics/SVG/SVG-Implementations.htm8**). A test suite is available (**http://www.w3.org/Graphics/SVG/Test/**). SVG has both native and Document Object Model (DOM) controlled animation features as described in Chapter 19 of the recommendation (**http://www.w3.org/TR/SVG/animate.html**). In addition, an "event model" has been defined for SVG providing functionality based on user interaction (**http://www.w3.org/TR/SVG/interact.html#SVGEvents**).

3.4.2.3 Factors Governing the Selection of CGM/WebCGM and Scalable Vector Graphics (SVG)

SVG and CGM (WebCGM in particular) are similar formats. CGM is a well established; stable standard supported by a mature set of software implementation tools. The set of tools supporting SVG is not as well established at this time. SVG is fully encoded in XML and some SVG advocates see this as a potential advantage as it will allow XML concepts or tools, such as XSLT (Extensible Stylesheet Language Transformations), to be applied to SVG images to achieve special transformation and visual effects. However, CGM images can be embedded within XML files or documents and displayed in XML applications. Each format requires special plug-in software to be viewed with web browsers. There is no compelling reason for programs with existing investment in CGM/WebCGM data to change to SVG. Both SVG and CGM/WebCGM data can reside in the same data base management system (DBMS). The size of the existing CGM/WebCGM repository investments in authoring and publishing tools may justify continued acquisition of CGM/WebCGM graphics. Furthermore, CGM/WebCGM can be transformed into SVG with relative ease and newer CGM/WebCGM tools can create SVG from CGM/WebCGM on the fly for delivery to the web.

3.4.3 2-D Images Intended for CAD

Two dimensional drawings, illustrations, and schematics, intended for CAD applications, should be delivered in accordance with **STandard for the Exchange of Product model data (STEP), ISO 10303, AP 201:1994 (Explicit Draughting) or AP 202:1996 (Associative Draughting)** format. If the visual accuracy of the image is critical then the vector form should be accompanied by a raster representation of the image in a format discussed in 3.4.1.

3.4.4 Indexing 2-D Drawings, Illustrations, and Schematics

Users must deliver all 2-D and 3-D drawings and illustrations with complete and accurate indexing data. Indexing data are identifiers and attributes that allow the receiver of the images to associate each with complete documents, and to associate documents with one another and with the correct material items. The 2-D images should be delivered as required by the JEDMICS Compact Disk Engineering Data Exchange (preferred) or as designated by MIL-STD-1840C.

3.4.5 3-D Vector Images Not Intended for CAD

Three dimensional drawings, illustrations, and schematics, not intended for CAD applications, should be delivered in digital 3-D vector format in accordance with the Virtual Reality Modeling Language (VRML97), ISO/IEC 14772-1:1997 (www.web3d.org). X3D is a developing specification within the international standards community that is generally expected to replace VMRL. X3D has reached Final Committee Draft status within ISO. Government programs should wait for X3D to achieve final publication status before citing it on contracts.

3.5 Electronic Motion Pictures

The recommended international standards for digital audio and video images are those developed by the Motion Picture Experts Group (MPEG) of the International Standards Organization (ISO/IEC/JTC1/SC29/WG11) (http://mpeg.telecomitalialab.com). These standards are:

- MPEG-1 (ISO/IEC-11172) for coding of motion pictures and associated audio for digital storage media at up to about 1.5 Mbits/sec.; for such products as video CDs
- MPEG-2 (ISO/IEC-13818) for generic coding of moving pictures and associated audio information; for such products as digital TV and DVD
- MPEG-4 (ISO/IEC-14496) for multimedia for user interaction and web applications.

3.6 Conversion of Legacy Drawings to Digital Format

Conversion of legacy data to digital involves careful business decisions regarding what to convert and what format the conversion should deliver:

- Conversion of drawings or graphics to vector formats is more expensive than conversion to bitmap or raster data but the vector data can be more versatile and easier to update.

- The legacy graphics themselves should be carefully assessed as to their importance, continuing usefulness with respect to product life cycle and maintenance, and anticipated frequency of use and modification before deciding on a target format for the conversion.

- Drawings that will require frequent modifications are best candidates for vector conversion because the vector formats are easier to modify.

- The conversion to raster is generally cheaper but provides a bitmap image of the original that is not easy to modify.

- The conversion to vector, however, can result in digital image files that are larger than those produced by raster conversion and just as difficult to manipulate, unless human intervention is included in the conversion process to improve the vector images. The human intervention desirable in vector conversion can achieve efficiency in file sizes and subsequent ability to manipulate the images, but does so at the expense of higher conversion costs.

3.6.1 Conversion Formats for Legacy Drawings

Existing (legacy) hard copy paper and aperture card drawings, illustrations, and schematics should be converted to 1) a raster format in accordance with MIL-PRF-28002, TIFF, BMP, JPEG or PNG or 2) a vector format CGM per MIL-PRF-28003 (which includes WebCGM) or SVG. The preferred raster formats in MIL-PRF-28002 are either the Joint Engineering Data Management Information and Control System (JEDMICS) C4 (CALS Type 4) compressed image format, or the Navy Image File Format (NIFF) (CALS Type 3) compressed image format, or the CCITT Group 4 (CALS Type 1) compressed format specified therein. DON acquisition and conversion efforts should not use the ODA/ODIF format (CALS Type 2) included within MIL-PRF-28002. The C4 format is recommended for engineering drawings to be easily accommodated within JEDMICS. TM illustrations and schematics should be converted to a format compatible with the intended use.

4. SPECIFICATIONS FOR TECHNICAL MANUALS/DOCUMENTS

Technical manuals are to be acquired, authored and developed in either the Standard Generalized Markup Language (SGML) or the Extensible Markup Language (XML) as described in Section 4.1. Legacy hard copy technical manuals may be converted to SGML or XML, or Portable Document Format (PDF) or raster formats, where document use and content do not warrant the added expense of conversion to SGML/XML. The DON CIO has published the "DON Policy on the Use of Extensible Markup Language (XML) of December 2002" dated 13 December 2002 and the "Department of the Navy XML Developers Guide, Version 1.1" dated 1 May 2002 to promote interoperability in the exchange of data. Specific guidance for the XML Technical Manual developer is being written to accompany the DON XML Developer's Guide. The DON CIO guidance for XML in TMs is not expected to conflict with this technical data guidance. TM developers are encouraged to follow the guidance presented below and also to monitor the progress of the DON CIO XML guidance for technical publications. This guidance will be updated if necessary when the DON CIO guidance is completed.

4.1 New Technical Manuals

All new technical manuals should be acquired and authored in digital form in XML in accordance with the W3C Recommendation, "Extensible Markup Language (XML) 1.0 (Third Edition)." For the special exceptions identified below, new technical manuals may be acquired in the Standard Generalized Markup Language (SGML) in accordance with MIL-PRF-28001. The selection of XML or SGML is discussed in the following section. U. S. Marine Corps acquisitions should follow specific USMC guidance contained in Section 4.1.7.

4.1.1 Factors Governing Selection of XML or SGML

XML was conceived within the World Wide Web community as both a simplification and enhancement of SGML that would more easily provide the markup language functionality of SGML on the World Wide Web. In the past two years, XML has matured rapidly since its publication as a W3C Recommendation. The XML specification has been formally published, a wide range of software tools is commercially available, and XML has become the industry-preferred format for WWW applications. The strength of the XML technology and current DON plans and strategies for web-enabling applications and data (*Web-Enabling Navy Logistics, Implementation Plan*, June 2001) make XML the preferred format for new technical manual (TM) acquisitions.

Programs and activities with no existing digital data in the SGML format should acquire and author new technical manuals in XML in accordance with the W3C Recommendation, "Extensible Markup Language (XML) 1.0 (Third Edition)" as described below in Section 4.1.1.1.

Programs with existing investment in SGML data need not migrate to XML immediately as it may not be cost-effective for them. The amount of the existing SGML data, the need to use an SGML DTD (Document Type Definition), and the investments in DTDs, style sheets, and publishing tools are valid reasons for continuing acquisition of SGML TMs. Since SGML and XML are quite similar it is relatively easy to transform SGML into XML for rendition on the web. This reduces the risk of SGML-based programs from being excluded from the preferred DON web-based data environment. It should also be noted that XML and SGML data can reside in the same SGML/XML data base management system (DBMS), and most SGML/XML DBMSs can create XML from SGML on the fly for delivery to the web. Programs who need to continue acquisition of TMs in SGML should follow guidance set forth in Section 4.1.1.2.

4.1.1.1 XML for New Manuals

Programs and activities, that have no business case to remain in an SGML environment, should author and acquire new technical manuals (TMs), Electronic Technical Manuals (ETMs), and Interactive Electronic Technical Manuals (IETMs) in XML format in accordance with the W3C Recommendation, "Extensible Markup Language (XML) 1.0 (Third Edition)". XML is a subset of SGML designed to facilitate the use of SGML on the WWW. XML accommodates a wide variety of Web applications and can greatly enhance user interaction.

4.1.1.1.1 XML DTDs for New Manuals

At present, most XML technical manual applications use a DTD, an XML/SGML data construct defining the structure and content of the type of document to be created. Some DTDs are complex and costly to develop, but may be created to satisfy a broad range of documents. Program and acquisition managers should require the deliverables described in Sec 4.1.2 for XML TMs.

4.1.1.1.2 XML Schemas for New Manuals

XML literature often refers to XML Schemas. A Schema is an XML construct to describe data content. XML Schemas have a very strong data typing capability that makes XML Schemas ideally suited for describing data transactions and interchanges between information processing systems. Most XML Schema applications, to date, have been for electronic business transactions. Software tools and application software support for TM Schemas have yet to mature to a satisfactory level. Therefore, new XML TMs should be authored and acquired in accordance with an XML DTD with deliverables described in Section 4.1.2. When XML Schemas are fully implemented and adequately supported with application software for technical manuals, this guidance will be reviewed and modified as required. XML Schemas are defined in the following three W3C Recommendations: "XML Schema Part 0: Primer" dated 2 May 2001 (**http://www.w3.org/TR/xmlschema-0/**); "XML Schema Part 1: Structures" dated 2 May 2001(**http://www.w3.org/TR/xmlschema-1/**); and "XML Schema Part 2: Datatypes" dated 2 May 2001 (**http://www.w3.org/TR/xmlschema-2/**).

4.1.1.1.3 Conclusion

XML Documents and DTDs must conform to the W3C Recommendation, "Extensible Markup Language (XML) 1.0 (Third Edition)". Authors and contractors should be encouraged to use existing DTDs and style sheets for all TMs/ETMs/IETMs. DON DTDs and style sheets are currently stored in the Navy XML/SGML Repository (**http://navycals.dt.navy.mil/dtdfosi/repository.html**).

4.1.1.2 SGML for New Manuals

Programs and activities with pre-existing SGML repositories, databases, and management and distribution infrastructures, for which XML is not yet feasible, should author and acquire new TMs, ETMs, and IETMS in SGML format in accordance with MIL-PRF-28001. MIL-PRF-28001 is the DoD performance specification defining the DoD requirements (military interpretation or profile) for the application of the International Standard for SGML, ISO 8879, *Information Processing - Text and Office Systems - Standard Generalized Markup Language (SGML).* Proper creation of a document in SGML requires a DTD, an XML/SGML data construct defining the structure and content of the type of document to be created. DTDs may be complex and costly to develop but may be created to satisfy a broad range of documents. Authors and contractors should be encouraged to use existing DTDs and style sheets for all TMs/ETMs/IETMs. DON DTDs and style sheets are currently stored in the Navy XML/SGML Repository (**http://navycals.dt.navy.mil/dtdfosi/repository.html**).

4.1.2 Deliverables for New Technical Manuals

TM/ETM/IETM delivery to the Government should consist of the following:

- XML/SGML source file(s)
- Graphic source files
- Associated DTD (whether new or existing)
- Entity files
- DTD Data Dictionary
- Tagging Conventions Document
- Any associated style sheets and filters,

All of the above are necessary to manage, maintain, edit, and re-author the documents. Delivery must also include the style sheets and filters necessary to produce the desired presentation to users. The XML/SGML source file consists of the TM text with the embedded XML/SGML tags. This file is what will be stored and maintained in a repository or database at the document management activity. Entity files are files associated with the source file that may be created and referenced by the DTD. Some entity files are created when there is standard text in the document that will be used or shared among instances of a class of documents. Other entity files, such as those provided in the ISO character entity sets, are used to provide special characters (e.g. the degree symbol and mathematical symbols) in the documents. The contents of the entity files are available to any document using the associated DTD. The DTD Data Dictionary defines the meaning of XML/SGML tags used within the DTD. The Tagging Conventions document describes the rules for applying each XML/SGML tag to actual data or document content. It is meant to be a practical guide to authors in applying the markup to real document content and to describe the preferred way to markup (tag) the document in accordance with the DTD. The Tagging Conventions document is especially useful to authors and editors when new or custom DTDs are being used. The information contained within the Dictionary and Conventions documents will be helpful in the maintenance and revision of the TMs and should also be provided to the Navy XML/SGML Repository (**http://navycals.dt.navy.mil/dtdfosi/repository.html**).

4.1.3 HTML and XHTML for New Manuals

Neither the Hypertext Markup Language (HTML) nor the Extensible Hypertext Markup Language (XHTML) is a suitable format for the storage and management of new technical manual data. DON activities should receive and manage documents in XML or SGML in accordance with a DTD that describes some degree of multi-level structure and content for the manual. HTML is a specific SGML application. It uses a set of three standardized SGML DTDs used for data formatting and delivery on the WWW using Web software browsers. XHTML is a reformulation of HTML 4 as an XML 1.0 application. It consists of three XML DTDs corresponding to the three SGML DTDs defined by HTML 4. Both HTML and XHTML consist of a fixed set of tags. Web browsers present the data by interpreting each tag to provide an agreed upon format.

If an HTML or XHTML version of the manual is desired for delivery and presentation, program and document managers should also require delivery of the manual in XML in accordance with a W3C Recommendation "Extensible Markup Language (XML) 1.0 (Third Edition)" compliant DTD, or in SGML in accordance with a MIL-PRF-28001 compliant DTD in addition to the HTML or XHTML deliverable. If a contractor develops conversion software or filters to convert the SGML or XML document to an HTML or XHTML document, the DON procurement activity should request delivery of the conversion software or filters also.

Programs choosing to acquire or create manuals directly in HTML or XHTML will have very limited content management capability and limited ability to utilize the data re-use and content searching functionality provided by XML/SGML document management tools. If a program chooses to author manuals in HTML or XHTML, it should require delivery of the HTML or XHTML DTD used for authoring. Since there are many versions and browser extensions of the HTML and XHTML DTDs, copies of the authoring DTDs should be retained with the manuals for updates and revisions.

4.1.4 Formatting XML/SGML Content

Since an XML/SGML file is intended to contain no formatting information, presentation applications use descriptions of formats called style sheets to determine what style/format to apply to a TM written to a DTD. Style sheets can apply to all instances conforming to a DTD, not just a single XML or SGML files. A DTD can have multiple style sheets associated with it to provide alternate formats for instances conforming to that DTD. The filter conversion (Section 4.1.5) of SGML or XML text into an HTML or XHTML file with predetermined format is -an alternative to a style sheet.

4.1.5 Filter Conversion

Filters are translation programs or software that convert one encoded data stream, such as XML or SGML text, into another data stream with codes that can be readily interpreted and processed by the user's equipment and software. Filters may be developed to translate, or "filter", an SGML file into an HTML or XHTML file. This may be done when the TM management activity wants to store and manage data in SGML but have HTML or XHTML as one method of delivery/presentation. Filters may also be used to translate data, tagged as an instance of one DTD, into data, tagged according to another DTD.

4.1.6 IETM and ETM Functionality

Interactive electronic technical manuals (IETMs), the interactive version of electronic technical manuals (ETMs), have evolved to include a broad spectrum of visual and functional characteristics. This diversity is due to wide variances in electronic presentation form and format, as well as embedded functionality. Consequently, the guidance and associated specifications governing these documents and implementations must remain flexible and accommodate the desired appearance and functionality of the product. In general, a primary factor in specifying an IETM is the desired level of functionality in the presentation of the IETM information. IETMs may, on the one hand, be as simple as selectable Table of Contents access to electronic representations of paper pages or non-interactive implementations of technical data encoded as elemental PDF, HTML, or XML. At the other extreme, IETMs may be very complex, such as highly interactive electronic documents dynamically created out of a database that are designed and authored specifically for electronic screen presentation with navigation control built into the IETM database itself. The Aerospace Industries Association (AIA) IETM functionality matrix (included in Chapter 6.4 of the 2003 release of AECMA Specification S1000D, discussed in 4.1.6.4 below) may be used to characterize the various levels of IETM functionality for acquisition purposes.

4.1.6.1 Justify Requirement for Advanced Functionality

Requiring high-end functionality within an IETM can add significantly to its development cost. Programs should acquire high functionality IETMs only in situations where they can return suitable value. High functionality IETMs (i.e., dynamically created and database supported) are usually required for a tightly, and interactively, controlled presentation of procedural information such as a troubleshooting or diagnostic procedure. Such an advanced IETM may also be desirable when a program is acquiring a large number of high-end weapon systems that are likely to be differently configured. In this case, highly dynamic IETMs created from a single database will be more cost effective than the distribution of unique IETMs for each platform.

4.1.6.2 Basic Level of Functionality Adequate for Most IETMs

For most IETM applications, basic interactive functionality can be achieved by a presentation format employing scrolling text or small linked information frames specifically designed to eliminate the need for scrolling. In most cases the only needed interactive functionality is user selectable links contained in a Table of Contents or embedded in the presented text. This core functionality should be adequate for general-purpose use. At this time no single format exists for the run-time form of such IETMs. However, the editable source data should be developed and maintained in an authoring system independent form. This editable source should be delivered to the procuring activity along with the actual run-time version of the IETM. In accordance with guidance provided Section 4.1.1 of this document, this format should be that of SGML or XML tagged data developed in accordance with a documented DTD that is part of the procurement package. The most common formats currently utilized for the runtime versions of these IETMs are Adobe PDF, HTML, or XML. All of these can work satisfactorily using commonly available browsers and provide the basic interactive functionality needed for most of the Navy IETMs. Only approved plug-ins should be utilized when required for the graphics and illustrations selected for the IETM project (see Section 3.4.2.3 on graphic selection in this document.).

4.1.6.3 Old IETM Specifications

The current military performance specifications for IETMs, MIL-PRF-87268 and MIL-PRF-87269, **are very old and out of date and should not be used by DON.** MIL-PRF-87268 prescribes the user interface and presentation format for these IETMs. MIL-PRF-87269 presents both an approach and a DTD protocol to guide the development of the DTDs for such high-end IETMs and requires that a content-specific DTD be negotiated and documented for each procurement. The content-specific DTD in MIL-PRF-87269 is only an example intended for guidance and is not the required procurement DTD. Both of these specifications require significant input and participation from the Acquisition Program in determining a suitable, mutually agreed upon IETM design.

4.1.6.4 New Options for Specifying IETMs

Both NAVSEA and NAVAIR have new specifications that are preferred for acquisition of IETMs. The NAVSEA MIL-DTL-24784B specification, maintained by NSDSA, is being modified to contain requirements for IETMs. Very soon it will be available for preparing Technical Manual Contract Requirements (TMCRs) as an option for specifying NAVSEA IETMs. The NAVAIR specification, MIL-STD-3001-1 (AS) may be used for NAVAIR IETMs. Another option for IETM/ETM specification is the **AIA/AECMA *International Specification for Technical Publications Utilizing a Common Source Database*, Spec 1000D, Issue 2.0, 31 May 2003** (**http://www.s1000d.org**). The United States Department of Defense (DoD) and defense industry partners have teamed with their European counterparts to transition S1000D from a strictly European specification to an international one. The technical team working on the S1000D specification intends to have a suitable replacement specification for the DoD IETM specifications by the next iteration of the specification planned for late 2004 along with a formal "adoption" by the DoD for that purpose.

4.1.6.5 Common User Interface Look and Feel

Achieving a common user interface and uniform look and feel for DON IETMs has been a long-sought objective of IETM specification developers. The latest consensus among the DoD Services concerning IETMs is contained in MIL-HDBK-511, *Department of Defense Handbook for Interoperability of Interactive Electronic Technical Manuals,* published in May 2000. This handbook provides useful guidance regarding a move towards a Web-oriented weapon system support infrastructure. It also provides general guidance for achieving a common user interface look-and-feel to IETMs based on WWW browsers. Efforts are currently underway to include common look and feel specifications in the next version of MIL-DTL-24784, as well as, future versions of AIA/AECMA S1000D.

4.1.7 Acquisition of New Technical Manuals for the Marine Corps

In accordance with Marine Corps Order P5215.17C, "The Marine Corps Technical Publications System", digital data publications are required for all new Marine Corps programs with an initial operating capability (IOC) during FY 2000 and beyond, unless the Commander, Marine Corps Systems Command, approves a waiver.

Program Managers (PMs) shall identify unique or unusual user environments not serviced by Marine Corps Common Computer Hardware Suites and items that may not be conducive to digital data to the Director of Acquisition Logistics at Marine Corp Systems Command.

4.2 Conversion of Legacy Technical Manuals and Documents to Digital Format

The DON, subject to availability of funding and justification by cost benefit analysis, will convert legacy (including hard copy and raster) TMs to a digital format. Conversion to an XML or SGML format can provide great flexibility for the edit; revision, management and presentation of the manual as discussed in Section 4.1.1, but the cost of this type of conversion can be expensive and require significant involvement of subject matter experts. Conversion to a raster format or to PDF may be less expensive, easier on the requesting activity, and still provide acceptable versatile digital copy. Guidance and considerations for choosing the appropriate format for conversion are presented below. Specific guidance for U. S. Marine Corps conversion efforts is contained in Section 4.2.4.

4.2.1 Conversion to XML or SGML

Legacy TMs, which experience high usage, extensive life cycle, and frequent revision, should be converted to either XML or SGML. XML is the preferred format for digital TMs, as it will become the prominent format for the DON's web-enabled digital environment. Many more TMs are now in SGML form than in XML. Consequently, programs with existing SGML TM databases and repositories may convert hard copy legacy to SGML. The selection of XML or SGML for the conversion format is subject to the same considerations discussed in Section 4.1.1 concerning acquisition formats. When converting technical manuals, program and document managers should require delivery of XML in accordance with a W3C conforming DTD or SGML in accordance with a MIL-PRF-28001 compliant DTD that is suitable for the document being converted. Where possible, existing DTDs and style sheets should be used. Programs should require conversion of data format and should not demand or expect full or detailed replication of the composition and pagination of the original legacy documents as this may greatly increase the complexity and cost of the conversion effort and related style sheet development. The DTD defines the extent, complexity, and ultimate functionality of the XML or SGML encoding of a document. Conversion to simple DTDs is easier and cheaper than conversion to more complex DTDs. Options for management, access, and presentation of the TM data based on a simple DTD will be more limited than if the TM is based on a complex DTD. Conversion to complex DTDs requires more manual effort and is more expensive but can provide (if the DTD is properly designed) many more options for data/information management and presentation. If a new DTD is used for the conversion, the program should request delivery of the DTD as well as other files identified in Section 4.1.2 with the XML or SGML data to enable the DON to properly maintain the converted documents. XML Schemas may replace DTDs as models for document classes that require significant data typing. XML DTDs will most likely continue to be used for the traditional technical manual. For reasons discussed in Section 4.1.1.1 "XML for New Manuals", programs should use DTDs for conversion. The maturity of software tools for XML Schema development and processing in the technical manual area will be monitored, and this guidance will be modified as necessary.

4.2.2 Conversion to HTML or XHTML

HTML (RFC 1866) is a specific SGML application or DTD that provides a uniform means for creating documents for presentation and viewing on the WWW using standard software browsers. XHTML is a specific XML application consisting of a set of XML DTDs that provide a uniform means for creating documents for presentation and viewing on the WWW using standard software browsers. In this context, HTML and XHTML are acceptable digital formats for distribution and presentation of TMs. However, neither HTML DTDs nor XHTML DTDs are suitable for storage and management of data since they contain no content tags and only minimal structure tags. The DTDs are generic in nature and do not add intelligent markup for TM data. HTML merely identifies areas in a document to affect formatting and is not meant to identify data for storage and management.

If conversion to HTML or XHTML is desired, program and document managers should also require delivery of documents converted to XML in accordance with a W3C conforming DTD or SGML in accordance with a MIL-PRF-28001 compliant DTD in addition to the HTML or XHTML deliverable. By requiring delivery of XML or SGML and the DTD used, the DON will be better able to manage updates and revisions to the document. If the contractor develops conversion software or filters to convert the XML or SGML document to an HTML or XHTML document, the program should request delivery of the conversion software or filters also. The DON's intention is to receive and manage documents in XML or SGML and if desired convert to HTML or XHTML only for distribution and presentation purposes. If a program chooses to convert directly to HTML or XHTML and not another XML or SGML DTD, it should require delivery of the HTML or XHTML DTD used for conversion. This DTD will be necessary for management and revision of the HTML or XHTML documents since there are many versions as well as browser extensions of the HTML and XHTML DTDs.

4.2.3 Conversion to Raster and PDF

Legacy manuals may be converted to the PDF or the Navy Implementation for Raster Scanning NIRS/NIFF (MIL-PRF-28002, Type 3) for distribution and use. Both of these formats are suitable for obtaining a digital image representation of the original document and for electronic display and presentation to users. Neither format is well suited for document edits and revisions. Consequently, a common approach taken by programs is to initially convert documents to raster or PDF and, as some manuals begin to require significant amount of revisions, consider converting them or re-authoring them in XML or SGML.

PDF is a popular commercial format that has achieved widespread use through availability of free viewer software. Conversion to PDF is quite commonplace and activities can easily contract for conversion to PDF or can convert documents themselves by purchasing the Adobe Capture software. Conversion to basic PDF may not be much more expensive than conversion to raster. The PDF format and Adobe tools, however, can be used to add various navigation functionality (such as indexing, linking, hot-spotting) to the documents, and the extent and degree of this added functionality could drive the conversion cost much higher. Many commands and activities consider PDF as their minimum electronic format.

The conversion of paper (or raster) to PDF generates an ASCII rendition as an interim product. If this ASCII is available, it should be saved as a possible basis for performing revisions to the document. Managers, who are converting documents to PDF, should request delivery of the ASCII or other revisable files, if they exist, to satisfy future revision and edit needs. If revisable files are not available, they should be created only when needed.

Hard copy paper (legacy) TMs may be raster scanned in accordance with NIRS/NIFF specified in MIL-PRF-28002. NIFF is a version of TIFF. NIRS/NIFF can be specified on contract by citing Type 3 raster conversion in the raster performance specification, MIL-PRF-28002. TIFF is widely interchangeable with common computer systems. NIRS/NIFF documents are stored aboard ship in the ATIS (Advanced Technical Information Support) repository and the ATIS system provides the necessary viewers to display the documents. NIRS/NIFF provides some document navigation capabilities and is generally a smaller file than an image-based PDF version and thus may be preferable to an image-based PDF format. Text-based PDF, however, is recommended over NIRS/NIFF.

Programs should be aware that viewing raster scanned foldout illustrations and schematics is a problem for users without oversized monitors unless the foldout images are re-authored or reprocessed to satisfy the viewing software, or special viewing software is provided.

4.2.4 Conversion of Marine Corps Legacy Manuals to Digital Format

All Marine Corps legacy TMs will be converted to SGML. They will be managed and maintained in SGML and published and made available to users as either an IETM or indexed PDF (IPDF) form based on operational needs and requirements. Commercial manuals will be made available in IPDF format only. Additional information can be found in MCO P5215.17C.

4.3 Technical Manual Graphics

The DON, subject to availability of funding and justification by cost benefit analysis, will convert technical manual graphics to a digital format. Conversion to a vector format can provide great flexibility for the edit, revision, management and presentation of the technical manual graphic but the cost of this type of conversion can be expensive and require significant involvement of subject matter experts. Conversion to a raster format or to PDF may be less expensive, easier on the requesting activity, and still provide acceptable versatile digital copy. Guidance and considerations for choosing the appropriate format for conversion are presented below. Specific guidance for U. S. Marine Corps conversion efforts is contained in Section 4.2.4.

4.3.1 Vector

The following vector formats are preferred for all new 2-D drawings, schematics, and illustrations:

- CGM delivered in accordance with the ISO/IEC 8632 international specification and the implementation profile of the WebCGM recommendation (**http://www.w3.org/Graphics/WebCGM REC-WebCGM-19990121**)

- SVG delivered in accordance with the W3C "Scalable Vector Graphics (SVG) 1.0" specification (**http://www.w3.org/TR/2001/REC-SVG-20010904/**)

SVG is preferred for vector graphics requiring animation or gradients.

4.3.2 Raster

Raster imaging is generally discouraged for the acquisition of legacy 2-D drawings, schematics, or illustrations. However, raster formats such as TIFF, BMP, PNG or JPEG may be used to capture existing drawings not already in an acceptable vector format.

Raster graphics should not be used where there is a requirement:

- For navigation (hot-spotting or hyper-linking) within the image or

- To attach metadata or added information to text or graphic elements within the image.

Legacy applications may continue to use MIL-PRF-28002C format types 1, 3, and 4 for raster graphics representation in binary format. However, the MIL-PRF-28002C type 2 format, the ODA/ODIF format (CALS Type 2), should not be used. While the NIFF format is allowed for drawings and schematics, its use is discouraged.

4.4 Publication, Distribution, and Management

TMs should be published in ETM or IETM formats suitable for distribution and use based upon availability of the requisite hardware and software in the user community.

The DON will cease the practice of creating, managing, stocking, and distributing change-pages. TM/document editing and management should be performed at a document component level through processes suitable for an XML/SGML document environment. Under this approach, when a document is modified, only the component(s) added/deleted/changed are modified in the document repository or database. A new version of the whole document does not have to be stored. When data is managed at a component level, components that are common to multiple document instances (e.g., cautions, warnings) can be edited and managed in one spot and shared among documents. This eliminates redundancy as well as increases accuracy of data. Updates of user digital documents will be distributed at a full document level.

At present, there is no DON-wide consensus that can be cited concerning highlighting or identification of document changes or procedures for notification of users of those changes. Activities should define and employ change identification and user notification procedures that best fit their TM management and usage practices.

5. DELIVERY OF TECHNICAL DATA

Because all users may not have the latest computer technology, it may be necessary to reproduce the digital data in traditional hard copy formats.

5.1 Delivery of Schematics and Fold-out Drawings

Particular consideration should be given to digital foldout drawings and long line schematics, which can be difficult to work with in electronic form. Paper copies of these drawings are often considered necessary for their effective use by technicians. For this reason, programs and data management activities should be prepared to provide drawings in easily readable paper copies to users. These special considerations for foldouts and schematics should remain in effect until the user community has the capability to satisfactorily view and print them when needed.

6. INTEGRATION OF PRODUCT / TECHNICAL DATA AND TRAINING DATA

The training and human performance community is one of the largest users of technical and product data in the Navy. Typically, the engineering community creates the technical data needed to maintain, repair, and support the platforms, systems, and equipment in the Fleet. The training and human performance community produces the necessary training curricula and materials based on the technical data products. Both of these communities have recognized the value of sharing data and are actively engaged in defining an environment for the integration of technical content, training content, and management and delivery systems. The guidance contained within this document supports the creation of digital, standards-based authoritative sources for technical and product data that can be accessed and used by training developers. Training product development is guided by the performance specification, MIL-PRF-29612B, "Training Data Products", which establishes the data requirements to support life cycle maintenance of training data products, and by the Sharable Content Object Reference Model (SCORM) produced by the Advanced Distributed Learning Initiative. An OPNAV N40 and NOOT sponsored Training / Technical Data Workshop, 13 – 15 November 2002 endorsed a "Concept of Operations for Technical and Training Data Integration". In the summer of 2003, the Naval Personnel Development Center is leading an effort to plan for the inclusion of the Naval System Commands in the Integrated Learning Environment and to integrate training content with product and technical data. Programs and Commands are encouraged to track these efforts and employ a digital content management and reuse strategy that enables integration of technical data and publications with learning and job performance support applications.

7. COMMERCIAL OFF-THE-SHELF (COTS) PRODUCT DOCUMENTATION

When acquisition and product life cycle support requirements involve the procurement of Commercial Off-The-Shelf (COTS) items and associated product/technical data, Acquisition Managers should contract for the delivery of the data and documentation in digital form and/or access to the data and documentation as provided digitally from the contractor. Where COTS providers only have the data in hardcopy, acquisition managers should negotiate agreements for digital conversion to formats outlined above. In the case of copyrighted data, acquisition managers must be prepared to accept limited rights or access to the data and, in some cases, accept paper copies. These limited rights to the content should be obtained to allow the government to maintain, modify, extract, and re-use the content in digital form.

REFERENCES

ENGINEERING DRAWINGS AND ASSOCIATED DATA REFERENCES

CAD and Product Data

Standard for the Exchange of Product Model Data (STEP), ISO 10303

AP202: *Associative draughting* (ISO 10303-202:1996)

AP203: *Configuration controlled 3D designs of mechanical parts and assemblies* (ISO 10303-203:1994)

AP207: *Sheet metal die planning and design* (ISO 10303-207:1999)

AP209: *Composite and metallic structural analysis and related design* (ISO 10303-209:2001)

AP210: *Electronic assembly, interconnect and packaging design* (ISO 10303-210:2001)

AP212: *Electrotechnical design and installation* (ISO 10303-212:2001)

AP214: *Core data for automotive mechanical design processes* (ISO 10303-214:2001)

AP215: *Ship arrangement* (ISO 10303-215:2004)

AP216: *Ship molded forms* (ISO 10303-216:2003)

AP218: *Ship structures* (ISO 10303-218:2004)

AP224: *Mechanical product definition for process planning using machining features* (ISO 10303-224:2001)

AP225: *Building elements using explicit shape representation* (ISO 10303-225:1999)

AP227: *Plant spatial configuration* (ISO 10303-227:2001)

AP232: *Technical data packaging core information and exchange* (ISO 10303-232:2002)

Product Data Exchange using STEP (PDES), (ANS US PRO/IPO-200 Series)

Additional implementation guidance for STEP APs:
National Shipbuilding Research Program (NSRP) Navy/Industry Digital Data Exchange Standards Committee (NIDDESC) STEP Application Protocols (APs):

NIDDESC Piping AP, NSRP 0424, (ISO 10303 AP 227:2001)

NIDDESC Electrical & Raceways AP, NSRP 0425, (ISO 10303 AP 212:2001)

NIDDESC Heating Ventilation, and Air Condition (HVAC) AP, NSRP 0426, (ISO 10303 Draft AP 227 Edition 2)

NIDDESC Outfit and Furnishings AP, NSRP 0428

NIDDESC Ship Structural Systems AP, NSRP 0429, (ISO 10303 Draft AP's 215, 216, 218)

Geospatial Data for Naval Installations

Spatial Data Standards for Facilities, Infrastructure, and Environment (SDSFIE), Tri-Service CADD/GIS Technology Center, Technical Report CADD-98, July 1998, **http://tsc.wes.army.mil**

Content Standard for Digital Geospatial Metadata, CSDGM, Version 2, Federal Geographic Data Committee, **http://www.fgdc.gov/metadata/contstan.html**

Vector Data

MIL-PRF-28003B, 30 April 2000, *Digital Representation for Communication of Illustration Data: CGM Application Profile*, **http://navycals.dt.navy.mil/cals/documents/PRF28004.pdf**

International Standard ISO/IEC 8632:1999, *Information Technology – Computer Graphics Metafile for the Storage and Transfer of Picture Description Information*

WebCGM 1.0 Second Release W3C Recommendation, 17 December 2001, REC-WebCGM-20011217, **http://www.w3.org/TR/REC-WebCGM**

Raster Data

ISO/IEC 15444:2000 Information Technology – *JPEG 2000 image coding system*

ISO/IEC 10918.1, Information Technology -- *Digital compression and coding of continuous-tone still images*

JPEG File Interchange Format JFIF, version 1.02, Sept 1, 1992, Eric Hamilton, C-Cube Microsystems

JPEG, Still Image Compression Standard, William P. Pennebaker and Joan L. Mitchell, Van Nostrand Reinhold, New York, 1993

MIL-PRF-28002C, 30 September 1997, *Raster Graphics Representation in Binary Format, Requirements for*, **http://navycals.dt.navy.mil/cals/documents/28002C.pdf**

Portable Document Format Reference Manual (PDF), Adobe Systems Inc.

Portable Network Graphics (PNG) 1.0 specification, which has been published as RFC-2083 and as a W3C Recommendation 01-October-1996. Expected to be released eventually as ISO/IEC International Standard 15948.

BMP is the native bitmap file format of the Microsoft Windows environment. Inside Windows File Formats, Tom Swan, Sams Publishing 1993. ISBN 0-672-30338-8, Sams Publishing

TIFF™ Revision 6.0, Final — June 3, 1992

TECHNICAL MANUAL REFERENCES

MIL-PRF-28001C; 2 May 1997, *Markup Requirements and Generic Style Specification for Exchange of Text and its Presentation (SGML)*,**http://navycals.dt.navy.mil/cals/documents/28001C.pdf**

International Standard ISO 8879, *Information Processing - Text and Office Systems - Standard Generalized Markup Language (SGML)*, International Organization for Standardization, 1986.

Amendment 1 to ISO 8879, International Organization for Standardization, 1987.

ISO/IEC JTC1/SC34 N0029, *Document Description and Processing Languages, Annex K (Normative): Web SGML Adaptations* - December 6, 1998, **http://www.ornl.gov/sgml/sc34/document/0029.htm**

HTML 4.01 Specification - 24 December, 1999, **http://www.w3.org/TR/html4/**

Extensible Markup Language (XML) 1.0 (Third Edition), W3C Recommendation, 4 February 2004, **http://www.w3.org/TR/REC-xml**

International Specification for Technical Publications utilizing a Common Source Database, Specification S1000D (S1000D), Issue 2, 2003-05-31, The European Association of Aerospace Industries (AECMA) and Aerospace Industries of America (AIA)

MIL-HDBK-28001, 30 June 1995, *Application of MIL-PRF-28001 Using Standard Generalized Markup Language (SGML)*, **http://navycals.dt.navy.mil/cals/documents/28001.pdf**

MIL-HDBK-511, 15 May 2000, Department of Defense Handbook for Interoperability of Interactive Electronic Technical Manuals (IETMs), **http://navycals.dt.navy.mil/ietm/webstuff/HDBK511.PDF**

MIL-DTL-24784B, Manuals, Technical: General Acquisition and Development Requirements, 15 Feb 2002

MIL-STD-3001-1(AS), Preparation of Digital Technical Information for Multi-Output Presentation of Technical Manuals, 15 May 2001

SPECIFICATIONS AND STANDARDS GENERAL REFERENCES

MIL-STD-1840C; 26 June 1997, Automated Interchange of Technical Information, **http://navycals.dt.navy.mil/cals/documents/1840C.pdf**

Information Technology Standards Guidance, Version 99-1, 5 April 1999, DON CIO ITSG Integrated Product Team, http://www.doncio.navy.mil/training/ools/itsg/index.html

XML Schema Part 0: Primer, 2 May 2001, **http://www.w3.org/TR/xmlschema-0/**

XML Schema Part 1: Structures, 2 May 2001, **http://www.w3.org/TR/xmlschema-1/**

XML Schema Part 2: Datatypes, 2 May 2001, **http://www.w3.org/TR/xmlschema-2/**

MIL-PRF-29612B, 31 August 2001, *Training Data Products*, **http://www.dtswg.org/PDF%20Files/29612B.pdf**

Appendix A

DIGITAL DATA STANDARDS and SPECIFICATIONS TABLES

These tables present a quick guide to data formats and standards. The information is compliant with the DON Information Technology Standards Guidance published by the DON Chief Information Officer (CIO).

TABLE 1 - Legacy Data Conversion

LEGACY FORM	DESIRED CONVERSION	STANDARDS & SPECS
TECHNICAL MANUALS (section 4.2)	Conversion to XML (section 4.2.1)	XML per W3C Recommendation And Use existing XML DTD or Use new XML DTD & Request delivery of DTD
	Conversion to SGML (section 4.2.1)	SGML per MIL-PRF-28001 And Use existing SGML DTD or Use new SGML DTD & Request delivery of DTD
	Conversion to XHTML or HTML (section 4.2.2) (XHTML and HTML used for presentation only. XML or SGML is used for storage and management. This is the preferred method of XHTML or HTML conversion: supports life cycle management of the converted TM)	Convert first to XML per W3C Recommendation or SGML per MIL-PRF-28001 And Use existing XML/SGML DTD or Use new XML/SGML DTD & Request delivery of XML/SGML DTD Then Convert XML or SGML to XHTML or HTML And Deliver HTML or XHTML
	Conversion to XHTML or HTML (section 4.2.2) (XHTML and HTML used for presentation, storage and management. This is an alternate method of XHTML or HTML conversion: life cycle management of TM may be difficult due to instability of XHTML/HTML DTD)	Convert direct to XHTML or HTML per existing version of XHTML or HTML DTD And Deliver XHTML or HTML with the W3C DTD used
	Conversion to Raster (section 4.2.3)	PDF per Adobe Systems, Inc Or NIRS/NIFF per MIL-PRF-28002 Type 3 Or TIFF, BMP, JPEG, PNG

LEGACY FORM	DESIRED CONVERSION	STANDARDS & SPECS
GRAPHICS (section 3.6)	Conversion of hard copy graphics/aperture cards to raster	C4 (JEDMICS) per MIL-PRF-28002 Type 4 Or NIRS/NIFF per MIL-PRF-28002 Type 3 Or CCITT Group 4 per MIL-PRF-28002 Type 1 Or TIFF, BMP, JPEG, PNG
	Conversion of hard copy or raster graphics to vector	CGM per MIL-PRF-28003 Or SVG
	Conversion of hard copy or raster graphics to vector with hyperlink Capability	CGM, Version 4, per WebCGM Or SVG

TABLE 2 - Technical Manual Creation

DESIRED FORM	TEXT STANDARDS & SPECIFICATIONS	GRAPHICS	GRAPHICS STANDARDS AND SPECIFICATIONS
Electronic Technical Manuals (ETMs)	XML per W3C Recommendation Or SGML per MIL-PRF-28001 Use existing DTD Or Use new DTD & Request delivery of DTD (section 4.1.1)	2-D vector graphics for illustrations & TMs ---------------------------- 2-D graphics for hyperlinked illustrations ---------------------------- Raster (bitmapped) images	MIL-PRF-28003 -CGM ---------------------------- CGM Version 4 per WebCGM Or SVG ---------------------------- MIL-PRF-28002 Type 1 – CCITT.G4
Interactive Electronic Technical Manuals (IETMs) (Option 1)	XML per W3C Recommendation Or SGML per MIL-PRF-28001 And MIL-HDBK-511 (section 4.1.6)	2-D vector graphics for illustrations & TMs ---------------------------- 2-D graphics for hyperlinked illustrations ---------------------------- Raster (bitmapped) images	MIL-PRF-28003 - CGM Or SVG ---------------------------- CGM Version 4 per WebCGM Or SVG ---------------------------- MIL-PRF-28002 Type 1 – CCITT.G4
Interactive Electronic Technical Manuals (IETMs) (Option 2)	XML per W3C Recommendation Or SGML per MIL-PRF-28001 And AIA/AECMA S1000D (section 4.1.6.4)	Same as Option 1	Same as Option 1

TABLE 3 - Product Data Creation

APPLICATION	STANDARDS & SPECS
2-D graphics for use in CAD	STEP per ISO 10303 AP201 or AP 202
Product data CAD/CAM/CAE 3-D vector Product Model	STEP per ISO 10303

Appendix B

WWW RESOURCE GUIDE
FOR DIGITAL PRODUCT AND TECHNICAL DATA
IMPLEMENTATION

Www.w3schools.com	XML and programming language tutorials
Http://nsdsa.phdnswc.navy.mil	TD acquisition and lifecycle support
Http://armyec.army.mil/knowbase/docs/doc64/opening.htm	CALS Toolkit
Http://nsdsa.phdnswc.navy.mil/sgml/ietm-production.asp?lvl=1	Description of NAVSEA Publishing System
Http://navycals/ietm/CLASSES.PDF	IETM classes
Http://nsdsa.phdnswc.navy.mil/sgml/ietm-spawar.asp?lvl=1	Access to SPAWAR XML DTD, XSLT, tagging guidance and parser files
Http://navycals.dt.navy.mil	Navy CALS Web site
Https://www.uspro.org/	US Product Data Association
Http://www.usashipbuilding.com/niddesc/t23.html.	Shipbuilding product model data
Http://mpeg.telecomitalialab.com	MPEG information
Http://ric.crane.navy.mil/	Navy Resource and Implementation Cooperative (RIC)
Http://www.doncio.navy.mil/doncio/index.html	DON Chief Information Officer
Http://www.doncio.navy.mil/training/ools/itsg/	Information Technology Standards Guidance
Http://usn.hq.navy.mil/	Deputy Chief of Naval Operations for Logistics OPNAV N4 Logistics
Http://www.peoarbs.navy.mil	Program Executive Officer for Acquisition Related Business Systems (PEO(ARBS))
Http://diicoe.disa.mil/coe/	Defense Information Infrastructure (DII) Common Operating Environment (COE)
Http://www.adobe.com:80/support/techdocs/20ac6.htm	How to create Adobe PDF files for print and press
Http://www.oasis-open.org/cover/sgml-xml.html	SGML & XML information
Http://navycals.dt.navy.mil/dtdfosi/repository.html	Navy XML/SGML Repository
Http://www-jta.itsi.disa.mil/	DoD Joint Technical Architecture (JTA)
Http://www.adlnet.org/index.cfm?fuseaction=scormabt	Sharable Content Object Reference Model (SCORM) information through the Advanced Distributed Learning (ADL) Initiative website

Appendix C

LIST OF ACRONYMS

Acronym	Definition
2-D	Two Dimensional
3-D	Three Dimensional
AIA	Aerospace Industries Association
AP	Application Protocol
ASCII	American Standard Code for Information Interchange
ATIS	Advanced Technical Information Support
BMP	Bit Map Picture
CAD	Computer Aided Design
CADD	Computer Aided Drafting and Design
CAE	Computer Aided Engineering
CALS	Continuous Acquisition and Life-Cycle Support
CAM	Computer Aided Manufacturing
CGM	Computer Graphics Metafile
CIO	Chief Information Officer
COE	Common Operating Environment
CSDGM	Content Standard for Geospatial Metadata
DII	Defense Information Infrastructure
DON	Department of the Navy
DTD	Document Type Definition
ETM	Electronic Technical Manual
FGDC	Federal Geographic Data Committee
GCO	Government Concept of Operations
HTML	Hyper Text Mark-Up Language
IADS	Interactive Authoring and Display System
IDE	Integrated Data Environment
IETM	Interactive Electronic Technical Manual
IGES	Initial Graphics Exchange Specification

ISO	International Organization for Standardization
JEDMICS	Joint Engineering Data Management Information and Control System
JPEG	Joint Photographic Experts Group
NIBS	National Institute of Building Sciences
NIDDESC	Navy/Industry Digital Data Exchange Standards Committee
NIFF	Navy Image File Format
NIRS	Navy Implementation for Raster Scanning
NSDSA	Naval Systems Data Support Activity
NSRP	National Shipbuilding Research Program
NSWC	Naval Surface Warfare Center
ODA	Open Document Architecture
ODIF	Open Document Interchange Format
PDF	Portable Document Format
PEO	Program Executive Officer
PM	Program Manager
PNG	Portable Network Graphics
SCORM	Sharable Content Object Reference Model
SGML	Standard Generalized Markup Language
STEP	STandard for Exchange of Product Model Data
SVG	Scalable Vector Graphics
SYSCOM	System Commander
TIFF	Tagged Image File Format
TM	Technical Manual
TMINS	Technical Manual Identification Numbering System
VMRL	Virtual Reality Modeling Language
W3C	World Wide Web Consortium
WWW	World Wide Web
X3D	Extensible 3D, Draft International Standards
XHTML	Extensible Hypertext Markup Language
XML	Extensible Markup Language
XSLT	Extensible Stylesheet Language Transformations

DEPARTMENT OF THE ARMY
HEADQUARTERS, U.S. ARMY MATERIEL COMMAND
9301 CHAPEK ROAD
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REPLY TO
ATTENTION OF

AMC Policy Memo 711-1
Expires: 4 April 2007

AMCOPS 4 April 2005

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Army Materiel Command (AMC) Logistics Modernization Program Data Implementation Policy

1. **Purpose.** To establish AMC guidance for initiating and realizing a program that validates the accuracy (cleanliness) of data prior to migration from legacy systems to the Enterprise Resource Planning (ERP) system, the Logistics Modernization Program (LMP).

2. **Applicability.** This policy applies to all AMC organizations and activities with the responsibility for migrating and sustaining data to ensure information quality and accuracy. It forms the guiding framework in which AMC data managers will operate. In addition, Army Program Managers/Program Executive Officers (PM/PEOs) will be required to comply with specific data implementation requirements in order that their specific applications interface with and comply with AMC-defined requirements for the Single Army Logistics Enterprise (SALE).

3. **Scope.** The guidance will enable current and future integration into the SALE and for meeting compliance with Department of Defense (DoD) objectives for net-centric data exchange. It provides the foundation for military readiness by delivering Enterprise-wide business management processes and timely operational support to combat forces and to mission essential, non-combat related areas.

4. **Background.** The AMC is modernizing its logistics processes by instituting the LMP using SAP ERP software. The LMP replaces the national logistics functions now supported by the retiring Commodity Command Standard System (CCSS), the Standard Depot System (SDS), and other specified legacy systems and subsystems. As the AMC moves away from independent application development to an ERP environment where business process and data are integrated, mechanisms for identifying and fostering the use of best practices in data definition and data sharing are important issues. Migrating and exchanging data from legacy systems within an ERP environment in a way that supports end-to-end business processes and decision making are important considerations. Data cleansing, analysis and harmonization prior to migration is the optimum way to ensure the ERP and the legacy systems work together. Responsibilities of data owners and data custodians in the life-cycle management activities need to be clearly and consistently assigned. The LMP implementation is the responsibility of the AMC Deputy Chief of Staff for Operations (AMC G-3). Accomplishment and coordination of day-to-day SALE

requirements is performed by the AMC Director for Enterprise Integration (Dir, EI), who is dual-hatted as the Deputy for Army Logistics Enterprise Integration (DALEI).

5. **LMP Overview.** This policy applies to the LMP, which is a sub-component of the SALE and implements the Army's core mission area of National Logistics. The AMC's Data Policy supports LMP pre-deployment, stabilization, and post-deployment and strives for reliable information. It applies to LMP data migration and exchange with legacy systems, and provides guidance for data life-cycle management to include the:

a. Employment of centralized data management for cleansing, validation, analysis, and migration

b. Utilization of metrics to measure performance and progress

c. Minimization of data migration costs associated with the ERP implementation

d. Reductions in ERP post Go-Live productivity dips

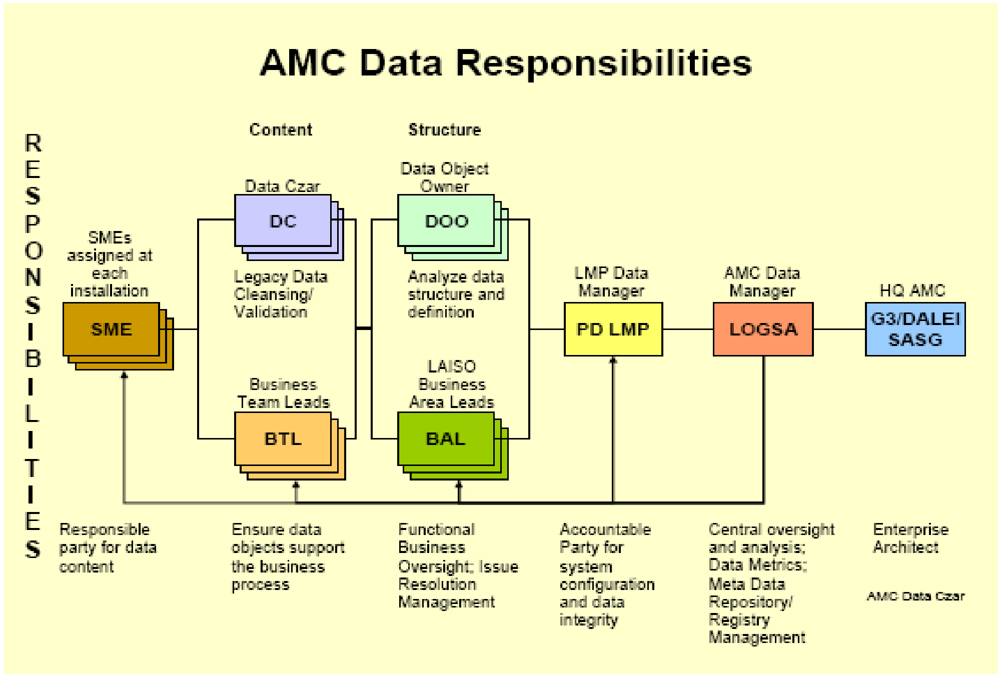
The AMC is pursuing a data strategy that transitions responsibilities from legacy system environment assignments. The chart below provides a view of changes to data responsibility designed to effectively migrate and then sustain modernized systems. Transitional roles and responsibilities are described in the paragraphs below.

Data Activity	Legacy Environment	New Environment
Central Oversight and Analysis	CDA	LOGSA
Quality Metrics	CDA	LOGSA
Meta Data Repository and Registry	CDA	LOGSA
System Configuration and Integrity	CDA	PD LMP
Data Loading	CDA	PD LMP
Legacy Data Migration Preparation	MSC DC	LCMC DC
Functional Business Oversight	DM	BAL
Data Mapping/Matching	DM	BTL
Access	DM	BTL
Data Object Structure	N/A	DOO
Quality/Cleansing	SME	SME

<u>LEGEND</u>:

DOO-Data Object Owner
BAL – Business Area Lead
LCMC – Life-cycle Management Command
BTL – Business Team Lead
LOGSA – Logistics Support Activity
CDA – Central Design Activity
MSC – Major Subordinate Command
DC – Data Czar
PD LMP – Program Director, Logistics Modernization Program
DM – Domain Manager
SME – Subject Matter Expert

6. **Responsibilities.** Responsibilities for AMC Data Management are depicted in the chart below. If issues are encountered, they are generally resolved from left to right as SMEs address initial migration tasks. Problems may also be passed to or resolved with additional parties. LOGSA acts in an oversight role.



a. Principal Deputy, AMC G-3. The Principal Deputy, AMC G-3 has been designated as the overall Data Czar for HQ AMC and will serve as the approval authority for all recommendations and decisions related to LMP Data Implementation, establish the framework for AMC data cleansing/validation/migration, provide oversight of the AMC G-3 functional proponent offices as they assign data object owners for data which they maintain managerial control, and approve or recommend decisions related to data cleansing tools.

b. Director of Enterprise Integration (EI), AMC G-3. The AMC G-3 Director of Enterprise Integration (EI) is responsible for developing the SALE architecture, which ensures that Army information systems support end-to-end logistics business processes, and includes data quality management and standards. The Director, EI is responsible for ensuring SALE architectural alignment with the DoD Business Management Modernization Program's Business Enterprise Architecture–Logistics and complies with the Net-centric Data Strategy as defined by the DoD Chief Information Officer and Comptroller/Chief Financial Officer. The Director, EI has a direct interest in the data quality for the LMP, since LMP is an ERP component of the SALE and the data that is exchanged with national legacy systems must be the cleansed, migrated, and exchanged in a manner that supports integration.

c. Strategies, Architectures and Standards Group (SASG). The SASG is a supporting staff activity to the AMC Director, EI with the responsibility for monitoring the design and development of the SALE and for maintaining the Operational, Systems, and Technical Architectures in accordance with the DoD Architecture Framework. The Army will use the ARIS information toolset as the repository for the SALE architecture products, to include the associated data architecture and metadata. The SASG ensures that LMP organizational structures and data object definitions support the SALE integration.

d. Logistics Support Activity (LOGSA). The LOGSA is responsible for central oversight and program administration of the migration (cleansing/validation) of AMC LMP Data. LOGSA's responsibilities for AMC data life-cycle control includes:

(1) Defining data goals, objectives, strategies and standards for data cleansing/validation administration.

(2) Exercising oversight of legacy data cleansing, analysis, harmonization and staging to support the ERP environment and prioritizes associated tasks. These activities take place outside of the ERP environment with third party solutions.

(3) Developing the technical solutions to support identified metrics.

(4) Monitoring LMP data quality and availability through the use of metrics and audits.

(5) Compiling and maintaining a catalog with discovery level metadata using a standard metadata template that provides information about the content, characteristics, accessibility, and ownership.

(6) Implementing LMP data security and access control.

(7) Coordinating the investigation of data related issues and data actions with the Business Area Leads (BALs), Business Team Leads (BTLs), Data Czars, System Integrators, and external trading partners, as applicable.

(8) Providing users, developers, system architects, and integrators with insight into the discovery, accessibility, LMP data content, and interoperability of Army logistics data.

(9) Developing Memoranda of Agreement (MOA) together with the appropriate BTLs and LMP trading partners to fix responsibility for ensuring the data quality of each external trading partner.

e. Program Director, Logistics Modernization Program (PD, LMP). The PD, LMP directs the efforts of the LMP support contractor. Upon data preparation, the PD, LMP:

(1) Develops and directs execution of the data migration plans.

(2) Accounts for system configuration and data integrity in the LMP system.

f. Data Object Owner (DOO). DOOs are responsible for the following actions:

(1) Analyze data structures, data definitions, data elements, and metadata.

(2) Develop and execute data validation plans.

g. Business Area Lead (BAL). BALs represent the approved SALE business process areas: Product Life-Cycle Management, Supply Management, Distribution, Maintenance, Ordnance Manufacturing, Acquisition, Force Planning, Financial Management, Personnel Management, Medical, and Battle Command. The BALs:

(1) Provide business process oversight, requirements definition, and assistance with policy and doctrine development.

(2) Manage, coordinate, and resolve data issues with LOGSA, Business Team Leads, Subject Matter Experts, Data Czars and other BALs.

(3) Facilitate the identification, proper management and effective use of data associated with the business processes.

(4) Define what quality metrics are applicable for a specific data entity (e.g., accuracy, completeness, age, etc.)

(5) Serve on enterprise working groups, such as: DoD Process Review Committee, DoD Data Strategy Working Group, Army Data Integrity Working Group and AMC Data Management Integrated Process Team (IPT).

(6) Develop and implement change management.

h. Business Team Lead (BTL). The BTLs are assigned for each of the functional business areas and are aligned with various BALs to support End-to-End business processes. They work with the respective BALs and LOGSA to ensure data objects support the business processes. The BTLs:

(1) Provide guidance to data object owners and data czars to manage the structure, content and validity of the data for their functional areas.

(2) Identify and resolve data issues related to their business areas and elevate unresolved issues to the appropriate BAL.

(3) Contribute to the development and execution of data specific scenario tests and cutover plans.

(4) Provide guidance to the Subject Matter Experts and Data Czars for their respective business areas to ensure that the enterprise data standards and policies are implemented.

i. Data Czar. The Data Czar is a Command's key representative for legacy data cleansing/validation of their respective site's data prior to migration. Once data is migrated to LMP, the Data Czar's responsibilities will transition to the BTLs. The Data Czars:

(1) Work closely with SMEs and BTLs to resolve legacy data issues.

(2) Internally coordinate their command's data issues.

j. Subject Matter Expert (SME). The SMEs are responsible for their respective business area data at their Command sites. They work with the data on a day-by-day basis which develops close familiarity. The SMEs:

(1) Act as responsible agents for data content and complete quality and cleansing activity, thereby achieving data accuracy for their respective business area.

(2) Establish and ensure data security and availability requirements.

(3) Report unresolved issues to the BTLs.

k. Project Implementation Team. The project implementation team is comprised of both contractor support and government representatives, who work within the data framework to ensure LMP data quality. The project implementation team configures the ERP system and modifies/adds interfaces to legacy software applications to meet functional requirements and capability needs. It performs mapping and other data migration tasks. The Project Implementation Team configures the system for user access in accordance with the organization's business processes. It uses problem or issue reporting systems that capture LMP data problems, and is charged with resolution of LMP data deficiencies. It also evaluates and recommends LMP data storage and hardware host requirements.

l. The AMC LMP Data Cleansing/Validation Management IPT. The AMC maintains a LMP Data Cleansing/Validation Management IPT that advises the existing AMC management of issues related to LMP data. The members are drawn from the established LMP data cleansing/validation management framework. The group will meet at the discretion of and be chaired by an AMC G-3 representative (LOGSA). The group's membership will include representatives from LOGSA, the Army Materiel Systems Analysis Activity (AMSAA), the Program Director LMP, SASG, and Lead AMC Integration Support Office (LAISO).

7. **Summary.** This policy memorandum establishes a program that works to ensure that cleansed legacy data is migrated to and sustained in the new logistics operating environment in an effective manner. It accomplishes that by designating roles and responsibilities for optimal results.

SUBJECT: Army Materiel Command (AMC) Logistics Modernization Program Data Implementation Policy

FOR THE COMMANDER:

//Signed//
MITCHELL H. STEVENSON
Major General, USA
G-3

DEPARTMENT OF THE ARMY
HEADQUARTERS, U.S. ARMY MATERIEL COMMAND
9301 CHAPEK ROAD
FORT BELVOIR, VA 22060-5527

REPLY TO
ATTENTION OF

AMCOPS-I

19 April 2005

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Army Standardization Improvement Policy, Memo 95-1 and 95-1 change 1, "Waivers for Use of Specifications and Standards"

1. References:

   a. Army Standardization Improvement Policy, Memo 95-1 and 95-1 change 1, "Waivers for Use of Specifications and Standards". http://www.amc.army.mil/amc/rda/milspec/policyguidance.html

   b. DODD 5000.1 "The Defense Acquisition System"

   c. Defense Acquisition Guidebook

   d. Defense Standardization Program Office Policy Memo 05-3 "Elimination of Waivers to Cite Military Specifications and Standards in Solicitations and Contracts"

2. The Army waiver policy contained in reference (a) is rescinded immediately based upon references (b), (c) and (d).

3. Although the waiver requirement is rescinded, I encourage Program Executive Officers, Program Managers, and others in the acquisition and technical communities to continue to use performance based acquisition documents. This includes defense performance specifications and standards, international standardization agreements, non-government standards, and commercial item descriptions.

4. The elimination of the waiver requirement is not to be interpreted as a return to the old way of doing business, but as recognition of the cultural change that took place in DoD regarding the proper application of specifications and standards. We need to ensure that those in the acquisition and logistics communities have the flexibility to assess program requirements, make good decisions and, where appropriate, require conformance to military specifications and standards.

5. Point of contact for this matter is: Karim Abdian HQ AMC, Army Standardization Manager, DSN 656-9234, Commercial 703-806-9234, e-mail kabdian@hqamc.army.mil.

Ronald J. Davis, Jr.
Army Standardization Executive

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, D.C. 20301-3010

ACQUISITION,
TECHNOLOGY
AND LOGISTICS

JUN 23 2005

MEMORANDUM FOR SECRETARY OF THE ARMY
(ATTN: ACQUISITION EXECUTIVE)
SECRETARY OF THE AIR FORCE
(ATTN: ACQUISITION EXECUTIVE)
COMMANDING GENERAL, ARMY MATERIEL COMMAND

SUBJECT: Standard for the Exchange of Product Model Data (STEP) – ISO 10303

I am bringing the attached policy to your attention to facilitate an interoperable approach for managing product and technical data across the Department. On Oct 23, 2004, John J. Young, Jr., Assistant Secretary of the Navy (Research Development and Acquisition), signed this memorandum entitled "Department of Navy Policy on Digital Product/Technical Data." I request you implement a similar approach that adopts ISO 10303 to enhance interoperability as described in paragraph 3.1 of the attachment.

I would particularly like to highlight the importance of the referenced data exchange standard "Standard for the Exchange of Product Model Data (STEP) – ISO 10303". STEP is critical to capitalizing on entity level visibility provided under the Unique Identification (UID) initiative and likewise supports other similar efforts addressing net-centric data use. ISO 10303 is being used in pilot projects to facilitate data exchange between multiple Services, depots and contractors. By providing neutral data exchange sets, STEP enables system agnostic communications for new and legacy data systems using a common language regardless of the functional domain of the data or the naming conventions of individual data systems.

This approach exemplifies a commercial best practice that results in numerous improvements including accurate records, additional data to support equipment upkeep and replacement actions, improved manpower scheduling, increased equipment life cycles, and reduced maintenance order backlogs.

For current UID information and future results from the ongoing pilots, please visit http://www.acq.osd.mil/dpap/UID/. Questions may be addressed to Mr. Robert Leibrandt by telephone at (703) 695-1099 or by email at robert.leibrandt@osd.mil.

Kenneth J. Krieg

Attachment:
As stated

Appendix E: NIST's Economic Impact Studies Related to Manufacturing

NIST invested in several economic impact studies since 1999 that researched and assessed the impact of various influences on the manufacturing community. The executive summaries of each are included here as an appendix for reference for the PEWG. The complete studies can each be found at http://www.mel.nist.gov/msidlibrary/impact_studies.html.

Executive Summary

The emergence of low-cost communications and information processing has made it possible for firms to revolutionize the way they operate internally, especially in distributing information throughout their organizations. Through the use of Manufacturing and Enterprise Requirements Planning (MRP and ERP) systems, they can operate with lower levels of inventory, can respond more quickly to changes in customer requirements, and can eliminate or outsource costly accounting functions.

However, companies have made much less progress in improving the efficiency of communications between their facilities and those of their suppliers and customers, along what is known as their ***supply chain***. A lack of universally accepted and implemented standards for the format and content of messages that flow between supply chain partners reduces the potential for inventory and expense savings, as well as leading to duplication of effort, maintenance of redundant systems, and investment in non-ideal information processes.

In this study, we examine the current state of ***supply chain integration (SCI)***, estimate the ***economic impact of inadequate integration***, and identify opportunities for governmental organizations to provide ***critical standards infrastructures*** that will improve the efficiency of supply chain communications. We estimate the total annual costs of inadequacies in supply chain infrastructures to be in excess of $5 billion for the automotive industry, and almost $3.9 billion for the electronics industry. These figures represent about 1.2% of the value of shipments in each industry.

1 HOW WORK GETS DONE IN SUPPLY CHAINS

Firms engaged in supply-chain relationships, as customers, suppliers, or providers of services, need to share a great deal of information in the course of their interactions. Over the years, companies have managed these information flows in a number of ways, including telephone calls, letters, telex, faxes, and electronic data interchange (EDI). More recently, firms have begun using the power of the Internet to create more effective and open transmission protocols for machine-to-machine communication of the same high-frequency data now handled by traditional EDI.[1]

2 EFFICIENCY OF INFORMATION EXCHANGE

Supply chain information systems require a great deal of data input, both from automated sources (software applications, control systems, bar code readers, sensors, analytical instruments) and manual interactions. In an ideal system, each piece of data would be entered only once and be available to any system in the information network that needs it. High-frequency, routine data input tasks should be fully automated, with oversight on a periodic basis by skilled systems optimizers, such as planning or logistics personnel. In a similar manner, high-frequency information flows should be fully automated and transmitted in standard formats with common protocols.

Much evidence is available that this ideal information system integration is not evolving within industry supply chains:

- Manual data entry is widespread, even when machine sources are available; critical information is often manually reentered at many points in the chain.
- Interventions from purchasing clerks, order processors, and expediters are required to maintain supply-chain information flows.
- The use of translators to convert data from one format to another is almost universal, even between systems that are nominally compliant with established protocols.
- Organizations of all sizes and across industry tiers use “informed” estimates rather than actual or production plan data in scheduling, materials management, and expediting.

[1] It is the implementation of these Internet-based information systems that is most often referred to as SCI, even though EDI and telephone/fax are also ways of integrating supply chains.

- Large numbers of firms, especially in the lower tiers, simply operate without essential data.

The business case for better integration has been evident in the automotive industry for several years and for more than a decade in the electronics sector. As a result, a number of companies in these industries have made efforts to provide partial or total solutions, almost all resulting in either inefficient or incomplete integration. Under *inefficient integration*, systems are put in place to automate information inputs and flows, but the unavailability of a suitable standards infrastructure leads to excessive capital investment, duplication of effort, higher than optimal staffing and support levels, and inadequate organizational flexibility. In the case of *incomplete integration*, key elements of a comprehensive system are missing, or improved systems are only implemented for a subset of supply-chain partners. In the latter case, the supply chain as a whole still experiences costs well above optimal levels, and many of the gains from integration remain unrealized.

3 MARKET FAILURES IN THE PROVISION OF INFRASTRUCTURE

From the standpoint of public economics theory, the efforts of private businesses are likely to lead to inadequate standards infrastructures for at least two reasons. The first arises from the public goods nature of these standards, which inevitably leads to a free-rider problem[2] and resultant under-investment in provision of these infrastructures. The second reason is coordination failure, in which asymmetric incentives lead participants to pursue investments that are suboptimal for the industry as a whole.

Resolving these public-goods and coordination failures requires intervention from an organization outside of industry. Underinvestment can be partly corrected by government provision of research funding, by subsidies for private R&D efforts, and by agency participation in standards and infrastructure development efforts. Direct participation by a government agency can also help eliminate coordination failure, as long as industry participants are willing to accept its leadership.

[2] A free rider problem arises when firms can benefit from the actions of others in producing a public good, without themselves contributing, i.e., they may *free ride*. This gives every firm an incentive to under-invest in production of the public good. In the present case, the public good is an adequate standards infrastructure for SCI.

This study was initiated by the National Institute of Standards & Technology (NIST), an agency of the Department of Commerce whose mission includes supporting industry by helping to improve our country's technology infrastructure. The public good content of the infratechnologies underlying most industry standards often causes under-funding of needed research in the private sector. One of NIST's roles is to provide industry's standards-setting processes with these infratechnologies. Furthermore, NIST's expertise and unique research facilities can result in greater efficiency, and hence, cost savings in the development of the technical basis for standards.

Secondly, NIST's role as a third party independent of the supply chain and its competitive constraints allows it to serve several vital coordination roles as well. NIST's status as a competitively-neutral third party permits its technical experts to seek timely solutions that are optimal for the entire sector, as opposed to the technically inferior or incomplete standardization that often results when competing private entities cannot agree on the public goods content that results in optimal standards. The collaborative process used by NIST ensures that all parties have the opportunity to be represented and involved, which is not always the case with trade associations or voluntary standards groups. A NIST-led process can reduce transactions costs through its competitively-neutral leadership role in coordinating consensus building.

4 SUPPLY CHAINS IN INDUSTRY

The U.S. manufacturing sector is the largest in the world; its 15.9 million workers produced $1.85 trillion in value-added in 2001, according to the most recent government data (U.S. Census Bureau, 2001). The success of the United States in efficiently producing consumption and investment goods has relied on the optimal management of the logistics of manufacturing (i.e., forecasting demand, scheduling production, and ordering and receiving raw materials). To that end, businesses have at various times

- vertically integrated to control as many materials and interfaces as possible,
- maintained large inventory buffers to protect their operations from risk, and
- installed sophisticated planning systems to speed key information to decision-makers.

4.1 The Automotive Supply Chain

The U.S. automotive supply chain is not easy to characterize. It consists of thousands of establishments ranging in size from 50 to many thousands of employees. In addition, many of the lower-tier suppliers also supply the aerospace and other transportation industries. The sheer size of the industry is overwhelming. Manufacturing employment in the motor vehicle and motor vehicle parts industry was 949,984, or about 6.5 percent of all manufacturing employment, in 2001. Shipments of motor vehicles and motor vehicle equipment amounted to almost $403 billion in 2001, or approximately 10 percent of the value of all manufactured goods (Census Bureau, 2003).

Further complicating an analysis of the automotive supply chain is the complexity of the relationships between customers and suppliers. OEMs design and produce only some of the 15,000 parts and accessories that make up an automobile; they procure others from first-tier suppliers. The first-tier suppliers can in turn outsource to subtier suppliers. A company's position in the supply chain may differ depending on the part and the customer. Thus, a company that is a first-tier supplier of transmissions to one OEM may be a subtier supplier of other parts to the same or other OEMs.

At the production stage of the product life cycle, most of the information exchanged between an OEM and its vendors concerns ordering and schedule requests, acknowledgements of messages received, ship notices, and order tracking. To assure on-time delivery, there is also information exchange with logistics functions (i.e., warehousing and shipping). Communication with logistics often means communication between the OEM and the supplier, but it could also mean communication with a third party to whom logistics has been outsourced.

4.2 The Electronics Industry

The electronics industry is an aggregation of several widely disparate product segments, from radar equipment to biomedical devices. A combination of factors, including mass customization, rapidly shrinking product life cycles, lean inventory practices, complex multisource supply chains, and rising global competition, have created a highly competitive industry. Electronics products are brought together by commonality in components, manufacturing technologies, or consumption patterns.

With almost $430 billion in sales in 2001, or approximately 10 percent of the value of all manufactured goods, and 1.6 million employees, electronics is the third-largest manufacturing industry, behind chemicals and transportation equipment (U.S. Census Bureau, 2003). Of total electronics sales, semiconductors and electronic components made up the majority of sales followed by computers and peripherals and telecommunications equipment.

5 METHODOLOGY FOR MEASURING COSTS

In this study, we modeled our analytical approach on ones used successfully by RTI in several previous economic studies for NIST, including an *Interoperability Cost Analysis of the U.S. Automotive Supply Chain*, an *Economic Impact Assessment of the International Standard for the Exchange of Product Model Data (STEP)*, and *The Economic Impact of Inadequate Infrastructure for Software Testing* (Brunnermeier and Martin, 1999; Gallaher and O'Connor, 2002; and RTI, 2002, respectively). We began by developing a task/cost matrix for the industry sectors being studied. This matrix identified the most important information flows for which excessive costs were likely being incurred. Representative case studies or in-depth interviews were then used to estimate excessive costs for each cell of the task/cost matrix. A large-scale survey was conducted to provide data that will allow us to estimate the incidence of these costs across the heterogeneous population of the entire industry. Finally, secondary data on industry sales and employment and wage rates allowed aggregation to industry-level impacts.

Primary data collection was necessary to inform the impact metrics developed during the conceptual phase of the study. As it would be difficult or impossible to design a single instrument to collect information from a cross-section of the industry's firms, much of the data needed was obtained from a small number of in-depth interviews. These structured conversations were similar to the case studies done in many qualitative analyses, although in this case the intent was to gather components of excessive costs borne by firms due to a lack of adequate information infrastructure. By summing these components of cost, we developed an estimate of the cost of inadequate standards for SCI.

6 RESULTS AND COST CALCULATIONS

The initial thrust our data collection for this study was the series of nine in-depth interviews we conducted during the summer and fall of 2003. Several of these firms have *traditional relationships* with their suppliers, indicating that they communicate primarily over the telephone and by faxing machine-generated documents. These firms required the highest levels of effort to accomplish their supply chain information tasks.

Firms with *incomplete integration* most often used EDI for their customer communications, and several reported using EDI with their larger, more sophisticated suppliers. In addition, the first-tier firms in this category were obligated to support one or more proprietary logistics systems by their customers. As a result, their costs were a combination of planning and coordination effort and information systems charges, including license fees, in-house software development, contract software costs, and charges for EDI translators.

Finally, we estimated these types of costs for firms we would characterize as having an *ideally integrated supply chain information system*. Despite their high degree of automation, they still experienced some costs of inefficient integration, mostly in dealing with suppliers with a low degree of e-capability and customers that required use of proprietary systems.

6.2 Large-Scale Survey Results

With the results of the in-depth interviews in hand, we proceeded with large-scale surveys of the two industry sectors. The automotive portion of the survey was fielded with an AIAG working group through an email list-serve announcement and was completed by logistics or information systems professionals actively working on supply chain integration issues. The survey posed questions about the degree of integration and labor effort required in each of the major supply chain processes, the number of software systems supported and their annual costs, and effort expended in several avoidance and mitigation areas. Results from the survey used in quantifying the cost of inadequate integration are summarized in Table ES-1.

In electronics, we were fortunate to be granted access to results from a RosettaNet survey conducted in the fall of 2003 by San Jose State University. Although we did not have influence on the questions posed in the survey, they were quite similar to the core questions in our survey and yielded a reasonable profile of the degree of integration of electronics firms in the process areas we had identified in the in-depth interviews. The results from this survey used in quantifying costs are summarized in Table ES-2.

Table ES-1. Relative Use of Different Communication Methods by Representative Automotive Firms

	With Suppliers (%)	With Customers (%)
XML/Internet	22.6	22.5
EDI	45.2	45.1
Paper/Fax	32.2	32.4

Table ES-2. Relative Use of Logistics and Accounting Process Integration by Electronics Firms

	Traditional (%)	Incompletely Integrated (%)	Ideally Integrated (%)
Customer Logistics	46	32	22
Customer Accounting	43	34	23
Supplier Logistics	51	14	35
Supplier Accounting	52	20	28

Note: Logistics refers to communications about and coordination of production schedules, inventory levels, shipment information, etc.

6.3 Aggregating Costs to Industry Level

With complete information on estimated effort levels, degree of integration by process, and industry data on sales and wage rates, it was possible to estimate the total annual costs to U.S. firms of inadequacies in their supply chain infrastructures. Using the methodology described above, we estimated total costs for the automotive industry slightly in excess of $5 billion per year, which equates to about 1.25 percent of total value of shipments. In electronics, the figures equate to almost $3.9 billion per year, or an almost identical 1.22 percent of the value of shipments. In both industries, roughly 50 percent of the total costs were in dealings with suppliers, while nearly 40 percent arose from interactions with customers, figures which were roughly constant along the supply chain.

In order to put these figures into perspective, it may be helpful to consider the costs of operating under each of the integration scenarios to a typical firm in the automotive and electronics industries. Using data from the most recent Economic Census reports, we calculate that the value of shipments for the average automotive parts establishment was $30 million in 1997. Had such a facility operated with traditional supply chain systems, its managers could expect to incur almost $500,000 in annual costs for the logistics and accounting functions described above. Investing in incomplete integration would lower that figure to about $400,000 per year, while implementing an ideal integration strategy would result in a total of $150,000 in annual costs.

In the electronics industry, the average value of shipments for a semiconductor facility is $71 million per year, while a typical computer maker produces about $55 million in annual shipment value. Using the summary data from Table 7-7, we can estimate that a semiconductor facility operating traditionally would incur annual expenses of $1.15 million, while a computer maker would see logistics and accounting costs of about $900,000. Once again, incomplete supply chain integration would lower costs only slightly. Implementation of an ideal system, however, would reduce these expenses substantially – to slightly more than $350,000 for a semiconductor establishment, and to $280,000 for the slightly smaller computer facility.

7 IMPLICATIONS OF THE STUDY

In this study, we have described how the emergence of low cost communications and information processing has made it possible for manufacturing firms to fundamentally change the way they manage their supply chains. Our quantitative analysis suggests that the total cost of managing supplier-customer inventory and schedule information exceeds $5 billion per year in the automotive industry, and almost $4 billion in the electronics sector. Almost all of this cost could be eliminated if firms implemented true interoperability, which we have termed 'ideal supply chain integration'.

A handful of firms in both automotive and electronics industries have come close to achieving this ideal state with some or most of their supply chain partners. Industry-wide adoption of interoperability will require significant investments in standards and other critical infrastructures that are not in place today. The evidence from our study strongly suggests that businesses in these two key sectors have not made sufficient infrastructure investments to capture the benefits from interoperability. The public goods nature of these infrastructures, along with possible coordination failures, suggests that government involvement is needed to support the optimal level of investment.

NIST's expressed purpose in commissioning this study was to determine if there was evidence of market failures in the creation of the critical infrastructures required to create effective integration. A secondary objective was to gather data that would enlighten potential roles taken by NIST's Manufacturing Engineering Laboratory (MEL) and Electronics and Electrical Engineering Laboratory (EEEL) in industry-wide consortia working on improving supply chain information systems. In the judgment of the present authors, the study's results provide support for both of these aims.

Planning Report 02-5

Economic Impact Assessment of the International Standard for the Exchange of Product Model Data (STEP) in Transportation Equipment Industries

Prepared by:
RTI International
for

National Institute of
Standards & Technology

Program Office
Strategic Planning and
Economic Analysis Group

December 2002

NIST
U.S Department of Commerce
Technology Administration

Executive Summary

The Standard for Exchange of Product model data (STEP) is an international standard designed to address interoperability problems encountered in the exchange of digital product information. STEP is a suite of standards enabling manufacturing companies to exchange digital representations of engineering and manufacturing data. The first 12 parts of STEP were formally approved as international standards in January 1995. Since then, an additional 18 parts have become international standards. Over 20 more are nearing international standard status, with many more in earlier development stages.

STEP has the potential to save $928 million (2001$) per year by reducing interoperability problems in the automotive, aerospace, and shipbuilding industries alone. Many other industries could achieve similar savings.

The National Institute of Standards and Technology (NIST) has made significant contributions to STEP, beginning in the mid 1980s and continuing today. NIST has contributed to the development of the STEP standard, the integration of STEP functionality into applications, and the adoption of STEP functionality by end users. NIST also participated in several public-private partnerships involving demonstrations and development projects with software developers, industry, and other federal agencies. Many of these initiatives were designed to demonstrate STEP's economic advantages relative to defender technologies and promote its deployment.

The objective of this study is to conduct an economic impact assessment of STEP's use by transportation equipment industries, namely the automotive, aerospace, shipbuilding, and specialty tool and die industries. Both the full potential and current realized benefits are quantified. In addition, the study investigates the impact of NIST's administrative and technical contributions to STEP.

Currently, approximately 17 percent of the potential benefits of STEP quantified within the scope of this study are being realized.

We estimate the economic value of the efficiency gains due to improved data exchange enabled by using STEP, and we quantify NIST's contributions to those gains.

Data collected from industry surveys and case studies are used to estimate the potential benefits of existing STEP capabilities. We estimate that STEP has the potential of save $928 million (2001$) per year by reducing interoperability problems in the automotive, aerospace, and shipbuilding industries. Currently approximately 17 percent ($156 million) of the potential benefits of STEP quantified within the scope of this study are being realized.

Table ES-1 presents the present value of benefit and costs, along with the ratio of benefits to costs and the social rate of return for domestic STEP activities. Benefits and costs were projected through 2010 assuming a 75 percent penetration rate for STEP in 2010. STEP development costs include expenditures by government agencies, software vendors, and industry users, and were estimated to be approximately $17 million per year in the late 1990s.

Table ES-1. Measures of Economic Return

	Economic Returns to STEP	Returns to NIST Expenditures
Present Value of Benefits (millions 2001$) [b]	1,186	206
Present Value of Costs (millions 2001$)[a,b]	(104)	(26)
Net Present Value (millions 2001$)[b]	1,082	180
Benefit-to-Cost Ratio	11.4	7.9
Social Rate of Return (percent)[b]	36.1	31.6

[a]Costs are presented as negative numbers.

[b]OMB-recommended social discount rate of 7 percent is used.

Table ES-1 also estimates returns to NIST's approximate $41.7 million (present value $26 million 2001$) investment to support STEP development and software implementation. Industry indicated that NIST's activities accelerated the development and adoption of STEP by about 1 year, yielding and an economic impact of $180 million (NPV 2001$).

ES.1 BENEFITS FROM STEP

Benefits accrue to end users through increased interoperability of computer-aided design, engineering, and manufacturing and product data management systems (collectively referred to as CAx in this study) used in the product design supply chain. These benefits can be generally categorized as

- decreased avoidance costs,
- decreased mitigation costs, and
- decreased delay costs (RTI, 1999).

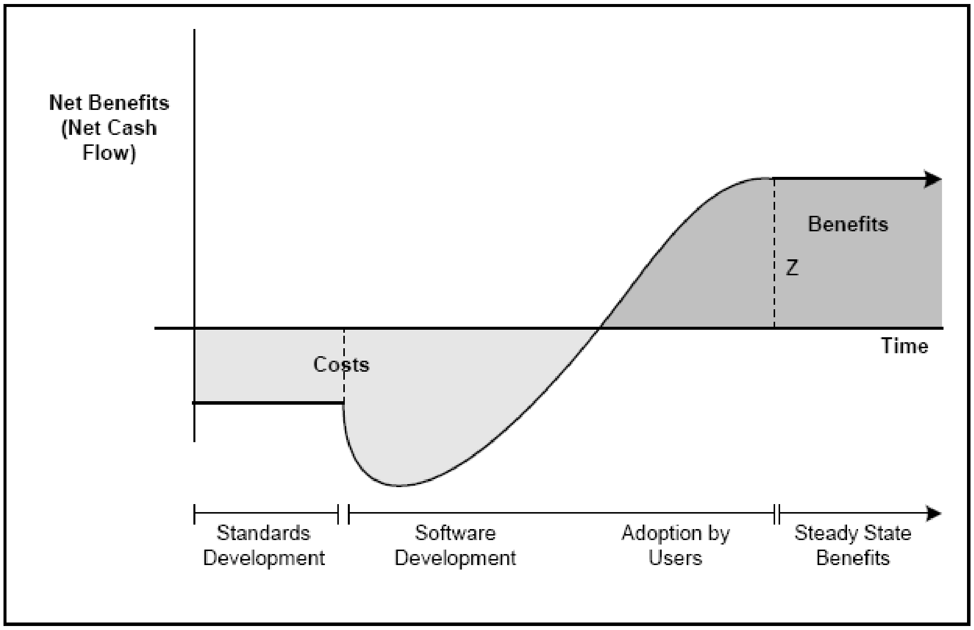
The primary economic benefits are realized by end users of these systems in the automotive, aerospace, and shipbuilding industries. However, for these benefits to be realized by end users, resources must be invested to make STEP functionality available. These resource investments include

- government sector involvement in the standards development process and demonstration of STEP;
- software developers' costs associated with the standards development and demonstration (referred to as R&D); and expenditures to integrate STEP functionality into commercial products; and
- end users' costs associated with the standards development, demonstration, and implementation of STEP.

Benefits and costs actually occur as flows over time. Figure ES-1 illustrates the net benefits (benefits less costs) over time. The curve in Figure ES-1 represents the total change in economic welfare for all entities over the life-cycle a particular STEP functionality or application protocol. The costs of standards development, infrastructure tools, and software development are shown occurring early in the life-cycle of STEP functionality. Once commercial products are available with STEP functionality, aggregate manufacturers' benefits increase as adoption occurs until the CAx markets are saturated.[1] "Steady state" benefits (Z) continue to accrue until the STEP functionality incorporated with the software becomes obsolete.

[1]In our context, net benefits to manufacturers include decreased interoperability expenditures less employee training costs. The cost of software purchases are not included because they have been netted out of the economic welfare by increased revenue for software developers.

Figure ES-1. Flow of Costs and Benefits



Users of CAx software in the supply chains incur several types of costs related to imperfect interoperability. Reducing these costs are the benefits of STEP. We focus on three types of interoperability costs. Manufacturers incur *avoidance costs* to prevent technical interoperability problems before they occur, *mitigating costs* to address interoperability problems after they have occurred, and *delay costs* that arise from interoperability problems that delay the introduction of a new product.

Avoidance costs are primarily associated with maintaining redundant systems and include

- the cost of purchasing redundant CAx systems for the purpose of same format data exchange,
- training cost for maintain designers skills in redundant CAx systems,
- productivity loss due to designers working on systems they are less familiar with,
- IT staff to support redundant CAx systems, and

- outsourcing costs incurred when outside companies are hired to provide data exchange services.

Mitigating costs include

- the cost of reworking models are part of the transfer process, and
- the cost of manually reentering data when methods of data exchange are unavailable or unsatisfactory.

Delay costs include

- profits lost due to decline in market share caused by delays, and
- profits lost due to delay of revenues (discounts on the value of future profits).

Interoperability problems in manufacturing industries affect society's economic welfare in two ways: by increasing the cost of designing and producing final products and by delaying the introduction of new improved final products. An increase in the cost of designing and producing a new automobile or aircraft may lead to an increase in the equilibrium price of their respective markets. However, for the purpose of this study we measure all benefits of STEP at the manufacturers' level of the supply chain in terms of decreased production costs and accelerated new product entry. We do not attempt to partition these impacts into producer and consumer surplus.

ES.2 SOCIAL COSTS OF STEP

Participants throughout the supply chain contributed to the development, demonstration, and implementation of STEP. The social costs are mostly the staff time contributed to standards development, software development, and adoption by end users. These costs include labor hours, overhead, and dues and fees paid into industry standards bodies. From 1987 to 2001, society has incurred $198.4 million (2001$) in expenditures in STEP development.

Public Sector Expenditures are segmented into NIST expenditures and non-NIST public expenditures, including defense-related funding. Using information supplied by NIST, we explicitly quantify all NIST expenditures on STEP-related activities. These include contributions to the standards development process, software tools, and testing services ($62.6 million).

Software developers' expenditures related to STEP include expenditures on the three standards and tools development categories, plus expenditures for implementing STEP functionality into their CAx products. During the telephone interviews with software developers, we asked them to estimate the resources they invested in the standards development process, as well as their expenditures for integrating STEP into their products ($54.3 million).

Users of CAx software have also been integrally involved in the STEP development process. For example, many manufacturers have participated in standards development and demonstration pilot programs ($81.5 million).

ES.3 ECONOMIC IMPACT ESTIMATES

Table ES-2 presents an overview of the empirical findings. STEP has the potential to reduce interoperability costs in the three industries studied by approximately $928 million (2001$) annually. The automotive industry represents the largest share of potential benefits (51 percent), followed by aerospace (27 percent), and shipbuilding (16 percent).

Table ES-2. Potential Annual Benefits of STEP (millions 2001$)

	Potential Benefits of STEP			Current Benefits
Industry	Avoidance	Mitigation	Total	Total
Automotive	$253.1	$217.1	$470.2	$86.6
Aerospace	$108.4	$144.6	$253.0	$35.2
Shipbuilding	$76.4	$70.7	$147.1	$25.7
Specialty Tool & Die	$13.5	$44.4	$57.9	$9.1
Total	$451.4	$476.8	$928.2	$156.6

Avoidance cost savings accounted for approximately half of the potential benefits of STEP. Eighty percent of avoidance costs were labor costs associated with the use and support of redundant CAx systems. Mitigation costs resulting from file transfer and data reentry accounted for the balance of benefits. No company interviewed indicated that they experienced delay costs associated with interoperability problems.

STEP has the potential to reduce CAx interoperability costs in the three industries studied by approximately $928 million (2001$) annually. STEP development costs, were estimated to be approximately $17 million per year during the mid to late 1990s.

The current benefits resulting from STEP use in 2001 are estimated to be approximately $156 million. Realized benefits represent approximately 17 percent of STEP's estimated potential, with most current benefits again realized by the automotive industry.

Although this analysis estimates that the potential annual benefit, based on 2001 data, of STEP is $928 million for these industries, it is unlikely that STEP will experience full adoption within a short time frame.

To calculate measures of return, which are presented in Section 8, the STEP penetration rate is assumed to be 75 percent in 2010. This yields a projected annual benefit of STEP of about 697 million (2001$) in 2010. STEP penetration therefore moves from 0 percent in 1994 to 17 percent in 2001 to 75 percent in 2010. Forecasting STEP's rate of diffusion is difficult because it is in the early stages of adoption. Its diffusion is a function of the number of current adopters, the number of potential adopters, and the rate at which information and knowledge pass from one agent to another. Anecdotal evidence collected during the surveys and case studies indicates that a 75 percent penetration rate is a reasonable expectation for 2010.

Planning Report 02-3

The Economic Impacts of Inadequate Infrastructure for Software Testing

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NIST
U.S Department of Commerce
Technology Administration

Executive Summary

Software has become an intrinsic part of business over the last decade. Virtually every business in the U.S. in every sector depends on it to aid in the development, production, marketing, and support of its products and services. Advances in computers and related technology have provided the building blocks on which new industries have evolved. Innovations in the fields of robotic manufacturing, nanotechnologies, and human genetics research all have been enabled by low cost computational and control capabilities supplied by computers and software.

In 2000, total sales of software reached approximately $180 billion. Rapid growth has created a significant and high-paid workforce, with 697,000 employed as software engineers and an additional 585,000 as computer programmers.

Reducing the cost of software development and improving software quality are important objectives of the U.S. software industry. However, the complexity of the underlying software needed to support the U.S.'s computerized economy is increasing at an alarming rate. The size of software products is no longer measured in terms of thousands of lines of code, but millions of lines of code. This increasing complexity along with a decreasing average market life expectancy for many software products has heightened concerns over software quality.

Software nonperformance and failure are expensive. The media is full of reports of the catastrophic impact of software failure. For example, a software failure interrupted the New York Mercantile Exchange and telephone service to several East Coast cities in

February 1998 (*Washington Technology*, 1998). Headlines frequently read, "If Microsoft made cars instead of computer programs, product-liability suits might now have driven them out of business." Estimates of the economic costs of faulty software in the U.S. range in the tens of billions of dollars per year and have been estimated to represent approximately just under 1 percent of the nation's gross domestic product (GDP).

"In analyzing repair histories of 13 kinds of products gathered by *Consumer Reports, PC World* found that roughly 22 percent [of PCs] break down every year—compared to 9 percent of VCRs, 7 percent of big-screen TVs, 7 percent of clothes dryers and 8 percent of refrigerators" (Barron, 2000).

In actuality many factors contribute to the quality issues facing the software industry. These include marketing strategies, limited liability by software vendors, and decreasing returns to testing and debugging.

At the core of these issues is the difficulty in defining and measuring software quality. Common attributes include functionality, reliability, usability, efficiency, maintainability, and portability. But these quality metrics are largely subjective and do not support rigorous quantification that could be used to design testing methods for software developers or support information dissemination to consumers. Information problems are further complicated by the fact that even with substantial testing, software developers do not truly know how their products will perform until they encounter real scenarios.

The objective of this study is to investigate the economic impact of an inadequate infrastructure for software testing in the U.S. The National Institute of Standards and Technology (NIST) undertook this study as part of joint planning with industry to help identify and assess technical needs that would improve the industry's software testing capabilities. The findings from this study are intended to identify the infrastructure needs that NIST can supply to industry through its research programs.

To inform the study, RTI conducted surveys with both software developers and industry users of software. The data collected were used to develop quantitative estimates of the economic impact of inadequate software testing methods and tools. Two industry groups were selected for detailed analysis: automotive and aerospace equipment manufacturers and financial services providers and related electronic communications equipment manufacturers. The findings from these two industry groups were then used as the basis for estimating the total economic impact for U.S. manufacturing and services sectors.

Based on the software developer and user surveys, the national annual costs of an inadequate infrastructure for software testing is estimated to range from $22.2 to $59.5 billion.[1] Over half of these costs are borne by software users in the form of error avoidance and mitigation activities. The remaining costs are borne by software developers and reflect the additional testing resources that are consumed due to inadequate testing tools and methods.

ES.1 ISSUES OF SOFTWARE QUALITY

Quality is defined as the bundle of attributes present in a commodity and, where appropriate, the level of the attribute for which the consumer (software users) holds a positive value. Defining the attributes of software quality and determining the metrics to assess the relative value of each attribute are not formalized processes. Compounding the problem is that numerous metrics exist to test each quality attribute.

Because users place different values on each attribute depending on the product's use, it is important that quality attributes be observable to consumers. However, with software there exists not only asymmetric information problems (where a developer has more information about quality than the consumer), but also instances where the developer truly does not know the quality of his own product. It is not unusual for software to become technically obsolete before its performance attributes have been fully demonstrated under real-world operation conditions.

As software has evolved over time so has the definition of software quality attributes. McCall, Richards, and Walters (1977) first attempted to assess quality attributes for software. His software quality model characterizes attributes in terms of three categories: product operation, product revision, and product transition. In 1991, the International Organization for Standardization (ISO) adopted ISO 9126 as the standard for software quality (ISO, 1991).

[1]Note that the impact estimates do not reflect "costs" associated with mission critical software where failure can lead to extremely high costs such as loss of life or catastrophic failure. Quantifying these costs was beyond the scope of the study.

It is structured around six main attributes listed below (subcharacteristics are listed in parenthesis):

- functionality (suitability, accurateness, interoperability, compliance, security)
- reliability (maturity, fault tolerance, recoverability)
- usability (understandability, learnability, operability)
- efficiency (time behavior, resource behavior)
- maintainability (analyzability, changeability, stability, testability)
- portability (adaptability, installability, conformance, replaceability)

Although a general set of standards has been agreed on, the appropriate metrics to test how well software meets those standards are still poorly defined. Publications by IEEE (1988, 1996) have presented numerous potential metrics that can be used to test each attribute. These metrics include

- fault density,
- requirements compliance,
- test coverage, and
- mean time to failure.

The problem is that no one metric is able to unambiguously measure a particular quality attribute. Different metrics may give different rank orderings of the same attribute, making comparisons across products difficult and uncertain.

ES.2 SOFTWARE TESTING INADEQUACIES

Software testing is the action of carrying out one or more tests, where a test is a technical operation that determines one or more characteristics of a given software element or system, according to a specified procedure. The means of software testing is the hardware and/or software and the procedures for its use, including the executable test suite used to carry out the testing (NIST, 1997).

Historically, software development focused on writing code and testing specific lines of that code. Very little effort was spent on determining its fit within a larger system. Testing was seen as a necessary evil to prove to the final consumer that the product worked. As shown in Table ES-1, Andersson and Bergstrand (1995) estimate that 80 percent of the effort put into early software

Table ES-1. Allocation of Effort

	Requirements Analysis	Preliminary Design	Detailed Design	Coding and Unit Testing	Integration and Test	System Test
1960s – 1970s	10%			80%	10%	
1980s	20%		60%		20%	
1990s	40%	30%		30%		

Source: Andersson, M., and J. Bergstrand. 1995. "Formalizing Use Cases with Message Sequence Charts." Unpublished Master's thesis. Lund Institute of Technology, Lund, Sweden.

development was devoted to coding and unit testing. This percentage has changed over time. Starting in the 1970s, software developers began to increase their efforts on requirements analysis and preliminary design, spending 20 percent of their effort in these phases.

More recently, software developers started to invest more time and resources in integrating the different pieces of software and testing the software as a unit rather than as independent entities. The amount of effort spent on determining the developmental requirements of a particular software solution has increased in importance. Forty percent of the software developer effort is now spent in the requirements analysis phase.

Software testing infrastructure improvements include enhanced

- integration and interoperability testing tools,
- automated generation of test code,
- methods for determining sufficient quality for release, and
- performance metrics and measurement procedures.

Testing activities are conducted throughout all the development phases shown in Table ES-1. Formal testing conducted by independent test groups accounts for about 20 percent of labor costs. However, estimates of total labor resources spent testing by all parties range from 30 to 90 percent (Beizer, 1990).

The worldwide market for software testing tools was $931 million in 1999 and is projected to grow to more than $2.6 billion by 2004 (Shea, 2000). However, such testing tools are still fairly primitive. The lack of quality metrics leads most companies to simply count the number of defects that emerge when testing occurs. Few organizations engage in other advanced testing techniques, such as forecasting field reliability based on test data and calculating defect density to benchmark the quality of their product against others.

Numerous issues affect the software testing infrastructure and may lead to inadequacies. For example, competitive market pressures may encourage the use of a less than optimal amount of time, resources, and training for the testing function (Rivers and Vouk, 1998), and with current software testing tools developers have to determine whether applications and systems will interoperate.

In addition, the need for *certified* standardized test technology is increasing. The development of these tools and the accompanying testing suites often lag behind the development of new software applications (ITToolbox, 1999). Standardized testing tools, suites, scripts, reference data, reference implementations, and metrics that have undergone a rigorous certification process would have a large impact on the inadequacies listed above. For example, the availability of standardized test data, metrics, and automated test suites for performance testing would make benchmarking tests less costly to perform. Standardized automated testing scripts along with standard metrics would also provide a more consistent method for determining when to stop testing.

In some instances, developing conformance testing code can be more time consuming and expensive than developing the software product being tested. Addressing the high testing costs is currently the focus of several research initiatives in industry and academia. Many of these initiatives are based on modeling finite state machines, combinatorial logic, or other formal languages such as Z (Cohen et al., 1996; Tai and Carver, 1995; NIST, 1997; Apfelbaum and Doyle, 1997).

ES.3 SOFTWARE TESTING COUNTERFACTUAL SCENARIOS

To estimate the costs attributed to an inadequate infrastructure for software testing, a precise definition of the counterfactual world is needed. Clearly defining what is meant by an "inadequate" infrastructure is essential for eliciting consistent information from industry respondents.

In the counterfactual scenarios the intended design *functionality* of the software products released by developers is kept constant. In other words, the fundamental product design and intended product characteristics will not change. However, the realized level of functionality may be affected as the number of bugs (also referred to as defects or errors) present in released versions of the software decreases in the counterfactual scenarios.

An improved software testing infrastructure would allow developers to find and correct *more* errors *sooner* with *less* cost.

The driving technical factors that do change in the counterfactual scenarios are *when* bugs are discovered in the software development process and the *cost* of fixing them. An improved infrastructure for software testing has the potential to affect software developers and users by

- removing more bugs before the software product is released,
- detecting bugs earlier in the software development process, and
- locating the source of bugs faster and with more precision.

Note that a key assumption is that the *number* of bugs introduced into software code is constant regardless of the types of tools available for software testing; bugs are errors entered by the software designer/programmer and the initial number of errors depends on the skill and techniques employed by the programmer.

Because it may not be feasible or cost effective to remove all software errors prior to product release, the economic impact estimates were developed relative to two counterfactual scenarios. The first scenario investigates the cost reductions if all bugs and errors could be found in the same development stage in which they are introduced. This is referred to as the cost of an inadequate software testing infrastructure. The second scenario investigates the cost reductions associated with finding an increased percentage (but not 100 percent) of bugs and errors closer to the development stages where they are introduced. The second scenario is referred to as cost reduction from "feasible" infrastructure improvements. For the "feasible" infrastructure improvements scenario, developers were asked to estimate the potential cost savings associated with enhanced testing tools and users were asked to estimate cost savings if the software they purchase had 50 percent fewer bugs and errors.

ES.4 ECONOMIC IMPACT OF AN INADEQUATE SOFTWARE TESTING INFRASTRUCTURE: AUTOMOTIVE AND AEROSPACE INDUSTRIES

We conducted a case study with software developers and users in the transportation equipment manufacturing sector to estimate the economic impact of an inadequate infrastructure for software testing. The case study focused on the use of computer-aided design/computer-aided manufacturing/computer-aided engineering

(CAD/CAM/CAE) and product data management (PDM) software. Interviews were conducted with 10 software developers (vendors) and 179 users of these products.

Developers of CAD/CAM/CAE and PDM software indicated that in the current environment, software testing is still more of an art than a science, and testing methods and resources are selected based on the expert judgment of senior staff. Respondents agreed that finding the errors early in the development process greatly lowered the average cost of bugs and errors. Most also indicated that the lack of historic tracking data and inadequate tools and testing methods, such as standard protocols approved by management, available test cases, and conformance specification, limited their ability to obtain sufficient testing resources (from management) and to leverage these resources effectively.

Users of CAD/CAM/CAE and PDM software indicated that they spend significant resources responding to software errors (mitigation costs) and lowering the probability and potential impact of software errors (avoidance costs). Approximately 60 percent of the automotive and aerospace manufacturers surveyed indicated that they had experienced significant software errors in the previous year. For these respondents who experienced errors, they reported an average of 40 major and 70 minor software bugs per year in their CAD/CAM/CAE or PDM software systems.

Table ES-2 presents the economic impact estimates for the development and use of CAD/CAM/CAE and PDM software in the U.S. automotive and aerospace industries. The total cost impact on these manufacturing sectors from an inadequate software testing infrastructure is estimated to be $1.8 billion and the potential cost reduction from feasible infrastructure improvements is $0.6 billion. Users of CAD/CAM/CAE and PDM software account for approximately three-fourths of the total impact, with the automotive industry representing about 65 percent and the aerospace industry representing 10 percent. Developers account for the remaining one-fourth of the costs.

Table ES-2. Cost Impacts on U.S. Software Developers and Users in the Transportation Manufacturing Sector Due to an Inadequate Testing Infrastructure ($ millions)

	The Cost of Inadequate Software Testing Infrastructure (billions)	Potential Cost Reduction from Feasible Infrastructure Improvements (billions)
Software Developers		
CAD/CAM/CAE and PDM	$373.1	$157.7
Software Users		
Automotive	$1,229.7	$377.0
Aerospace	$237.4	$54.5
Total	$1,840.2	$589.2

ES.5 ECONOMIC IMPACT OF AN INADEQUATE SOFTWARE TESTING INFRASTRUCTURE: FINANCIAL SERVICES SECTOR

We conducted a second case study with four software developers and 98 software users in the financial services sector to estimate the economic impact of an inadequate infrastructure for software testing. The case study focused on the development and use of Financial Electronic Data Interchange (FEDI) and clearinghouse software, as well as the software embedded in routers and switches that support electronic data exchange.

> Financial service software developers said that better testing tools and methods used during software development could reduce installation expenditures by 30 percent.

All developers of financial services software agreed that an improved system for testing was needed. They said that an improved system would be able to track a bug back to the point where it was introduced and then determine how that bug influenced the rest of the production process. Their ideal testing infrastructure would consist of close to real time testing where testers could remedy problems that emerge right away rather than waiting until a product is fully assembled. The major benefits developers cited from an improved infrastructure were direct cost reduction in the development process and a decrease in post-purchase customer support. An additional benefit that respondents thought would emerge from an improved testing infrastructure is increased confidence in the quality of the product they produce and ship. The major selling characteristic of the products they create is the certainty that that product will accomplish a particular task. Because of the real time nature of their products, the reputation loss can be great.

Approximately two-thirds of the users of financial services software (respondents were primarily banks and credit unions) surveyed indicated that they had experienced major software errors in the previous year. For the respondents that did have major errors, they reported an average of 40 major and 49 minor software bugs per year in their FEDI or clearinghouse software systems. Approximately 16 percent of those bugs were attributed to router and switch problems, and 48 percent were attributed to transaction software problems. The source of the remaining 36 percent of errors was unknown. Typical problems encountered due to bugs were

- increased person-hours used to correct posting errors,
- temporary shut down leading to lost transactions, and
- delay of transaction processing.

Table ES-3 presents the empirical findings. The total cost impact on the financial services sector from an inadequate software testing infrastructure is estimated to be $3.3 billion. Potential cost reduction from feasible infrastructure improvements is $1.5 billion.

Table ES-3. Cost Impacts on U.S. Software Developers and Users in the Financial Services Sector Due to an Inadequate Testing Infrastructure ($ millions)

	The Cost of Inadequate Software Testing Infrastructure	Potential Cost Reduction from Feasible Infrastructure Improvements
Software Developers		
Router and switch	$1,897.9	$975.0
FEDI and clearinghouse	$438.8	$225.4
Software Users		
Banks and savings institutions	$789.3	$244.0
Credit unions	$216.5	$68.1
Total Financial Services Sector	$3,342.5	$1,512.6

Software developers account for about 75 percent of the economic impacts. Users represented the remaining 25 percent of costs, with banks accounting for the majority of user costs.

ES.6 NATIONAL IMPACT ESTIMATES

The two case studies generated estimates of the costs of an inadequate software testing infrastructure for software developers and users in the transportation equipment manufacturing and financial services sectors. The per-employee impacts for these sectors were extrapolated to other manufacturing and service industries to develop an approximate estimate of the economic impacts of an inadequate infrastructure for software testing for the total U.S. economy.

Table ES-4 shows the national annual cost estimates of an inadequate infrastructure for software testing are estimated to be $59.5 billion. The potential cost reduction from feasible infrastructure improvements is $22.2 billion. This represents about 0.6 and 0.2 percent of the U.S.'s $10 trillion dollar GDP, respectively. Software developers accounted for about 40 percent of total impacts, and software users accounted for the about 60 percent.

Table ES-4. Costs of Inadequate Software Testing Infrastructure on the National Economy

	The Cost of Inadequate Software Testing Infrastructure (billions)	Potential Cost Reduction from Feasible Infrastructure Improvements (billions)
Software developers	$21.2	$10.6
Software users	$38.3	$11.7
Total	$59.5	$22.2

99-1 Planning Report

Interoperability Cost Analysis of the U.S. Automotive Supply Chain

Prepared by:
Research Triangle Institute

for

National Institute of Standards & Technology

Program Office
Strategic Planning and Economic Analysis Group

March 1999

U.S Department of Commerce
Technology Administration

Executive Summary

> Interoperability is the ability to communicate product data across different production activities. It is essential to the productivity and competitiveness of many industries because efficient design and manufacturing require the coordination of many different participants and processes that rely on a digital representation of the product.

The National Institute for Standards and Technology (NIST) is the only U.S. research laboratory or institute whose primary mission is supporting economic growth. As part of this mission, NIST provides technical infrastructure to U.S.-based industries. NIST's Manufacturing Engineering Laboratory (MEL) provides manufacturing infrastructure, technology, measurements, and standards. MEL is currently involved in developing standards that promote interoperability among members of the U.S. automotive supply chain.

The objective of this study was to assess the costs of imperfect interoperability to the U.S. automotive supply chain and to describe the sources of these costs. By understanding the sources and magnitude of inefficiencies caused by interoperability problems, NIST can better determine the potential impact of its programs and focus them to maximize program effectiveness.

This study estimates that imperfect interoperability imposes at least $1 billion per year on the members of the U.S. automotive supply chain. By far, the greatest component of these costs is the resources devoted to repairing or reentering data files that are not usable for downstream applications. This estimate is conservative because we could not quantify all sources of interoperability costs.

ES.1 BACKGROUND

The productivity and competitiveness of the U.S. domestic automobile industry is important to the overall performance of the U.S. economy. The auto industry is responsible for about 9 percent of the total value of manufactured goods in the U.S. and 4 percent of manufacturing employment (U.S. Department of Commerce, 1998). U.S. consumers spend about 5 percent of total personal expenditures on motor vehicles and parts (BEA, 1998). The motor vehicle industry is also a major end-user for many materials.

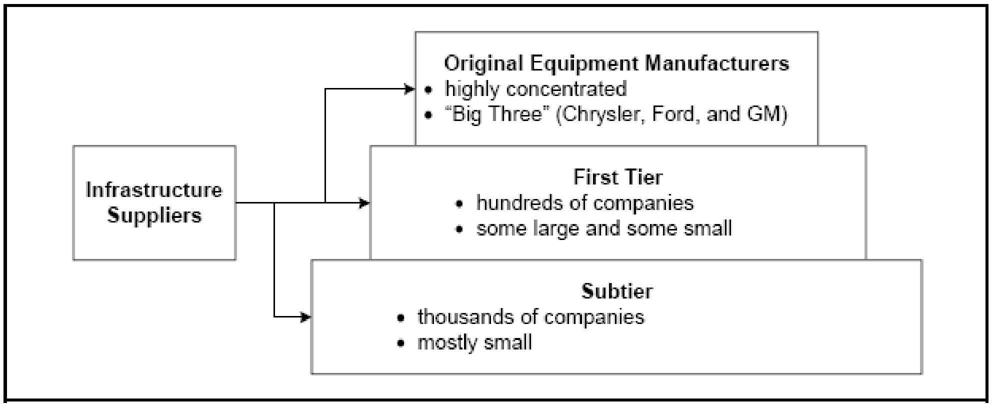
> The trend toward concurrent engineering and outsourcing in the auto industry have elevated the importance of high-quality product data and efficient product data exchange (PDE).

A number of characteristics and trends in the auto industry have elevated the importance of interoperability to the productivity and competitiveness of the industry. In an attempt to protect market share from imports, the U.S. auto industry began in the 1970s to implement a number of practices designed to improve the industry's productivity and competitiveness. These practices include concurrent engineering and other lean manufacturing methods as well as outsourcing a greater share of design and development to suppliers. These methods have significantly reduced lead times and have narrowed the productivity gap between the U.S. industry and its competitors.

Changes in the structure of the U.S. automotive supply chain have accompanied these trends toward concurrent engineering and outsourcing. The U.S. automotive supply chain has become more complex and difficult to define. As shown in Figure ES-1, the U.S. automotive supply chain consists of four primary elements: original equipment manufacturers (OEMs), first-tier suppliers, subtier suppliers, and infrastructure suppliers. However, individual companies may operate in several different positions in the supply chain. A company may work for many customers and function as a first-tier supplier on one project and a subtier supplier on other projects.

These trends have elevated the importance of the quality of product data and its efficient exchange. Many individuals and companies participate in the design of an increasingly complex automobile; hence, the design process depends critically on team members' ability to share information about essential design elements. Digital representations of products and parts have largely replaced physical drawings as the form in which product data are stored, analyzed, and communicated among the people contributing to the design of an automobile. One OEM estimates that as many as 453,000 exchanges of product data occur each year within the company and among the company and its suppliers.

Figure ES-1. U.S. Automotive Supply Chain
The complexity of the U.S. automotive supply chain compounds the industry's interoperability problems.



A number of problems arise when design data generated for one purpose are shared with other members of an automotive design team. Many different software and hardware systems are used throughout the automotive supply chain. These systems differ not only among companies but also among different functions within a company. Because each system has its own proprietary data representation, product data are created and stored in multiple, incompatible formats, which makes exchanging these data difficult. Resulting data files may contain errors, may be incomplete, or may be formatted in a way that makes them unusable for downstream applications.

Members of the auto industry generally acknowledge that imperfect interoperability is an important and expensive problem. A number of potential solutions have been developed over the years. These include

- standardization on a single system for each OEM and its suppliers and sharing of files in native format,
- development of point-to-point translators, and
- development of neutral format translators (Doty, 1994).

None of the solutions that have been widely used in the past have been successful at significantly reducing these problems. Single-system standardization forces suppliers to maintain redundant systems and does not eliminate interoperability problems. Point-to-point translators work reasonably well for some well-defined data translation tasks, but each combination of sending and receiving systems requires a different translator. Neutral format translators such as IGES and DXF have been very successful in some limited applications, but they have a number of weaknesses.

Standard for the Exchange of Product Model Data (STEP) is emerging as a promising solution to the interoperability problems in the automotive and other industries.

However, an alternative neutral format is emerging as a promising solution to the interoperability problems in the automotive and other industries. The International Standards Organization (ISO) adopted Standard for the Exchange of Product Model Data (STEP) as ISO 10303 to support product data exchange, independent of proprietary vendor computer-aided design/computer-aided manufacturing (CAD/CAM) or other system formats. STEP is currently evolving to extend data exchange capabilities to all aspects of a product's life cycle, from material specification to after-sale maintenance. More than 38 countries are involved in developing STEP (APAA, 1998).

Several of STEP's application protocols have been incorporated into commercially available translators. Tests of the performance of STEP translators are demonstrating that STEP has the potential to significantly reduce many of the interoperability problems that now plague the industry.

NIST represents U.S. interests in developing STEP and is developing a number of tools to assist industry in implementing STEP, including methods and software for testing STEP translation software. NIST has also participated in pilot programs for implementing STEP as the data exchange standard in the automotive and other industries.

ES.2 METHODOLOGY

The automotive supply chain incurs several types of costs related to imperfect interoperability:

- avoidance costs,
- mitigating costs, and
- delay costs.

The automotive supply chain incurs several types of costs related to imperfect interoperability. Automakers incur *avoidance costs* to prevent technical interoperability problems before they occur. *Mitigating costs* consist of the resources required to address interoperability problems after they have occurred. *Delay costs* arise from interoperability problems that delay the introduction of a new vehicle.

We employed two separate approaches to quantifying interoperability costs: the cost component approach and the aggregate cost approach. For the cost component approach, we identified many sources of avoidance and mitigating costs and asked industry executives to identify the labor, capital, and materials devoted to addressing each of these problems separately. We also asked executives to estimate the cycle time delay caused by interoperability problems and developed a cost estimate associated with this delay. We summed these components of cost to arrive at an estimate of the total interoperability costs in the industry. This approach provided insight regarding the primary sources of interoperability costs.

Using the aggregate cost approach, we interviewed key industry executives about interoperability cost issues and to ask them to consider the scope of all interoperability problems in their company. We asked them to provide an estimate of total interoperability costs. We added cycle time delay costs to this estimate. This method allowed the respondents to consider cost components that we may not have considered. It also provided a method for checking the consistency of the responses.

Our results are based on interviews with representatives of ten companies: two of the "Big Three" auto OEMs, five suppliers, and three tooling companies. To add qualitative information from a slightly different perspective, we also discussed interoperability issues with one company that manufactures auto-related equipment.

ES.3 RESULTS

Imperfect interoperability imposes at least $1 billion dollars per year on the members of the U.S. automotive supply chain.

Solving interoperability problems can significantly reduce costs for the U.S. automotive supply chain. Using the two different approaches described above, this study estimates that imperfect interoperability imposes at least $1 billion dollars per year on the members of the U.S. automotive supply chain. The majority of these costs are attributable to the time and resources spent correcting and recreating data files that are not usable by those receiving the files. These estimates are conservative because they do not include elements of cost that our industry contacts could not quantify.

Table ES-1 shows our estimates using both the cost component approach and the aggregate cost approach. The estimates differ by

Table ES-1. Summary of Interoperability Costs
Two approaches to estimating interoperability costs lead to similar estimates.

Source of Cost	Total Cost ($Thousands)	Percent of Cost
Cost Component Approach		
Avoidance cost	52,799	5
Mitigating costs	907,645	86
Delay cost	90,000	9
Total	1,050,444	100
Aggregate Cost Approach		
Interoperability cost	925,602	91
Delay cost	90,000	9
Total	1,015,602	100

only 3 percent. The similarity of these estimates provides some assurance that the respondents to our survey were consistent with respect to their answers and provides evidence that the estimates are credible.

We consider this estimate of interoperability costs of the U.S. automotive supply chain to be conservative. The project's scope, time and resource constraints, and data limitations prevented us from quantifying several sources of interoperability costs. These include the following:

- **Post-manufacturing interoperability costs.** We considered only the interoperability costs involved in the design and manufacture of automobiles. Interoperability problems also occur during other phases of the product life cycle, including marketing, after-market product support, and cost analysis.
- **Interoperability costs of small suppliers.** Because of constraints on project time and resources, we quantified interoperability costs to the OEMs, large suppliers, and tooling suppliers. However, smaller suppliers may also incur some costs.
- **In-house investments in interoperability solutions.** Because of the unavailability of data, we were unable to quantify all of the industry's investments in the development of interoperability solutions. These investments may be substantial. For example, GM's investment in its STEP Translator Center is not included in our estimates.

- **Costs to consumers resulting from delays.** Interoperability problems delay the introduction of new and redesigned autos. Our estimates do not include consumers' welfare losses resulting from delays in the availability of new and improved products.
- **Loss of market share resulting from delays.** We hypothesized that the U.S. auto industry could suffer a loss of market share resulting from interoperability delays, which could lead to a loss of profits to the industry. We were not able to quantify these lost profits.

Industry has been slow to act on its own to invest in the most promising solutions to these costly interoperability problems. Despite industrywide agreement that a neutral format such as STEP holds the best potential solution to interoperability problems (McEwan, 1995), STEP has not been universally adopted by the industry. A number of issues have hampered industry's commitment to STEP, including

- the significant investment required to develop a solution that will benefit all members of the industry;
- the technical risk associated with developing STEP translators;
- the market risk caused by competitive rivalries among the companies that develop CAD/CAM software and translators; and
- the need for an unbiased expert to negotiate, develop, and implement industry standards.

NIST's STEP activities can improve the value of STEP to the U.S. economy.

NIST can address many of these issues to advance the development of STEP translators, to hasten the adoption of STEP by industry, and to improve the value of STEP to the U.S. economy. By assisting in the development of STEP as an industry standard, NIST reduces the uncertainty and risk associated with industry's investment in STEP. NIST's activities in developing conformance testing practices helps to improve the quality of the STEP software, further reducing the technical risk to both the software industry and the auto industry. By helping to demonstrate the benefits of STEP through programs such as the AutoSTEP pilot program, NIST helps to reduce industry's perceived technical risk associated with investments in STEP. Finally, by continuing to participate in the development of STEP's application protocols and implementation prototypes, NIST lends expertise and credibility to the STEP development process and improves the process of standards implementation.

The resources NIST invests in participating in these activities benefit the entire U.S. automotive supply chain by reducing costs, improving cycle time, and strengthening the competitiveness of the industry. U.S. consumers also benefit because cost savings are passed on and new models become available more quickly.