White Paper

for

Technical Data Interoperability (TDI) Pathfinder Via Emerging Standards

Proof of Concept Phase

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A. Executive Summary

This document describes the Technical Data Interoperability (TDI) Pathfinder Via Emerging Standards project, which was performed for NASA IT Labs and also supported by the NASA Office of Chief Information Officer (OCIO). This project evaluated and tested a suite of industry standards for a proof of concept.

A-1 Overview

The TDI project ("TDI") investigates trending technical data standards for applicability to NASA vehicles, space stations, payloads, facilities, and equipment. TDI tested COTS software compatible with a certain suite of related industry standards for capabilities of individual benefits and interoperability. These standards not only esnable Information Technology (IT) efficiencies, but also address efficient structures and standard content for business processes. We used source data from generic industry samples as well as NASA and European Space Agency (ESA) data from space systems.

The TDI project setup a system to simulate data exchanges by importing and exporting technical data between different life cycle phases, using standards-based software for:

- **Product Data Management (PDM)** and **Computer Aided Design (CAD)** – ISO 10303 AP203 and AP214.
- **Product Life Cycle Support (PLCS)** – ISO 10303 AP239.
- **Logistic Support Analysis (LSA)** – S3000L and GEIA-STD-0007.
- **Technical Publications** (a.k.a. **"Tech Pubs"**, which includes work procedures, technical manuals, and training documents) – S1000D.

A-2 Problem Statement

Most NASA technical data systems still function with silo tools and methods which are inefficient in themselves or not compatible between systems or products. Data is often re-created or requires excessive searching. Long-term archiving and retrieval strategies are either non-existent or limited. Most current and past space industry systems are not designed for efficiency or interoperability across the whole life cycle, between design and Operations & Support (O&S); nor between vehicles, space stations, payloads, facilities, and equipment; nor between NASA centers; nor between customers and suppliers.

NASA lessons learned have indicated that disparate technical data increases safety risks from poorly integrated elements, as outlined in the Columbia Accident Investigation Board (CAIB) report.

Until recently, truly standardized interoperability was not possible. NASA wants more industry standards and interoperability, but sharing and breaking old ways is proving difficult—even with new programs. NASA policy promotes interoperability and requires to use industry standards where no comparable NASA standard exists. Without these, it will be difficult to meet some of NASA IT's strategic goals, such as enhanced mission success via efficient and effective access to enterprise information and collaborative functionality, innovative methods to attract a productive IT workforce, and partnership of best practices with other government agencies and commercial partners.

NASA agency strategic goals addressed by this project include:

- **OCT Technology Area Roadmaps**: Data interoperability in TA13 (Ground & Launch Systems Processing) and TA11 (Modeling, Simulation, IT, & Processing).
- **KSC Technology Capability Areas**: Life Cycle Optimization of Products, Projects, and Programs.
- **Space Technology Grand Challenges**: Economical Space Access, alleviating "40% of the total mission cost is…ground and launch processing." (higher % for RLV's)
- **OSTP Focus Areas**: "coordinate civilian, military, commercial, and national security space activities."

If appropriate choices are not made soon, then incompatible data systems and inefficiently-organized data and business processes will be custom-developed and operated independently, and future needs will drive inefficient software and data conversions as well as data re-creation. The missed opportunities to fix and optimize NASA systems for existing and developing programs will drive Life Cycle Costs (LCC) higher. O&S is typically 60-72% of LCC, and it needs to interface with design. Most importantly, disparate technical data reduces quality and increases safety risks.

A-3 Background

The NASA community has made some efforts to evaluate and use industry standards for technical data. Some updated NASA policies and plans now include references to modern industry standards, yet NASA is not taking advantage of these. Evaluation of the International Space Station (ISS) technical data environment reveals a target-rich compatibility for this project. Developing projects are also prime targets.

State-of-the-art Integrated Product/Logistic Support (IPS/ILS) interoperability has been developing in industry. The term ILS is used by many in international industry and government entities to describe details of and interaction between functional areas of the O&S phase, including a design interface. Product Life Cycle Support (PLCS) is an overarching term (and a specific standard) for interoperability of data across the whole life cycle, connecting design technical data to O&S data.

New and reworked standards for technical data have been released in recent years. More are in development. Joint agreements and efforts with international entities are in place, and integrated councils and work groups are working toward interoperability across the whole life cycle.

A-4 Conclusion

The TDI project has accomplished testing for this industry concept which has not been attempted much in the industry. Standards-based, vendor-neutral interoperability between PDM, LSA, and Tech Pubs data appears to be available or developing within a year or two. Further testing could validate this. Real NASA/ESA data as well as industry sample data were tested. A conversion tool was partially developed. Though not all interfaces were able to exchange data as intended, lessons were learned, and a path forward is laid out to validate desired exchanges.

Not all of the large list of proof-of-concept tests could be completed within the 90-day period for NASA IT Labs. Some challenges hindered advancement. These were anticipated, and additional funds were obtained to allow completion of objectives and possibly a few additional objectives.

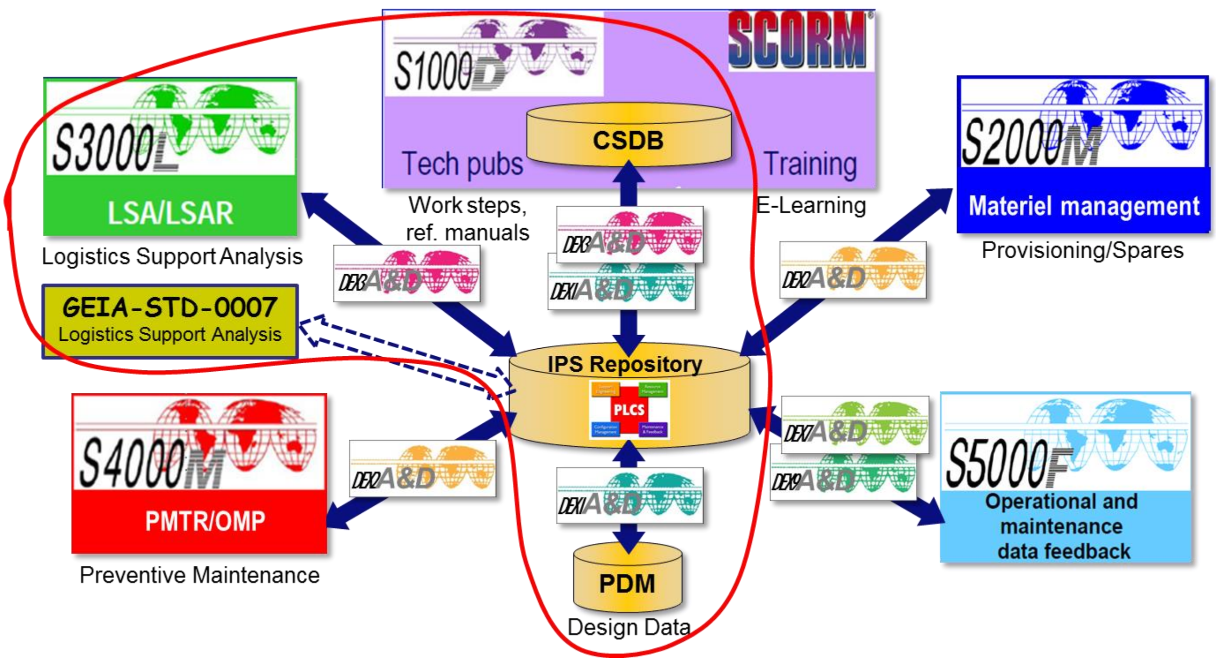
In the short term, it is recommended to continue with the unfinished proof-of-concept testing and development of the conversion tool. Updated results should be considered to incorporate into revision 1.1 of this white paper. For the long-term, it is recommend to carry results forward to the next level, by testing a networked integration, adding tests of additional functionality, adding more real data sets, and evaluating compatibility with work execution systems. Upon evaluation of test results described above, if results show good potential, then a full integration pilot should be pursued.

B. Project Activity

TDI DESCRIPTION

The TDI project ("TDI") performs a proof-of-concept of trending technical data industry standards which are designed for use on large, complex products, yet are also usable on smaller products. They apply to the IPS/ILS environment, intended to span the whole life cycle. These standards could also be used on space vehicles, space stations, payloads, facilities, and equipment.

This project researches, evaluates, and tests these standards for their individual benefits as well as their interoperability. Individual benefits advertised include intelligent product structures, data reuse, efficient formats and processes, and industry workforce commonality. These related standards also tout interoperability designed into the IT, based on the functional business processes needed across the life cycle for maximum efficiency. One industry model to achieve interoperability is shown in the figure below.



This concept for IPS/ILS interoperability has been circulating for the last few years, but has yet to be fully achieved as the model is still developing. This project intends to validate part of this model. The standards to be evaluated are outlined in the figure above. More information about each standard, and other related standards, is available in the appendix.

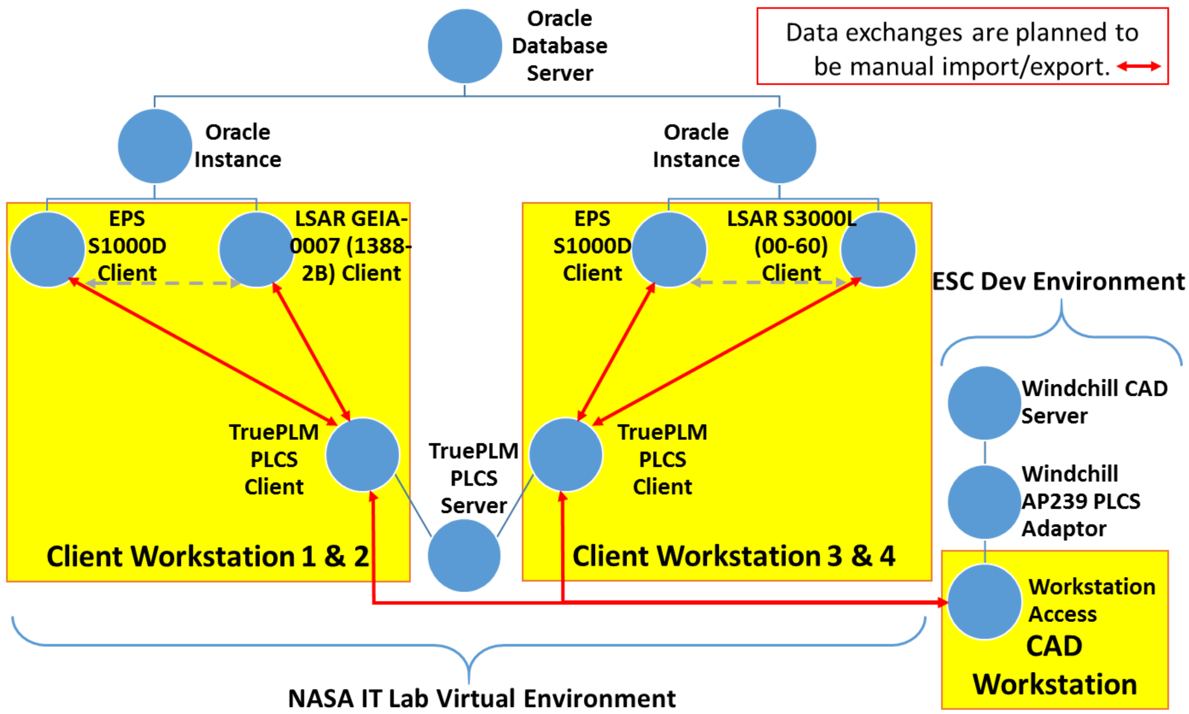
From a technical perspective, a common standard-based information backbone can greatly simplify integration complexity, by largely eliminating the need to develop and maintain point-to-point integration solutions. ISO 10303-239 (PLCS) has a comprehensive information model and the use of a Data Exchange Specification (DEX) is used to create subsets of the model for particular exchange needs. A DEX is a way of dividing up the huge ISO 10303-239 PLCS information model into sections suited for a particular business process. A DEX provides a subset of the PLCS information model and associated reference data and usage guidance. A DEX can be used to contract against or for setting conformance, but AP239 implementations do not have to use DEXs.

TDI SETUP

The TDI project setup a system to simulate data exchanges by importing and exporting some of this technical data, using unaltered, standards-based, Commercial-Off-The-Shelf (COTS) software. TDI obtained vendor software compatible with targeted TDI standards, listed below. This software is a sampling of vendor software on the market which complies with these industry standards. The project also used existing software at NASA centers, listed below.

- PLCS repository – Jotne's **EDMtruePLM** version 1.33
  - Product Life Cycle Support, ISO 10303-239
- CAD PDM – PTC's **Windchill** 10.2 (development server)
  - Existing KSC system for GSDO program.
- PLCS Adapter for Windchill PDM
  - PTC's ISO 10303 **AP239 PLCS Connector** trial acquired for TDI project.
- CAD – PTC's **Creo** 2.0 and **CreoView** 3.0
  - Supports ISO 10303 AP203 & AP214 STEP neutral CAD data conversion.
  - CreoView produces proprietary light CAD files.
- Tech Pubs – two applications for full S1000D functionality
  - Raytheon's **EAGLE Publishing System (EPS)** version 12 for S1000D authoring and CSDB management and publishing.
  - BAE Systems **Trilogi View** for an S1000D Interactive Electronic Technical Manual/Publication (IETM/IETP) viewer
- LSA – Raytheon's **EAGLE LSAR** version 12
  - TDI project version
  - Supports S3000L (script added to DEF STAN 00-60 version)
  - Supports GEIA-STD-0007
- LSA – Raytheon's **EAGLE LSAR** version 11
  - Version on existing JSC system for ISS
  - Supports MIL-STD-1388-2B
- LSA – U.S. Army's **PowerLOG-J** version 1.7.4 (KSC evaluation copy for GSDO program)
  - Supports GEIA-STD-0007 and MIL-STD-1388-2B
  - Also imports PLCS GEIA-0007 Provisioning and Category DEX
  - Also exports TM for S1000D, RPSTL

The NASA KSC IT Lab setup consisted of two custom-built virtual servers running Windows 2008 Release 2 and four custom-built Windows 7 virtual clients for installation of the trial vendor software. One server functioned as an Oracle Database Server for management of the server-based EAGLE software. The other server functioned as a proprietary database server for management of the server-based Jotne software. Each client workstation hosted the various suites of Jotne and EAGLE client-based applications depicted in the graphic below. The Windchill PDM and Creo CAD tools used were existing at KSC on a development server. The TDI test architecture and software are shown in the figure below.



TEST DATA SETS

Efforts were made to obtain available data to test from industry/vendor samples, NASA ISS, ESA ISS, & KSC ground systems, and manual data creation. The following data sets were obtained/created:

- Industry standard sample data for a bicycle ("bike data"). Raytheon provided this data which was structured for S1000D work procedures and an Illustrated Parts Data/Breakdown (IPD/IPB) and for LSA standards GEIA-STD-0007 and S3000L (based on DEF STAN 00-60). . LSA data was also linked to the S1000D data for producing Procedural and IPD/IPB Data Modules directly from LSA data. LSA data included LCN, BOM, MTA, Provisioning, Reliability, Support Equipment. Tech pubs data included S1000D Data Modules (DM) for technical procedures and for an Illustrated Parts Data/Breakdown (IPD/IPB). S1000D Publication Module (PM) for the creation of an IETP was also included.
- NASA ISS LSA data from JSC's EAGLE LSAR, customized based on MIL-STD-1388-2B. LSA-019 task analysis data was for entire Columbus Module. Data was export control approved.
- NASA ISS Station Operation Data Files (SODF) procedures from JSC's International Procedures Viewer (IPV) library. Data was from the Columbus Module, general

maintenance procedures and guidelines, and warnings and cautions, provided in XML format. Data was export control approved.

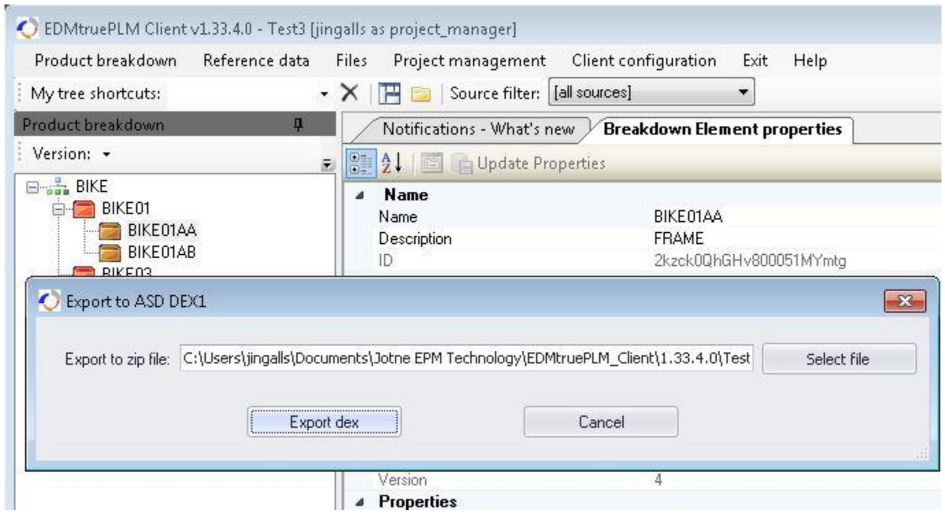
- NASA ISS Payload Operation Data Files (PODF) procedures from MSFC's IPV library. Data was from the European Module Cultivation System (EMCS), a payload from ESA. Data was export control approved.
- ESA ISS original procedures and graphics from the ESA source Payload Developer (PD) used by NASA to develop PODFs. Data was from the EMCS. Data usage was approved by ESA source and partners.
- ESA ISS PLCS product structure from Jotne. This real data is used in an ESA instance of EDMtruePLM for the EMCS on the ISS. Data usage was approved by ESA source and partners.
- CAD data from NASA KSC ground systems of the Mobile Launcher (ML) in development. This data was not export control approved and was used only locally for testing, not to share with the whole TDI team.
- CAD sample data of a golf cart and of an automobile, both by vendor PTC.
- Industry sample data of 3D models in S1000D. These were obtained from the recently formed S1000D Model Based Enterprise Task Team (MBETT).

TDI TESTING

The TDI team tested as much as possible of data interoperability between different functions. Interoperable points on the PLCS-centered TDI concept were pursued first. Then, point-to-point data exchanges were tested. Finally, individual standards were evaluated for their own merits. The following scenarios were tested.

PLCS Product Structure Creation and Export

- Used industry bike data to manually load product structure in PLCS repository. The data was exported as DEX1.
    - RESULTS: Used this PLCS export to evaluate format and aid in creating a map/conversion where no adapter exists for Raytheon's LSA or S1000D tools to exchange with PLCS format.



TDI LSA GEIA-STD-0007 Export, Map for Import to PLCS

- Exported GEIA-STD-0007 LSA bike data using a GEIA XML exchange file method.
- Developing a conversion from GEIA-STD-0007 XML data to PLCS data in either ASCII (ISO-10303-21) or XML (ISO-10303-28) form, based on LOGSA-developed LSA DEX. Focused on product breakdown structure.
- The LOGSA-developed LSA DEX provides a mapping between data conforming to the GEIA-STD-0007 LSA standard and the ISO-10303-239 PLCS standard. This DEX relies on templates for PLCS data, provided by the DEXlib environment, which in turn instantiate specific PLCS entities and attributes, as specified by the PLCS schemas, encoded in the EXPRESS (ISO 10303-11) language.
- Based on team member skills and experience, as well as the broad range of available implementations and development tools, the eXtensible Stylesheet Language for Transformations (XSLT) was chosen as the primary tool for implementing the translator. XSLT transforms can consume XML data and produce either plain text (i.e., ISO-10303-21 ASCII format files) or XML (i.e., ISO-10303-28 XML format files) as output. They offer a number of features for flexible, modular development.
- The design of the translator uses a bottom-up approach, with interchangeable XSLT modules for encoding PLCS output data in either text or XML format. Building upon these, the design will utilize existing EXPRESS parsing tools to generate XSLT modules containing parameterized templates for each PLCS entity and corresponding attributes. The PLCS DEXlib templates will be converted into a similar layer of XSLT modules, building on the previous layer and using a custom parser for the DEXlib templates' Instantiation Path syntax. Finally, the XML-based LSA DEX will be converted to a top-level XSLT transform that builds upon the lower-level modules to produce a complete translation.

- RESULTS: Translator development is ongoing, currently about 20% complete.

LSA S3000L (DEF STAN 00-60) Export

- Exported S3000L (basically DEF STAN 00-60) LSA bike data using the fullfile method.
- RESULTS: Uncertain results. Need to run again.

CAD Product Structure Export, Import BOM to LSA

- Exported CAD Product Structure to get Bill of Materials (BOM) data from the PDM.
- Golf cart data –**Imported directly into EAGLE LSAR**, using Raytheon's BOM import tool.
    - RESULTS: Creates records in 6 LSA tables and a non-standard table. See figure below. You cannot run an LSA BOM report immediately after a BOM import, because the user must perform LCN-end item UOC assignments. If no LCN, the import tool can auto-generate LCN's.
    -
```
Results:

Records inserted into Table XA = 0
Records inserted into Table XB = 44
Records inserted into Table XH = 1
Records inserted into Table BA = 44
Records inserted into Table HA = 39
Records inserted into Table HG = 44
Records inserted into Table ZHAEXT = 0
```

- NASA ML data (one of the most complex product structures in KSC Windchill) – **Imported directly into EAGLE LSAR**, using Raytheon's BOM import tool.
    - RESULTS: Same results as golf cart data. Importing from this complex model resulted in 13,293 records. An additional observation was that, the LCN creation tool was limited by the industry standard 18-character length, and can only produce classical LCN's (no option for sequential).

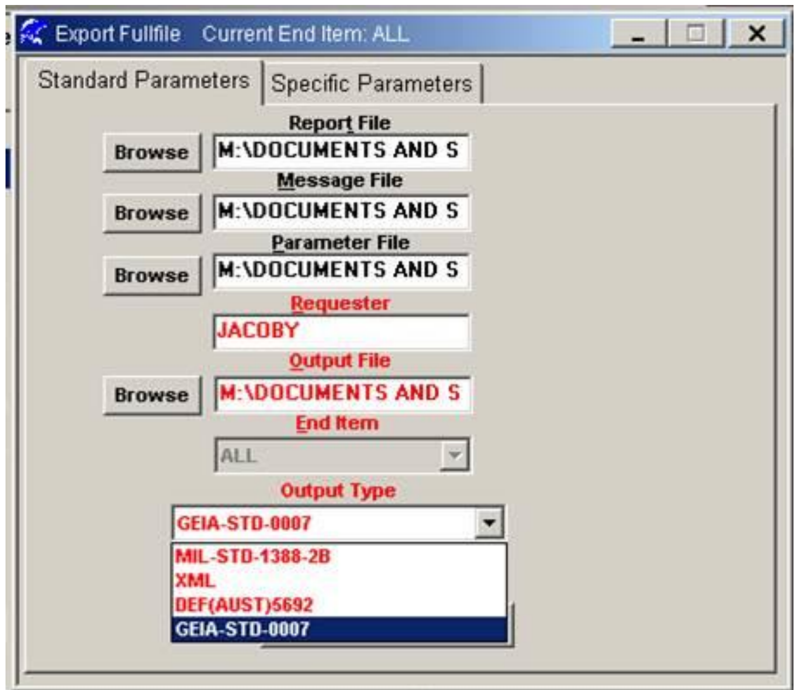
CAD Data Export from PDM Using AP239 PLCS Adapter

- PTC's AP239 PLCS Connector (adapter) was installed in KSC's Windchill 10.2 development server called EDMS. Installation was verified with PTC. Attempts were made to export data from Windchill.
    - RESULTS: AP239 was not evident in the client view. It was discovered from PTC that their AP239 adapter does not have a user interface. They were not funded to support this effort, so they suggested that PTC's Info*Engine be used to test exporting.

JSC LSA MIL-STD-1388-2B Data Exported as GEIA-STD-0007 Format

- Exported JSC ISS LSAR data (customized based on MIL-STD-1388-2B). Used ISS Columbus data.

- Export method used was GEIA fullfile. See the figure below. Note that this export option does not allow selection of just one end item, nor a range of LCN's. We discovered later that this export method is no longer supported by Raytheon, and they are planning to remove the ability to produce GEIA-STD-0007 data from MIL-STD-1388-2B systems. See export options in screenshot below.



- **Import to TDI EAGLE LSA GEIA-STD-0007 Rev A Client (as GEIA format)**
  - RESULTS: Data imported, recognized all LSA data tables, but there were specific records with import errors. The errors were suspected to be due to ISS EAGLE administrative customization (special character used in end item, as verified by Raytheon). There may be other error causes, which could not be identified as of yet. Before import, the GEIA revision had to be set, and the end item (iss_system) had to be created. Due to later discovery of the unsupported export method, errors would be expected with unconverted data.
- **Import to PowerLOG-J as GEIA-STD-0007 Rev A**
  - RESULTS: After about 4% progress during import, the software produced an SAXException and stopped the import. Due to later discovery of the unsupported export method, it may work if imported as MIL-STD-1388-2B.

JSC EAGLE LSA MIL-STD-1388-2B Data Exported as MIL-STD-1388-2B Format

- Exported JSC ISS LSAR data (customized based on MIL-STD-1388-2B). Used ISS Columbus data.

- Export method used was MIL-STD-1388-2B fullfile. Note that this export option does allow selection of just one end item, and allows a limited range of LCN's.
- In this test, a limited LCN set was chosen for just the desired LCN range: start LCN of SBAHA1LLL010 and stop LCN of SBAHA1LLL011, for the desired "PAYLOAD ETHERNET HUB GATEWAY 2 (PEHG-2) R&R - LAB1D2" on the Columbus Module. These LCN's were noted later to be 1 character off of the ISS-defined LCN Structure (112223223).

- **Import to TDI EAGLE LSA GEIA-STD-0007 Rev A**
  - RESULTS: Could not import into TDI EAGLE GEIA client, since there is not an option to import to the older MIL-STD-1388-2B format. This is expected, since EAGLE does not convert it.
- **Import to PowerLOG-J as MIL-STD-1388-2B**
  - RESULTS: This data did import into PowerLOG-J successfully as MIL-STD-1388-2B format, except for some expected duplicate table entries.
  - It was noted that PowerLOG-J has export options for various LSA standard formats. For future testing, if other EAGLE data can't transfer, then we could test from PowerLOG-J to EAGLE and evaluate if prior errors were due to software or standard incompatibilities, or ISS data customization.

TDI LSA Data GEIA-STD-0007 Export, Import to PowerLOG-J

- Exported LSA bike data from EAGLE GEIA-STD-0007 as a GEIA fullfile
- **Import to PowerLOG-J as GEIA-STD-0007**
  - RESULTS: The data did import, but with some errors. One TM code failed to transfer in the XI table, and another TM code had an error. The CJ table didn't transfer. The team needs more time to evaluate. We should perform this early test again, based on what's been learned since. We think we may be able to find the cause of these few errors, but may be able to determine if they're caused by the standard, the software, or the data customization.

DATA EXCHANGE METHODS

Methods described below are dependent on vendor tools and do not necessarily reflect the exchange capabilities of the standards.

PDM Data Export

KSC's Windchill enables users to export WTParts (Windchill Technology Parts), WTPart Attributes, and Indentured Parts Lists / Product Structures. There are multiple methods available to export data. The most direct method is Exporting an Importable Spreadsheet. The product structure and Parts data can be exported simultaneously by selecting the Parts and BOM Export Options. Note that attributes are not outputted in the same order from one report to another. Null values appear to affect the inclusion/exclusion of an attribute and the order of appearance in the generated report.

PTC's recently released AP239 PLCS Connector (adapter) for Windchill is intended to allow data exchanges between Windchill and any tool that is compliant with PLCS DEX1A&D. The AP239 adapter is a basic, but extendable import/export converter, which by default covers a small part of DEX1A&D only. It has an architecture which is designed to be extended. Extension of the converter scope requires further development by the customer or by PTC. In its default version, this converter was not ready to use out-of-the-box, and a method of enabling this adapter was not developed during the TDI project.

PLCS Repository Data Import & Export

Jotne's EXPRESS Data Manager (EDM) is able to support any ISO 10303 application protocol, not just AP239. It is a software development kit for users who want to create their own converters or even end user applications.

The PLCS software application used in the TDI project is Jotne's EDMtruePLM. This offers import and export of PLCS DEX1A&D data sets from and for any DEX1A&D capable application. EDMtruePLM could be extended to manage DEX3 maintenance task information in a PLCS compliant way, but such developments were beyond the scope of the initial TDI project.

LSA Data Import

Note that, unlike MIL-STD-1388-2B, GEIA-STD-0007 does not prescribe how the data must be stored. Data cannot be "maintained" in accordance with 0007, but it can be "exchanged" in accordance with the standard. EAGLE exchange files for MIL-STD-1388-2B are "fullfiles" and for GEIA-STD-0007 are "XML exchange files."

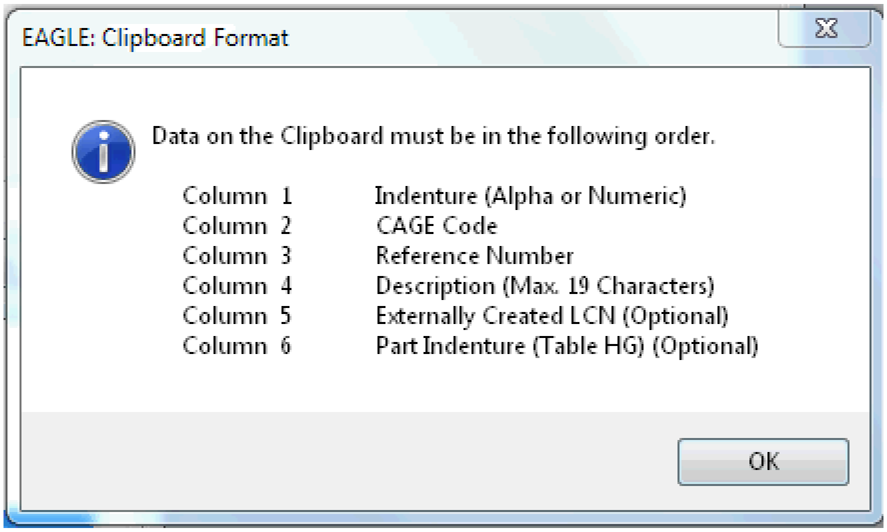
EAGLE LSAR's GEIA-STD-0007 version can import data of the same standard version.

EAGLE LSAR's S3000L (DEF STAN 00-60) version can import the same standard version, as well as MIL-STD-1388-2B data, for which conversion is attempted.

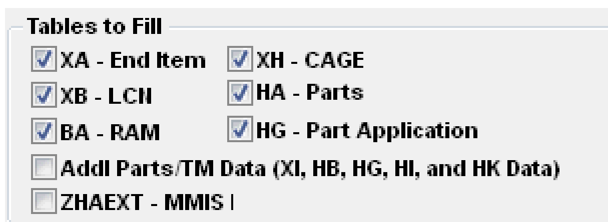
PowerLOG-J can import MIL-STD-1388-2B or GEIA-STD-0007 data. It can also import PLCS GEIA-STD-0007 Provisioning and Category DEX.

EAGLE can import external data thru pasting data into tables based on ad hoc SQL queries. This allows the user to import data into any desired table. The data must conform to the Data Element Definition standards and it must contain all mandatory key fields. The data must also conform to any unique key requirements.

EAGLE also has a Bill of Materials (BOM) import tool to load an indentured parts list and assign LCNs to part applications. The BOM import tool receives 6 data fields (see figure below) to copy from XLS format and paste from clipboard into EAGLE.



If you can get this information out of your existing data you would be able to use this utility to calculate your LCNs and populate the following LSAR tables (ignore ZHAEXT, an EAGLE table):



There is no automatic import of CAD drawings/models. The graphics can be saved individually to the XT document system (GEIA-STD-0007) or to the EAGLE drawing table once the part information has been established.

Raytheon once developed an experimental prototype in the past which was able to read the CAD models and drawings with BOM data and attempt to import the data into the EAGLE database. They discovered multiple challenges in doing this—most of them believe to stem from the business process of the CAD data creators, and not necessarily a technical issue. Very few drawings were complete in terms of this supporting data, and they were all missing different data elements. In certain companies, for example, the drawing may not necessarily be a significant item of record—perhaps instead were the as-built or reports generated from their PDM system. Raytheon has developed for some customers an XML export from PDM to import into EAGLE, which then linked their PDM to EAGLE through SOAP messaging. They would be given a WSDL and then write a custom SOAP client which enables this functionality.

LSA Data Export

EAGLE LSAR's GEIA-STD-0007 client can export fullfile data of the same standard version.

EAGLE LSAR's S3000L (DEF STAN 00-60) client can export fullfile data of the same standard version.

EAGLE LSAR's MIL-STD-1388-2B client at JSC can export fullfile data of the same standard version. The options available also offer to export as GEIA-STD-0007 format. Later, we discovered that this export method is no longer supported by Raytheon, and they are planning to remove the ability to produce GEIA-STD-0007 data from MIL-STD-1388-2B systems. This export outputs data, but does not attempt conversion.

With all EAGLE-to-EAGLE data conversions, Raytheon recommends the EAGLE XML format, which produces one consolidated "kick file" of non-matching data to resolve.

Since no EAGLE version can import/export PLCS format, the TDI project is developing a translator, as described earlier.

PowerLOG-J can export fullfile data as GEIA-STD-0007.

S1000D Data Import

This section will be updated later, in the next version of this white paper.

C. Use Cases

Many industry and government programs, products, and organizations either use or have tested standards evaluated by this TDI project. Known cases are described here, as well as similar NASA efforts. It should also be noted that the statistics on the S-series websites show thousands of hits and downloads, and the U.S. has the most page views by far.

SIMILAR NASA EFFORTS ON TECHNICAL DATA USAGE

ISO 10303: NASA-ESA Product Data Exchange (PDE) Workshops have been held annually to collaborate on utilization of the ISO 10303 STEP standard for CAD—especially AP203, AP214, and AP242. S-series and PLCS AP239 standards have been discussed there, but not pursued yet.

SGML Structured Authoring; Processing Integration: The Work Package Support System (WPSS) / Paper-Optional Work Environment (PWE) system used in the 1990's for Shuttle ground operations was one of the first NASA projects to attempt integration of various O&S data systems: work instructions, logistics inventory, scheduling, etc. Legacy work procedures were converted to SGML structured authoring format. A custom Document Type Definition (DTD) was developed, including interface integration tags for other systems. SGML was the standard for all types of technical manuals used by commercial airlines based on ATA Spec 100/iSpec 2200.

SGML Structured Authoring; Processing Integration: The Boeing Delta IV launch sites used SGML tools to develop and maintain their procedures. They developed a custom DTD and styling process which they used with COTS software (Adobe's Framemaker+SGML, Documentum's enterprise content management system, and both COTS and custom interface code). All of the assembly, installation, test, and nonconformance procedures for the launch sites used these tools and were able to re-use content. A dedicated LSA system was not a part of the suite, but many other tools were integrated, including an ERP for parts and materials, an MRO for tools, an MES for electronic procedure execution and nonconformance processing, and other custom tables for various data needs. Most integrations were custom. An XML transformation tool allowed procedures to be executed in the MES. Delta conducted multiple assessments of the tools and found that they improved procedure creation efficiencies on the order of 2.5-2.8x (compared to a basic MS Word suite without sophisticated content management tools). The USAF's Delta IV program was for DoD, NASA, and commercial payloads.

ATA Spec 100/iSpec 2200 (S1000D predecessor): The Shuttle Maintenance Manual (SMM) project developed a pilot to implement tech pubs for Shuttle vehicle and ground systems, based on the commercial airlines' ATA (now A4A) Spec 100 (now iSpec 2200) standard. This fully adopted industry standard was a major contributor to develop S1000D, and the ATA spec is now converging on full S1000D compatibility. The SMM efforts continued after the pilot to evaluate application to the Constellation program (Ares, Orion, and ground) for S1000D, and expanded a vision to evaluate the full S-series and PLCS AP239.

Trending TDI Standards: Past efforts made to evaluate trending TDI industry standards include industry workgroup participation, vendor discussions and demonstrations, NASA research & development (R&D) proposals, and conference papers and presentations.

Standards and Tools Related to TDI: Evaluation of the ISS technical data environment reveals a target-rich opportunity for this project. Separate data sources exist for LSA and technical publications (a.k.a. "tech pubs", which include work procedures, technical manuals, and training documents). Each data system currently uses technology with potential adaptability to modern industry standards evaluated in this project. Each system is customized. These systems are setup to be integrated with ISS International Partners/Participants (IP/P), but are not 100% integrated. One TDI project team member, Jotne of Norway (also a software company with industry standards expertise), was able to support the objective of testing out ISS data. The data was related to the NASA/ESA plant experiments and was provided by CIRIS and ASTRIUM Defense and Space (former Astrium).

EAGLE LSAR MIL-STD-1388: In the mid-90's, NASA and the ISS IP/P used SLIC, Leads, AlStar, and DILSA LSA software in MIL-STD-1388-1A format. ISS partners Russia, Japan, and Canada have always had separate LSA management. In 2000, when NASA changed to use EAGLE LSAR in MIL-STD-1388-2B format, they converted NASA and IP/P LSA data to create a consolidated ISS logistics maintenance database. Today, NASA and those IP/P's share the database with the ability to see live updates. The Canadian Space Agency (CSA) manages their part of LSA data directly in NASA's EAGLE LSAR. ESA manages their part of LSA data in their own EAGLE LSAR. NASA trained the Japan Aerospace Exploration Agency (JAXA) on EAGLE LSAR for the Centrifuge Accommodation Module (CAM), which later on was deleted from the ISS program. It is assumed that they still use LSA software compliant with MIL-STD-1388 for their Japanese Experiment Module (JEM). The Russian Space Agency (RSA) does not use COTS LSA software.

EAGLE LSAR MIL-STD-1388: Lockheed-Martin uses EAGLE LSAR (MIL-STD 1388-2B?) for NASA's Orion program.

PowerLOG-J LSA GEIA-STD-0007: NASA MSFC uses PowerLOG-J for the Space Launch System (SLS) program.

Custom LSA & PowerLOG-J: NASA KSC historically has not used an industry standard LSA data system, though they were evaluated. The Shuttle program had evaluated the industry standard COTS software SLIC, but it was never fully in production. The past CAPSS contract had developed a demo of PowerLOG-J, but it also did not continue. The current GSDO/TOSC LSA environment uses Logistics Engineering Database (LED), a custom MS Access database. They recently evaluated PowerLOG-J.

XML Tech Pubs, IETM, & S1000D Potential: NASA JSC and MSFC create operation and maintenance procedures, technical reference materials, Illustrated Parts Breakdowns (IPB), and training materials. Long ago, legacy source data was converted from a Manual Procedure Viewer (MPV) used for PDF/paper manuals to develop some Station Operation Data Files (SODF) to support on-orbit operations of station hardware and some Payload Operation Data Files (PODF) to support science payloads. Some SODFs and PODFs do not have LSA data available as development sources. These are typically created in NASA's Procedure Authoring Tool (PAT), which uses XMetal Author Enterprise to author in XML format. Those files are then used in the International Procedures Viewer (IPV) as the web-based front end tool to view procedures, link to other data, and be an interface for data recording. This is what industry and military would call an IETM, and S1000D calls an IETP. Astronauts and ground controllers for NASA and ISS IP/P's use IPV on-orbit, in mission control centers, and for ground training. XMetal software can also support XML authoring of S1000D. However, NASA's XML schema and IPV viewer are highly customized.

PLCS and Processing Integration: During the Constellation program, an integrated data system was developed at KSC using technology and standards which approached the PLCS standard. The Collaborative Integrated Processing System (CIPS) used a collection of Commercial-Off-the-Shelf (COTS) toolsets spanning the Requirements Management, PDM, ERP, MRO, MES, and Quality Control arenas. USA's Attentus™ Integrated Data Management system, in conjunction with a data management portal constructed for Ares I-X ground processing, provided users with a web-based visual interface that integrated multiple application-based datasets into a single logical view of processing operations. This single logical view, linked requirements, drawings, graphics, and other related documents, data, and content to the paperless Manufacturing Execution System (MES). The MES was used for work instructions for vehicle assembly (manufacturing) as well as the whole ground processing cycle. The COTS toolsets were all integrated using two software standards:

- **Open Application Group Integration Specification (OAGIS):** A common horizontal message architecture that provides XML-based schemas for the Business Object Documents (BODs) flowing within Enterprise Application integrations.
- **OASIS Web Services Business Process Execution Language (WSBPEL):** A business process orchestration language enabling users to describe business process activities as Web services and define how they are connected to accomplish specific tasks.

These standards linked requirements management, production control, and configuration management across systems, enabling data handoffs from design to manufacturing to assembly to operations. This IT system architecture neared an AP239 PLCS approach and was a successful test for future programs' needs.

Other interoperability/integration projects: Other projects began during and after the Constellation era at various NASA centers, working on interoperability/integration solutions. Some KSC examples were NASA Integrated Model-centric Architecture (NIMA), Digital Collaborative Environment (DCE), Information System Strategic Initiative (ISSI), and Enterprise Supply Chain System (ESCS). Each had some elements of using MBE, central data integration, COTS software, and industry standards.

OTHER SPACE INDUSTRY USAGE

S1000D: TRI-COR Industries adopted Inmedius S1000D Publishing Suite technical documentation production software to support NASA, military, commercial IT projects. TRI-COR is an Information Technology (IT) support services firm.

PLCS: Jotne's TruePLM was a European Space Agency (ESA) pilot project that lasted from 2007-2009, and created the first ISO 10303-239 PLCS compliant applications for space use cases as it also implemented selected parts of the European Cooperation on Space Standardization (ECSS) requirements. TruePLM is a standards-based data storage server and exchange facility long-term data archival capabilities based on PLCS-standardized data. The 18-month TruePLM program delivered a data management system that is capable of integrating product data from various stakeholders in complex space projects.

S1000D: ITT Exelis uses S1000D for its sustainment of range facilities under the SpaceLift Range System (SLRS) for 3 USAF bases, including Patrick Air Force Base (PAFB), Florida's Eastern Launch and Test Range, (used by NASA KSC).

S1000D & MIL-STD 1388-2B: DLR in Germany uses S1000D for Galileo satellite ground stations, European Satellite Navigation System Galileo, a joint EU/ESA project. The Galileo IETM Tool is a component of the Galileo Logistic Management & Information System and as such maintains a MIL-STD 1388-2B compliant interfaces to retrieve supportability data from the LSA Data Vault.

S1000D: ESO uses S1000D for a space telescope in Italy.

S1000D: Virgin Galactic's SpaceShipTwo and companion White Knight, as well as SpaceX's Falcon and Dragon, are supposedly developing S1000D usage, but these were not 100% confirmed as of this writing.

USAGE IN OTHER INDUSTRIES:

S1000D: Boeing 787 uses S1000D.

S1000D: Airbus A350 & A380 use S1000D.

S3000L: A Chinese (COMAC) civilian aircraft project uses S3000L.

PLCS: The AP239 PLCS Windchill adapter is being tested in a joint effort with Airbus and the LOTAR organization. Jotne is involved with them.

PLCS AP239, AP233, & CAD/CAE: The "Collaborative and Robust Engineering using Simulation Capability Enabling Next Design Optimisation" (CRESCENDO) project started in May 2009 and ended in October 2012. This project was coordinated by Airbus with a consortium of 59 partners from 13 countries. The CRESCENDO consortium initiated a step change in the way that Modelling and Simulation (M&S) activities are carried out, by multi-disciplinary teams working as part of a collaborative enterprise, in order to develop new aeronautical products in a more cost and time efficient manner. They developed the foundation for a Behavioural

Digital Aircraft (BDA) to use M&S for collaborative product development. The common approach was built on AP233 and AP239 standards. They developed DEX specifications, providing a mapping from the BDA to AP239 PLCS. This DEX is now included in ASD's developing Modelling and Simulation in collaborative System Engineering Context (MOSSEC) standard.

Miscellaneous S1000D Uses: Construction project in Sweden, Field hospital in Germany, IRS pilot in the US, Corporate documents in the US, Heavy Kitchen equipment in the US.

MILITARY USAGE:

S1000D: S1000D serves nearly every ship/aircraft in the U.S. Navy (as of 2014). The first S1000D test case was in 2004. Enterprise-wide solution benefits include reduction in total ownership cost.

PLCS, CAD, & PDM: UTRS used PTC's AP239 PLCS adapter and Jotne's EDMtruePLM PLCS repository to develop a way to exchange data from Boeing into the U.S. Army's Windchill Product Data Management (PDM). They transfer Technical Data Packages (TDP). They found that the adapter was not ready to use out-of-the-box (OOTB), and PTC had to help them fix and configure it. Additionally, they had to use Jotne's development toolkit to enable the use of the adapter.

S1000D & PLCS: Jotne North America designed, developed, and made a prototype mapping for the definition and configuration of electrical wire harness data from Boeing's proprietary Common Electrical Electronic Data System (CEEDS) to the PLCS standard - initially for the B1 bomber an later the CH47 platform. In the latter contract, the work was further enhanced to generate S1000D data modules for ingestion to an S1000D compliant publication system (Inmedius Author Pro) that is typically used by the industry. In the process it created a Common Source Data Base (CSDB) and relevant Standard Numbering System (SNS) folders that are generated by the software as part of the verification process when importing a S1000D data set. Final validation was done by visually comparing the data presented with the original. A demonstration was provided to a US Army representative at the end of Q1 2014.

S-Series: According to the NATO Support Agency (NSPA), they currently use S1000D for all new projects, and they have recommended that all NATO projects do the same. The book TME 2506 (Requirements for NATO Technical Documentation) will be reissued next year to reflect the changes that have occurred over the last couple of years. They have produced foundation Business Rules for use by NATO nations. These will be published in the new TME 2506. There is a major drive for all new NATO projects to use the S-series specifications, and NSPA is part of that drive. They are currently working on a project that will automate the links between our S1000D IETMs and S2000M. The same project will also make full use of the available specs in the S-series. NSPA provides NATO's delivering in-service support, maintenance and logistics support for weapons systems, as well as operational logistics and other services.

S1000D, S2000M, & S3000L: The NATO Alliance Ground Surveillance (AGS) Program chose to use S1000D, S2000M, and S3000L. Original requirements were to not tailor the standards. This was possibly the first S3000L project, so there was a lack of vendors with full support, and there was not much experience in application. To fill the gaps, they joined the S3000L Working Group and proposed AGS as a case study, and organized workshops with experienced companies. As of 2013, the plan was for initial LSA data to be in a format similar to MIL-STD-1388-2B (their experience base), but adaptable for full compliance later to S3000L. S2000M was easily applied due to NATO experience with it. S1000D Business Rules (BR) were being developed. Initial integration was a challenge due to all 3 standards initially planning on 3 databases. They claimed that PLCS was not possible to apply at the time, but recognized the need for DEX's with a concept like PLCS. As of 2013, they were developing an integrated database and backbone system.

S1000D: Numerous U.S. DoD projects are using or developing S1000D, such as F-35 Joint Strike Fighter, ZUMWALT Destroyer, Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS), Joint Precision Approach and Landing System (JPALS), AMRAAM Missile, Rolling Airframe Missile, ALR-67 RWR, Global Hawk, Ciaman, Future Command Vehicle, Distributed Ground Systems, Phalanx CIWS

S1000D: Numerous military agencies from other countries have project which are using or developing S1000D, such as Type 45 Destroyer, Astute Submarine, Future Carrier, Future Submarine, Airbus A400M, Merlin, Apache, ASTOR, PARS 8X* Armored Vehicle, Scot Specialist Vehicle, etc.

S3000L & PLCS: An S3000L Proof of Concept project for customer-supplier interoperability was performed by Engisis with Italian Inter-forces normative for Integrated Logistic Support (NIILS). They simulated the exchange of product data (engineering and LSA) between an Italian prime contractor and the defense within a subset of the ILS processes. The issues they targeted were based on MIL-STD-1388 disadvantages. PLCS DEX1A&D was used for data exchange.

S1000D & LSA: Raytheon delivered a system to the U.S. Army which integrated their LSA data and S1000D tech pubs. They used the integrated EAGLE LSAR and EAGLE EPS tools. The tech pubs were authored and delivered as an S1000D Interactive Electronic Technical Publication/Manual (IETP/IETM) on a militarized handheld viewer. Authoring task times were reduced by 30%.

S1000D: Raytheon delivered a system to a FMS customer in the United Kingdom's MoD which integrated LSA data and S1000D tech pubs. They used the integrated EAGLE LSAR and EAGLE EPS tools. Reuse of LSA data produced S1000D procedural and Illustrated Parts Breakdown (IPB) data modules. That program was able to reuse existing data to produce 80% of their IETM.

S1000D & GEIA-STD-0007: General Atomics worked with the U.S. Navy on the Electromagnetic Aircraft Launch System (EMALS) program for aircraft carriers to implement a GEIA-STD-0007 LSA data system that's interoperable with an S1000D tech pubs system. They also utilize Creo 3D models from Windchill in the tech pubs. The system is in production.

S1000D & LSA: LFK-Lenkflugk rpersysteme GmbH (LFK), a German missile system company belonging to the European MBDA group, and partner in the Medium Extended Air Defence System (MEADS) Program, uses the Inmedius technical publishing system to support the use of Logistic Support Analysis Record (LSAR) data to author and manage S1000D procedural documentation.

SOFTWARE COMPLIANT WITH INDUSTRY STANDARDS

Commercial Off-the-Shelf (COTS) software is available for many of the industry standards in the TDI concept. Some are listed in "Life-Cycle Logistics Support Tools, a Survey for NASA" from 2012. Customization is usually possible with any of these, but not desirable from the standpoint of keeping data and processes standard, per the TDI concept. At the time of this project, the following standards were known to have software available:

S1000D, S2000M, AP239 PLCS, AP203/AP214 CAD, GEIA-STD-0007, and SCORM.

S3000L has a few use cases, but no COTS software is fully compatible yet with this young standard. S4000P was just released this year, so there is no software for it yet, but some is being developed already.

Adapters, or data exchange converters, are also available for various vendor tools:

- PDM to PLCS
- 3D CAD to S1000D
- LSA to S1000D

Proprietary vendor solutions are also available from various vendors to do many of these and other data exchanges or inherent integrations. The TDI concept strives for a plug-n-play, vendor-neutral environment, based on industry standards.

D. Risk Identification

To continue with the TDI project, further testing needs to be performed. The additional funding received will allow completion of planned testing. Without further testing, the risk of continuing this project to a prototype phase could result in unfounded data exchange mechanisms or poor results, which could lead to premature decisions to proceed or stop pursuit. Mitigation would be to continue testing and update the white paper.

Trial licenses and support for all TDI software will expire soon (at various intervals). TDI testing will not be possible without these. Mitigation would be to pursue extensions or other support. Another mitigation would be to pursue different vendors who have software compatible with the desired TDI standards, though it would increase time due to setups and learning curves.

TDI project team members may not be available to support further efforts. Each team member worked this project part-time. If not available, mitigation could be to find alternate personnel, but specific expertise available is limited. External support could be sought to help.

If the AP239 PLCS Windchill adapter is not tested, or if a user interface is not developed, then the PDM to PLCS exchange will likely not be practical due to the amount of effort involved. It is recommended to use Info*Engine to develop a method of testing AP239 Windchill exports. The rough order of magnitude (ROM) estimate is anywhere from 2 to 6 months for the Info*Engine testing method. Significant time is required to study what is required before a more accurate estimate can be obtained. If local TDI team members pursue a working solution, additional funding may be needed. Vendor PTC support is only available with funding and an indicated scheduling backlog. Also, the 90-day trial of this untested adapter will expire in December, and another trial may not be granted without funding. If not funded, this known PLCS interoperable functionality cannot be tested.

The EAGLE LSAR to PLCS simple mapping developed in the TDI project provides a foundation for a more complete mapping and future adapter. It is not known yet if it would aid to develop a mapping of EAGLE EPS S1000D to PLCS. It is not known if the vendors will develop such adapters. The TDI project could encounter a lengthy effort to develop these data exchange mappings. The current approach for this mapping relies on the LSA Data EXchange (DEX) specification developed by the Army's LOGSA division. LOGSA developers who were involved in that effort have stated that the DEX is only about 90% complete. Improving the end result from 90% to a point closer to 100% may require a level of familiarity with the GEIA-STD-0007 and ISO-10303-239/PLCS standard that TDI project personnel will not quickly obtain. Mitigations may include requesting reviews of the mapping by LOGSA developers or other with more extensive experience with the relevant standards.

Using the S-series or PLCS may not be allowed in current NASA policies or contracts. Based on the Army's LOGSA findings, contracting may be a challenge with the S-series. Mitigation may require some NASA policy or contracting adjustments.

The AP239 PLCS standard is complex and still not fully mature. It may not gain support for widespread industry use. This risk has been accepted by all S-series and GEIA-STD-0007 committees for years, based on the high need for such interoperability, the lack of other such standard options, and the strong foundation of the parent ISO 10303 STEP standard.

CAD data exchange with non-CAD entities may not be effective if design data is not structured in a compatible manner. The draft NASA-HDBK-0009, "Engineering Model Maturity Level (EMML): Model Definitions" could help this, but it is not yet released. Mitigation could be to develop local guidelines based on the draft and industry evaluations like the S1000D MBETT. KSC's CAD community already has some local standards and training in place, as a good place to start.

CAD data converted using neutral formats (STEP, IGES, etc.) can lose some integrity during conversions. These risks have been accepted for years in industry. These must be considered again when performing CAD data exchanges using the TDI concept to pass data to entities outside of the design life cycle phase. Accept this risk, but check integrity.

Standardization of 3D CAD visualization in S1000D is not fully mature. Mitigation is to rely on the S1000D MBETT's interim solutions and planned advancements in 2015. Meanwhile, other methods of 3D graphic usage in S1000D are available.

NASA communities may resist changes such as those described in the TDI concept:

- Adoption of LSA standards and tools compatible with these standards.
- Direction to design with data structured in a manner compatible with non-design entities.
- Adoption of S1000D and tools compatible with it.
- Mitigation could be enabled by education/demonstration of life cycle use as well as communication by direct management support.

General Risks Identified in Industry

According to AIA, there is a natural cycle of buy-implement-support-buy that companies and government agencies seem to follow when deciding to use software applications to help improve employee productivity, comply with contracts, or win new business. There is a series of events that usually transpires in the life cycle of product development where interoperability standards are not considered in the selection or implementation of electronic business systems. **There are significant business risks to any business or government entity associated with not adopting data interoperability standards.** These business risks manifest themselves in multiple use cases, some of which are detailed here. This is not an exhaustive list:

- Data loss due to application obsolescence.
- Business process stagnation due to application obsolescence
- Liability of incorrect manufacture from inconsistent non validated translated data

- Intellectual property loss due to application obsolescence and the associated data loss
- Hardware obsolescence
- Operational and support costs associated with obsolete applications

Risk mitigation:

- Implement standards based interoperability thinking in the business analysis and decision-making described above.
- Develop a data succession plan and an application obsolescence plan
- Do an exhaustive analysis and evaluation of application functionalities from competing application providers prior to acquisition.
- Choose an application ecosystem and stick with it
- Avoid any and all application customizations
- Change or reinvent business processes to accept default application functionality
- Be careful not to take on too much too fast – implement in gradual steps
- Stick to a pre-defined plan and avoid scope creep

E. Setbacks

Project start was originally scheduled for April 2014. Various delays in contracting caused a delay until August 2014.

Project requirements limited performance to 90 days for NASA IT Labs deliverables. The TDI project attempted to accomplish many tasks with various untested IT configurations and data exchanges. Each project team member was only available to provide limited support. With these time and resource limitations, software installation and configuration issues hindered progress. Most issues appeared to be typical of new systems which would normally be resolved quicker with full-time production support. With the typical issues that were mostly resolved, forward progress should not cause problems with those IT functionalities.

Obtaining test data progressed slowly. Raytheon provided the quickest test data—the bike data based on industry standards—though it needed some adjustment to work for the project. Jotne has good connections with their ESA customer and initiated requests for ESA ISS data (EMCS) which resulted in a long process for approvals and data transmission. NASA JSC provided quick access and approval to use their ISS LSA data for the Columbus module—the closest LSA data known which is partly related to the EMCS data. NASA JSC and MSFC work procedures related to the ESA ISS data set were pursued. Contacts and permissions were obtained after a long process, shortly before TDI project testing was being finished for the final paper and presentation.

One expected obstacle was the lack of existing adapters in the industry. The ideal concept being evaluated in this TDI project is where each vendor has one adapter to plug their tool into a PLCS-compliant tool. One adapter exists for the Windchill PDM to exchange data with EDMtruePLM. No adapter exists for EAGLE LSAR or EAGLE EPS to exchange with EDMtruePLM. This was assumed upon project start. This obstacle was magnified due to lack of resources to perform full evaluation of mapping/conversion needs. Many vendor tools support various emerging standards, but adapters have not been developed yet for most of them to the PLCS standard.

The AP239 PLCS adapter was not ready out-of-the-box to use for CAD data exchanges. The adapter was installed in Windchill, but there is no user interface. PTC was not funded in this project and therefore was not able to support other than suggesting that we develop our own import/export interface, or else use PTC's Info*Engine to develop a way to test functionality, same as they do in their R&D and quality departments. The TDI project did not have resources to perform these potentially extensive efforts. The rough order of magnitude (ROM) estimate is anywhere from 2 to 6 months to develop an Info*Engine testing method.

The PLCS repository client performs DEX1 exchanges out-of-the-box, but requires development for DEX3 functionality. The software has the capacity to handle DEX3 data, but developer software is required, until a planned future update enables this for user clients.

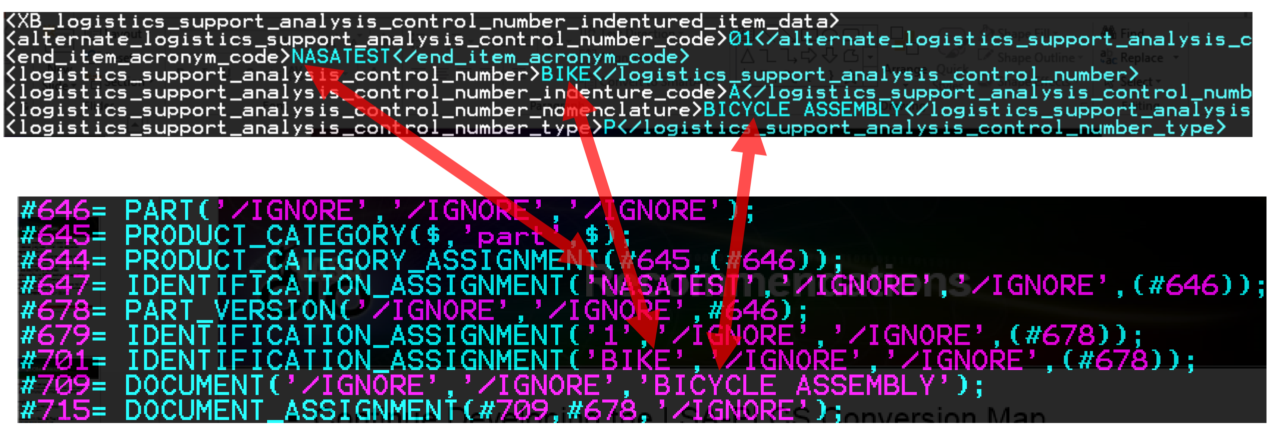
ISS LSA data exchanges from JSC's EAGLE LSAR were not clean. This was somewhat expected, since the system is customized and based on the older standard MIL-STD-1388-2B. Also, it's suspected that software limitations restricted desired results. Exports to the desired GEIA-STD-0007 format could not be performed on the desired small subset of data, but rather the entire ISS data set had to be exported. When GEIA-STD-0007 or MIL-STD-1388-2B exports were then imported into TDI's EAGLE LSAR GEIA-STD-0007 version, a special character in the end item had to be removed before imports worked. Other errors occurred during import attempts to both TDI's EAGLE versions and to PowerLOG-J. More time was needed for thorough evaluation of data exchange integrity.

F. Successes

The TDI project has accomplished some validation testing for this industry concept which has not been attempted much in the industry. The concept of a PLCS central repository with the IPS/ILS elements all exchanging data through that one interface has been presented at many industry and government conferences globally. This project broke some of that ground which was untested, or rarely known/tested—steps toward further validating that concept. Though not all interfaces were able to exchange data as intended, lessons were learned, and a path forward is laid out to enable desired exchanges.

The most significant accomplishment in the ideal TDI concept of exchanging data through PLCS is the mapping of LSA data from EAGLE LSAR to PLCS format. The TDI team created a partial data conversion map, due to lack of an adapter available for EAGLE in PLCS format. Though the TDI project will target this for import into Jotne's EDMtruePLM PLCS repository, the conversion would be usable for any PLCS compliant tool. The translator is about 20% complete. Portions of the LSA-PLCS translator design implemented include:

- A module for text encoding of PLCS output data.
- Hand-generated versions of several modules for PLCS entities and attributes, which will eventually be auto-generated from the EXPRESS schemas.
- Partially-generated modules for the DEXlib templates, which will be fully automated with the inclusion of a parser for the Instantiation Path syntax.



Other testing accomplishments:

- The PLCS repository was populated with several test data sets. Data was entered by DEX1 import and manual entry.
- The PLCS repository exported data as DEX1, and this was used to evaluate for development of a conversion map with EAGLE LSAR.
- ISS EAGLE LSA data was exported, then imported to PowerLog-J successfully.

- Windchill CAD product structures were exported to exchange BOM data, and they were imported into EAGLE LSAR using the vendor BOM import tool. One of the largest, most complex KSC CAD product structures was successful in this, as well as the industry standard bike sample data set.

The AP239 PLCS Windchill adapter was verified by PTC as installed correctly. It was not functional, but an industry project was discovered that recently went into production which utilized this adapter with a PLCS repository. This evidence demonstrates a PLCS-centered system that works with Windchill, the PLCS adapter, and TruePLM. An estimate to perform the testing gives hope of reasonable performance expected.

Much research was accomplished to better understand the suite of related ILS/IPS standards and how they can best exchange data. Updates to and position papers on many of these standards surfaced between TDI project submission and the writing of this paper. These shed a positive light that the global standards communities involved are committed to resolving interoperability challenges.

Various data sets were obtained for the TDI project, freely providing a healthy foundation for further testing. Real ISS data was obtained with export control approval from multiple NASA and ESA sources. Sample data used by the industry is also lined up for simple, generic testing.

G. Recommendation

Results so far point to a positive direction for the TDI standards. Standards-based, vendor-neutral interoperability between PDM, LSA, and Tech Pubs data appears to be available or developing within a year or two. Further testing could validate this.

In the short term, it is recommended to continue with the testing that is able to be accomplished. Updated results should be considered to incorporate into revision 1.1 of this white paper. More time is needed for thorough evaluation of data exchange integrity. Desired testing which was not completed during the project so far was:

- JSC ISS EAGLE LSAR export as XML, import to TDI EAGLE GEIA client as XML.
- JSC ISS EAGLE LSAR export as 2B, import to PowerLOG-J, then export as GEIA, then import to TDI EAGLE GEIA client as GEIA.
- JSC ISS EAGLE LSAR export as 2B, import to TDI EAGLE S3000L (DEF STAN 00-60) client as 2B.
- Export TruePLM PLCS data as DEX1, attempt import to PowerLOG-J.
- Use JSC ISS data imported into TDI EAGLE LSAR (both GEIA & S3000L versions) to produce EAGLE EPS S1000D data and publish as an IETP. Compare with NASA's IPV.
- Evaluate what it would take for NASA IPV's XML version of SODF/PODF procedures to convert/import into EAGLE EPS S1000D.

Another test we recommend is to request for JSC's Orion EAGLE LSA and MSFC's SLS PowerLOG-J LSA to test data exchanges with each other, and then with other TDI standards.

For the LSA-PLCS translator development, detailed designs and project plans are needed for remaining components, with an aim of obtaining support for additional time and resources to complete the implementation, fully leveraging existing mappings encoded in the LSA DEX. Pending completion of these plans, an estimated rough order of magnitude (ROM) for completion of translator implementation is 3 months of full-time development effort. Coverage at this stage would include approximately 90% of the DEX1 (product breakdown structure) subset of the PLCS standard. Analysis of translator performance and coverage would be required to determine additional effort required for greater coverage of the full PLCS standard.

For the long-term, it is recommended to carry results forward to the next level, by testing a networked integration of this setup, by adding tests of additional functionality, and by adding data sets from more space products/systems. One of the additions which should be tested is an evaluation of the potential of the TDI standards, tools, and data exchange methods to exchange data or integrate with Manufacturing Execution Systems (MES) or similar work execution systems. KSC currently uses Solumina and Maximo software for this. Past research indicated an S1000D usage with Maximo. Such potential should be evaluated to determine the value related to TDI concepts. Also, pursue development of a way to test CAD data exports using PTC's AP239 PLCS adapter. Evaluate if this could be done with local KSC personnel or if funded vendor support would be required. Additional funding will be needed to perform these recommended long-term actions.

Upon evaluation of test results described above, if results show good potential, then a full integration pilot should be pursued.

G-1 Feasibility

The TDI concept appears to be technically feasible, but more testing and evaluation needs to be performed to determine how ready the COTS tools and industry standards are. For S1000D and GEIA-STD-0007, those standards are more mature and have COTS software ready for individual or integrated implementations without customization required. Others like PLCS (COTS software available) and S3000L, and interoperability solutions between any TDI standard, can be implemented, but the levels of customization or development needed are not clearly understood. Further study will continue to evaluate this better. S2000M was not evaluated, but COTS software is available, and it's used by many in NATO and Europe. SCORM was not evaluated, but numerous COTS software and use cases exist.

Initial development of the LSA-to-PLCS translator indicates that the basic approach is sound, with additional work required to further develop highly-automated generation of the translation based on existing mappings encoded in PLCS DEX form.

Financial feasibility has not been analyzed in detail at this time. Further study would provide this assessment. Industry use cases show cost and time savings. Initial investment has been noted to be higher, with much greater long-term gains later.

Since many NASA programs/projects are currently in development, now is the best opportunity to realize technical and financial feasibility. For NASA systems which don't adopt the TDI concept now, savings would be less and later.

G-2 Value

True interoperability of life cycle technical data which is vendor-neutral, non-customized, and based on standards has not been possible until recently. The TDI concept is designed to lower the LCC with early design influence on the full life cycle, continual interaction of technical data across the life cycle, utilization of industry standards and COTS software instead of custom data systems, and efficiency, quality, and safety gains available within each of the modern standards and software.

Use of the TDI concept standards have shown time and cost savings in the use cases described earlier. The best gains of course are for new projects, and some programs have found benefit in converting legacy systems. Access to specific cost savings data has been pursued, but is generally proprietary.

Efficient IT systems, and intelligent organization of the content which IT manages, can save significant time and therefore cost with NASA's high volume of technical data. Too much time is wasted due to lack of finding or reusing data. According to "The Hidden Costs of Information Work," a 2006 IDC study of information/knowledge workers, it revealed that:

- They spend 48 percent of time searching (9.5 hrs/wk) & analyzing (9.6 hrs/wk) information.
- They waste 3.5 hrs/wk in unproductive searches (info not found).
- They waste 3 hrs/wk recreating content that already exists.
- Not finding the information needed costs an organization employing 1,000 knowledge workers about US$5.3 million per year.

The PLCS and S-series standards, and GEIA-STD-0007, emphasize data reuse and provide efficient mechanisms to make data easier to find and utilize.

Model-Based Enterprise (MBE) is the modern trend of designing data systems to allow direct access to 3D models and related data. Much of design data can be reused for technical manuals, LSA, etc., saving hours of research and re-creation time. Mere PDFs of 2D drawings doesn't provide such savings, and they're not always easily found when searched for.

An example of the value of using S1000D is described well by one customer of a U.S. military product who listed the following realized cost benefits:

Decreased Lifecycle Support Costs

- Streamlined change management and multi-format delivery process
- Increased revision efficiency
- More time for data review leads to reduced data errors
- Decreased Technical Orders (TOs)
- Contracting Data Modules (DMs), not publications
- Quality ↑ Costs ↓

ROI Factors

- Average cost savings % using S1000D for the program – "High Teens"%
- Data Reuse – achieved up to 70%
- Realized up to 50% cost savings producing manuals
- Realized opportunities to manage common data – 10% same in all books
- Realized added benefits of Applicability
- Reduces numbers of books authored, edited, maintained, but retain ability to deliver all configurations required
- Increased output consistency

In one white paper on S1000D, they summarize some "real-life ROI cases":

- 63% cost reduction by an aerospace engine manufacturer that simultaneously increased the number of parts catalogs from 81 to 132, while reducing the number of authors from 18 to 3.
- 20% productivity gain by aircraft mechanics by providing customized job cards (for example, an engine removal procedure was reduced from 100 pages to 30 pages, thus making 200 mechanics more efficient!).
- 48% cost reduction (after 9 months) in the production of technical documentation using S1000D.
- 20%+ cost reduction in the production of computer-based training by using S1000D and SCORM.

That same white paper also discussed the value of availability, using an example scenario of using LSA data and S1000D tech pubs data. An energy company performed a study to determine how the availability of correct and intelligent technical information would contribute to the increased availability of their energy facilities. They found that facility availability was impacted by:

- Mean Time Between Failure (MTBF) – this is also known as “Reliability”.
- Mean Time To Repair (MTTR) – this is also known as “Maintainability”.
- Mean Waiting Time (MWT) – this is also known as “Supportability”.

Availability was calculated as a function of MTBF, MWT and MTTR. The energy company determined the value of 1% availability was:

- 1% availability of a windmill is worth 15,000 EUR per windmill per year
- 1% availability of a nuclear reactor is worth 5 million EUR per year

In the projected calculations using LSA data linked with S1000D data improved from 90% to 94% availability. In addition to savings using S1000D itself, their experience displays the ability to save 20% in transforming LSA data to S1000D DM’s.

The white paper went on to estimate a scenario where, with adoption of S1000D, assuming an investment of $500,000 in technology, $20,000 in implementation services and $100,000 in software maintenance, the Net Present Value and Internal Rate of Return over 3 years is highly favorable. They show a break-even point after about 1.5 years.

ILS/IPS has a large impact on LCC. Handling of technical data is a significant part of that. Dr. Kevin Watson of NASA Headquarters Logistics said in a 2010 AIAA paper:

> *“Neglecting ILS or implementing poor ILS decisions invariably have adverse effects on the life cycle cost of the resultant system…NASA is placing renewed emphasis on the importance of considering the support concept for systems (e.g., a spacecraft) at the earliest stages of a program or project… For NASA space flight projects, the NASA life cycle phases of formulation and implementation are divided into incremental pieces…Of critical importance is the acquisition logistics content (often referred to as supportability planning), which should focus on the tasks that*

examine all elements of a proposed system or product to determine the logistics support required to keep the system/product/asset usable for its intended purpose and life cycle, and to ensure that the design process results in a system that can be supported at a reasonable cost. With a significant percentage of product life cycle costs occurring in the sustainment phase of the life cycle, applying acquisition logistics in the design phase is the best way to reduce the life cycle costs."

Initial assessment is that the integrated standards of the TDI concept would likely provide significant value to NASA centers. Benefits are available with adoption of each individual standard, but benefits would be greatly magnified upon adoption of each part of the integrated suite of standards.

H. Appendix

H-1 Lessons Learned

LESSONS LEARNED FROM TDI PROJECT

Lessons were learned on how to plan and acquire all that's needed to perform testing like the TDI project. These "logistics" took much of the project's time and effort, even before the start of the 90-day project period of performance. It was discovered that the only mechanism for ESC contractors to perform work such as the TDI project is a Task Order (new or in-scope addition). This required a long lead time and used some of the allotted funding. Some additional funding was obtained in the beginning, intended to help accomplish TDI objectives in that time, as well as allow budget to continue testing or add features. Mechanisms are in place to continue testing for a short while longer.

If future efforts are funded, plans should include hours and travel to attend appropriate industry conferences or working group meetings. Time would be needed to propose papers and/or make presentations. An additional deliverable for the TDI project is to submit results to industry forums.

One lesson learned from testing was to not perform exports from an EAGLE LSAR MIL-STD-1388-2B client in GEIA-STD-0007 format, since this is no longer supported by the vendor.

LESSONS LEARNED FROM NASA

Disparate technical data increases safety risks from poorly integrated elements, as outlined in the Columbia Accident Investigation Board (CAIB) report.

An SLS Program LSA report says that initial LSA development should be provided in conjunction with the design effort. After initial development, an operations contractor should then be brought in to lend insight and past operational experience with similar systems to further develop LSAs. TDI comments: LSA is sometimes ignored during the O&S phase, as it was for Shuttle. A formal LSA data system should be organized and planned for continual use during the whole life cycle. ISS currently does this.

LESSONS LEARNED FROM DOD/INDUSTRY INTEROPERABILITY PROJECTS (from AIA)

There have been a few examples in the media recently that illustrate the hidden costs that can surface when interoperability is not considered as a key element of an application architecture or implementation.

- A European aircraft manufacturer announced an additional 5 billion euro cost increase in a product launch from design flaws due to lack of interoperability between different CAD systems.

- In the March 1999 NIST study of the interoperability cost analysis of the US automotive supply chain estimated that imperfect interoperability imposes a $1 billion annual cost on the members of the US automotive supply chain.
- Respondents to a 2008 mold design and manufacturing industry survey were asked if customer unique CAD requirements added significantly to their cost of doing business. Of those responding, more than a quarter estimated that those requirements add 20 percent or more to the cost of doing business.

H-2 Benchmarking

No benchmarking was performed.

H-3 Description of TDI Industry Standards

This section will describe the industry standards evaluated in the TDI project. It encompasses research relevant to project evaluations, and it is a reference for readers who may not be familiar with some details or current developments with these emerging standards.

Various organizations produce standards and specifications. The space industry has a few, such as NASA, European Cooperation for Space Standardization (ECSS), Consultative Committee for Space Data Systems (CCSDS), etc. There are standards organizations that are not exclusive to the space industry which include some standards applicable to space. Many of the almost 300 Technical Committee (TC) areas in the International Organization for Standardization (ISO) apply to aerospace. Each Technical Committee is divided into SubCommittees (SC) for major functional areas, and the subcommittees are further parsed into Working Groups (WG) with very specific focus.

Standardization of space hardware design is important and increasingly needed. However, with all Standards Development Organizations (SDO), ground processing is one of the areas least addressed. By ground processing, that could include assembly/integration, test and checkout, launch operations, maintenance and repair, supporting infrastructure systems, etc. Any of these could apply to a launch vehicle, payload/cargo, space station/habitat, launch pad, processing facility, or support equipment. “Ground processing” is typically covered by what the industry calls Integrated Logistics Support (ILS) or Integrated Product Support (IPS). The Evolved Expendable Launch Vehicle (EELV) requirements include a call to standardize infrastructure and processes in addition to design. The EELV requirements document stated in 1998 that one of the reasons that the Expendable Launch Vehicle (ELV) launch systems at the time were cost ineffective was due to lack of standardization of facilities, processes, vehicles, procedures, and supporting infrastructure, making each mission a unique event.

Many ILS/IPS entities rely heavily on technical data. To create, use, and manage technical data efficiently requires Information Technology (IT). Many IT industry standards exist. Some IT applications utilize these standards efficiently, and some are too custom to be efficient. It has been rare to find sets of industry standards that are unified between IPS and IT, or find standards which define both needs together well. The suite of standards being evaluated in the TDI project provide not only unified definition of both IPS and IT for each IPS function, but they are working together to integrate across all IPS entities and to cross-over to design entities.

Emerging Standards Evaluated in TDI Industry Concept

New and reworked industry and military standards for Integrated Product/Logistics Support (IPS/ILS) or technical data have been released in recent years. More are in development. Joint agreements and efforts with international entities are in place, and integrated councils and work groups are working toward goals of interoperability across the whole life cycle. The emerging industry standards which are related to each other in the industry concept are:

- **ISO 10303-239** Product Life Cycle Support (PLCS), a.k.a. AP239.
- **S-series** Suite of Specifications
  - Jointly managed by Europe's Aerospace and Defence Industries Association (ASD) and America's Aerospace Industries Association, (AIA). S1000D management also includes Airlines for America (A4A), formerly the Air Transport Association (ATA).
  - **S1000D**: International Specification for Technical Publications Utilizing a Common Source Database (CSDB), Issue 4.1, Dec 2012.
  - **S2000M**: International Specification for Materiel Management, Issue 5.0, May 2012.
  - **S3000L**: International Procedure Specification for Logistic Support Analysis (LSA), Issue 1.1, Jul 2014.
  - **S4000P**: (formerly S4000M), International Specification for Developing and Continuously Improving Preventive Maintenance, Issue 1.0, May 2014.
  - **S5000F**: International Specification for Operational and Maintenance Data Feedback, Issue 0.2, Jun 2014.
  - **S6000T**: International Procedure Specification for Training/TNA (draft in work).
- **INDUSTRY LSA** managed by SAE (overlap S3000L)
  - **GEIA-STD-0007**: Logistics Product Data, Rev B, May 2013.

- GEIA-HB-0007: Logistics Product Data Handbook, Rev B, Feb 2014.

- **SCORM** (Sharable Content Object Reference Model): A collection of standards for e-learning. SCORM 2004 4th Edition was released in 2009. It's compatible with S1000D.

The S-series ILS/IPS standards have their own councils and working groups. The ASD/AIA ILS Specification Council was formed when the need was identified for an "umbrella" specification to ensure the compatibility and commonality of ILS processes among the suite of ILS specifications. In 2011, the decision was made to develop, publicize and maintain an ILS guide, named SX000i, so as to provide a compatible and common ILS process to be used in the other ILS specifications. SX000i will also define the mechanisms that will be used to ensure that the suite of ILS specifications is both integrated and interoperable.

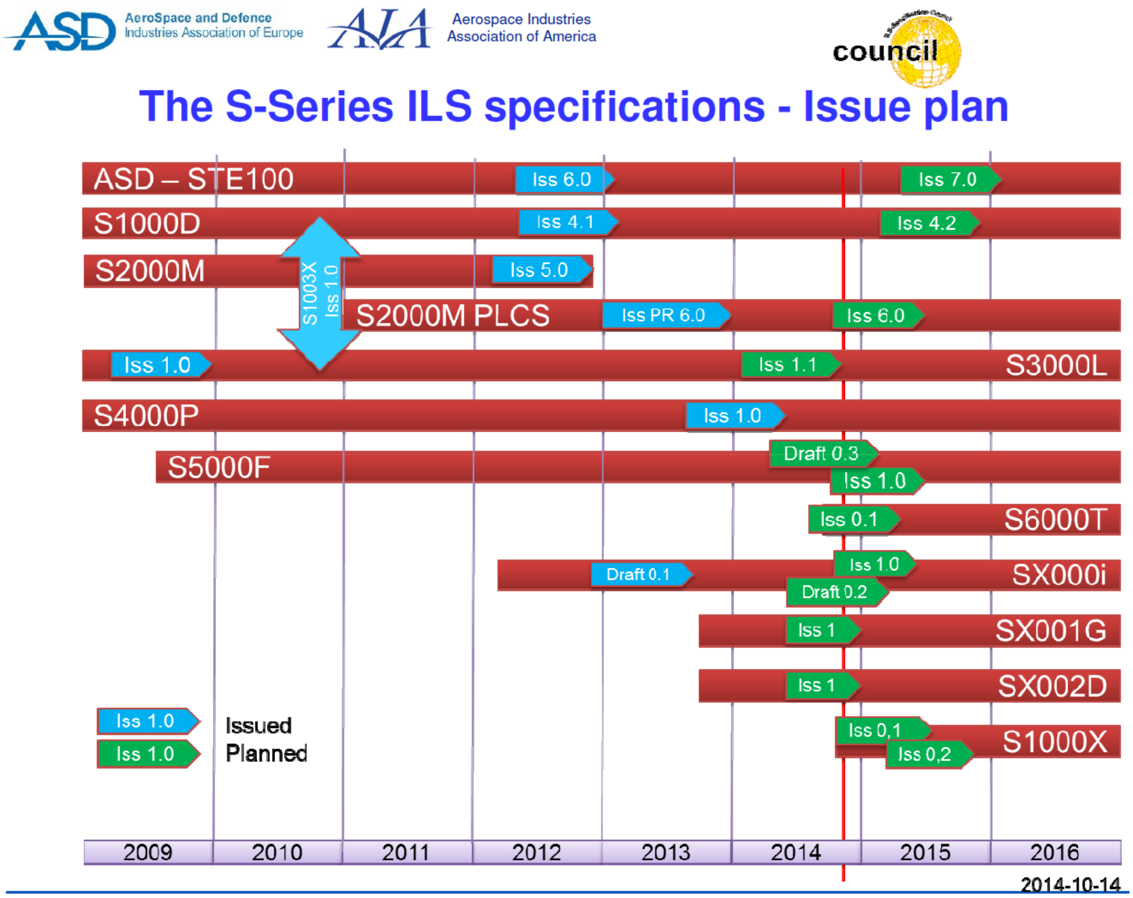
The ASD/AIA Data Model and Exchange Working Group (DMEWG) was formed under the ILS Specification Council in 2011. The DMEWG coordinates the data modeling activities that are performed within the respective ILS Specification Steering Councils and Workgroups so as to harmonize and consolidate data requirements into one coherent data model. The DMEWG is also responsible for the governance, review and publication of Aerospace and Defense Data Exchange Specifications (A&D DEXs), using ISO 10303-239 Product Life Cycle Support (PLCS).

The AP239 PLCS standard is the link between technical data for ILS/IPS entities and design entities. This provides data exchange mechanisms across the entire life cycle of a product/program. The ISO TC collaborates with the S-series and similar standards for interoperability. Global military standards have been very interested in AP239, and some of those standards have been getting modified to align with PLCS.

What's "Emerging" about Technical Data Standards?

When the TDI project was proposed in December 2013, the suite of TDI standards was promising. Since then, various standards have either had initial release, a significant release update, or industry positions taken on their adoption. These standards have been developing for years, but maturity and adoption has been only recent. Maturity appears to be taking a fast turn at this time

The figure below shows the large number of releases of the S-series suite of standards (specifications) due to occur in 2014 and 2015. This is due to planned harmonization coming to fruition.

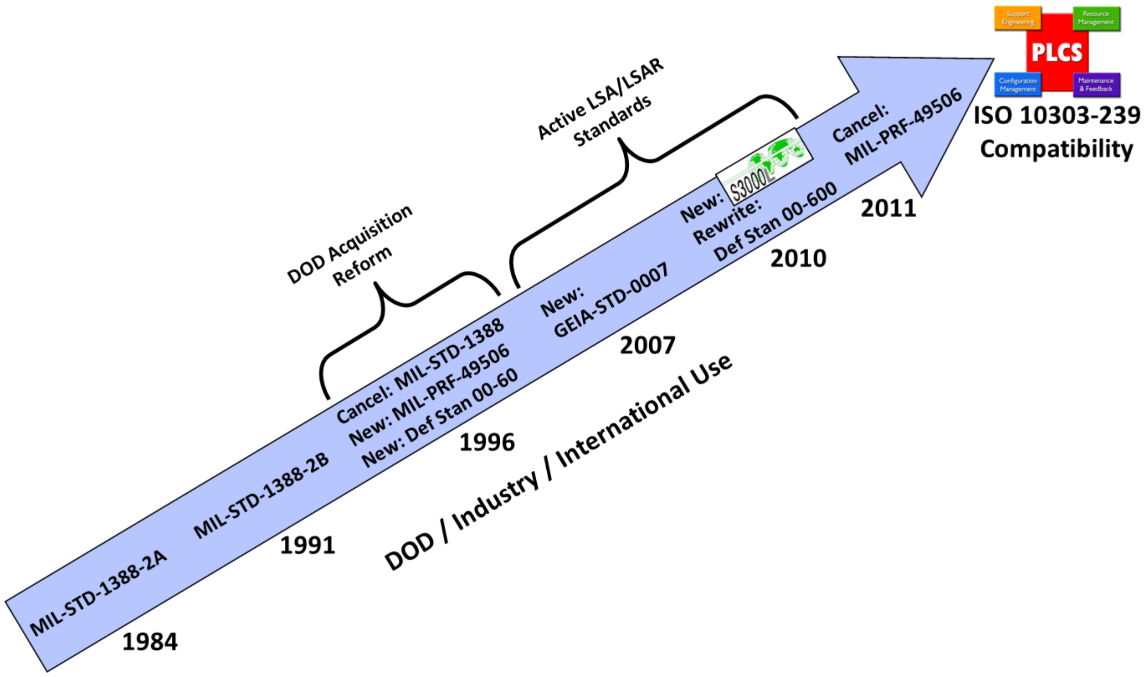


The U.S. DoD went through acquisition reform in 2009. In 2011, they updated ILS standards, handbooks, and directives, renaming classic ILS terminology to Integrated Product Support (IPS). The set of changes includes:

- 10 ILS elements changed to 12 IPS elements. (These include all technical data in the TDI industry concept and their corresponding functional entities.)
- Performance Based Logistics (PBL) changed to Performance Based Life Cycle Product Support (PBL).
- Performance Based Logistics: A Program Manager's Product Support Guide ("The PBL Guide") changed to Product Support Management (PSM) Guidebook.
- ILS Plan changed to Life Cycle Sustainment Plan (LCSP).
- PLCS and the S-series references were added to various IPS handbooks, policies, and training.

The U.S. military's LSA standard was developed in 1984 and has been used globally by various countries – even to this day. As seen in the figure below, LSA standards have been through various changes. S3000L is the recent S-series answer to part of an LSA data system's needs. The U.S. DoD adopted an industry standard, GEIA-STD-0007. The

U.K. developed Def Stan 00-60. Each of these active LSA standards have been working their way toward compatibility with AP239 PLCS.



The ISO 10303-239 PLCS standard came from a joint industry and government initiative to accelerate development of new standards for product support information (basically IPS or ILS). This international project began in 1999, and the initial revision release was in 2005. The AP239 second edition was released in 2012.

Convergence of Standards toward Interoperability

How does one know that these recent standards are proven and worth adopting? In addition to a growing set of global users, there is a history to their development.

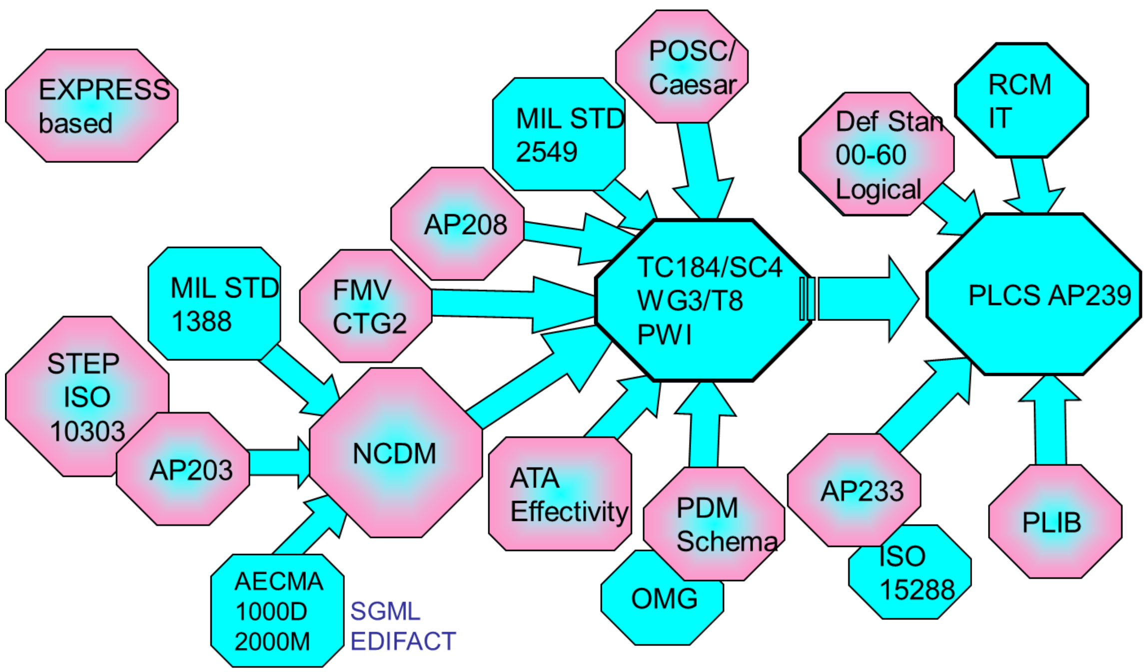
The Computer Aided Logistics Support (CALS) initiative was begun by the U.S. Defense Department in 1985. Later, NATO also took up CALS. Its purpose is and was to facilitate the integration of digital information for weapons system acquisition, design, manufacture and support functions. CALS later changed to mean "Continuous Acquisition Lifecycle Support." An LSAR (Logistics Support Analysis Record) database standard MIL-STD-1388-2 was formed in relation to CALS, which the FAA also adopted. CALS required the OEM to create LSAR data and to include it with Interactive Electronic Technical Manual (IETMs), Support Equipment Recommendation Data, and Training Data. IETMs were based on MIL-M-87268 and MIL-D-87269, with SGML text authoring and CCITT Group 4 and CGM graphics standards.

Meanwhile, in Europe, the AECMA aerospace organization developed their own related standards, 1000D for IETMs, and 2000M for Illustrated Parts Catalogs (IPC) and

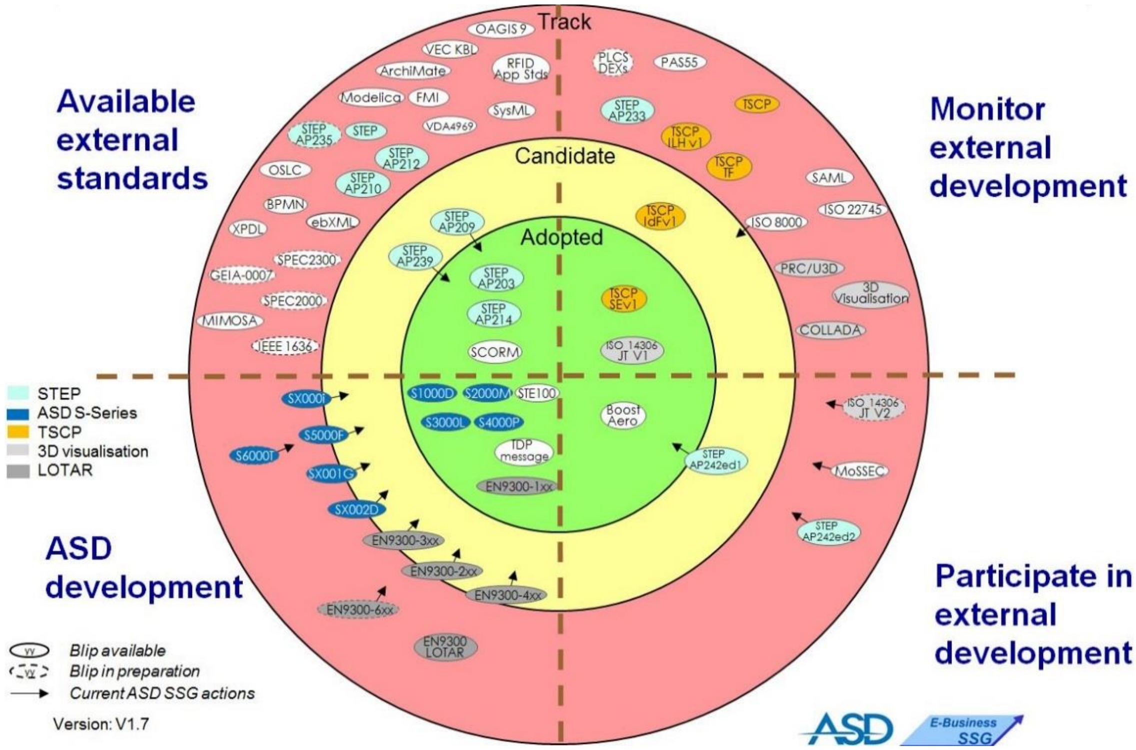
Provisioning. The NATO CALS model was based on 3 standards: MIL-STD-1388-2B, 1000D, and 2000M.

AECMA has since been renamed ASD (AeroSpace and Defence Industries Association of Europe), and the two specifications are called S1000D and S2000M. These standards have transitioned their data exchange standard from SGML to XML. The U.K. has since developed DEFSTAN 00-600 for ILS, GEIA's LSA standard GEIA-STD-0007 replaced U.S. military standards, and ASD has since developed S3000L and S4000P for LSA.

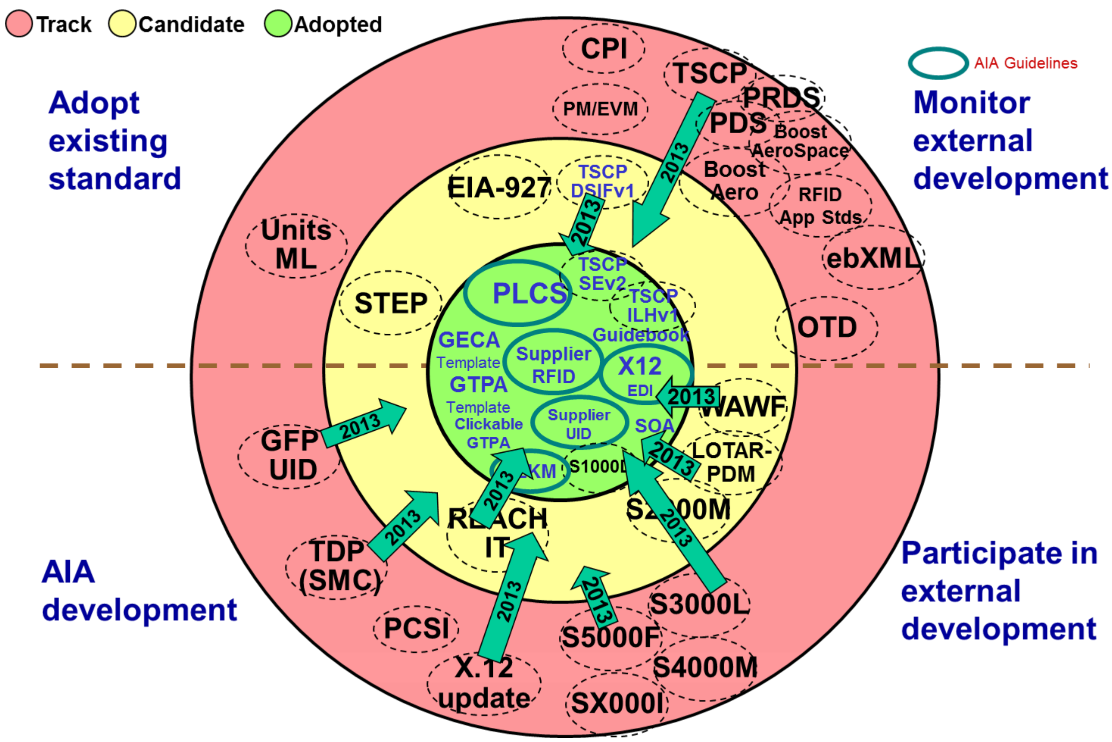
PLCS AP239 is the interoperable link which connects the O&S data environment with the design data environment. It's parent ISO 10303 is managed by ISO Technical Committee (TC) 184, but AP239's working group collaborates with the ILS/IPS community of standards. The figure below shows PLCS relationships to standards and programs which contributed to AP239 during development from 1999-2004. It represents a view of the trends where industry and government standards are converging toward a common interoperable model.



The most recent status of adoption and development of all related standards being tracked by ASD is shown in the figure below, from October 2014.



The most recent status of adoption and development of all related standards being tracked by AIA is shown in the figure below, from 2013.



S-Series Data Exchange Standards

Interoperability and commonality between each of the S-series standards has been in development by the ASD/AIA ILS Spec Council. The specifications to harmonize these standards are coming to fruition in 2014 and 2015, listed below:

- SX000i: International guide for the use of the S-Series Integrated Logistics Support (ILS) specifications (draft in work)
- SX001G: Glossary, Issue 1.0, Dec 2014
- SX002D: Common Data Model, Issue 1.0, Dec 2014
- SX003x: Compatibility Matrix for the S-Series ILS Specifications (draft in work)
- SX004G: UML model readers guidance (draft in work)
- S1003X: S1000D to S3000L Interchange Specification, Issue 1.0, Mar 2011
    - S1003X provides a cross reference matrix of S3000L to S1000D data element to facilitate the exchange of task information. An initial draft matrix of data elements between GEIA-STD-0007 and S1000D has been drafted but not published.

Technical Publications (Procedures & Manuals)

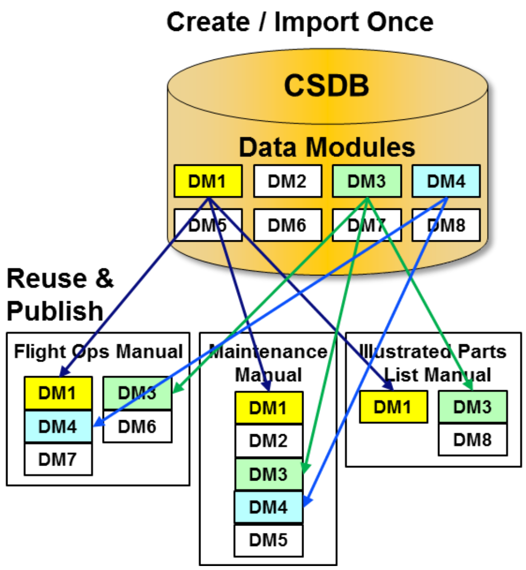
The general term Technical Publications (a.k.a. "Tech Pubs") is used in industry for technical reference manuals, work instructions, and training manuals. The term Interactive Electronic Technical Publication (IETP) is the most advanced form of Tech Pubs. Before S1000D, they were called Interactive Electronic Technical Manuals (IETM). Some identified them with class numbers based on complexity. The predecessor to IETM's is various forms of paper and electronic Tech Pubs, some which were governed by industry specifications or standards, and many which were governed by none or only internal policies.

S1000D International Specification for Technical Publications Utilizing a Common Source Database (CSDB)

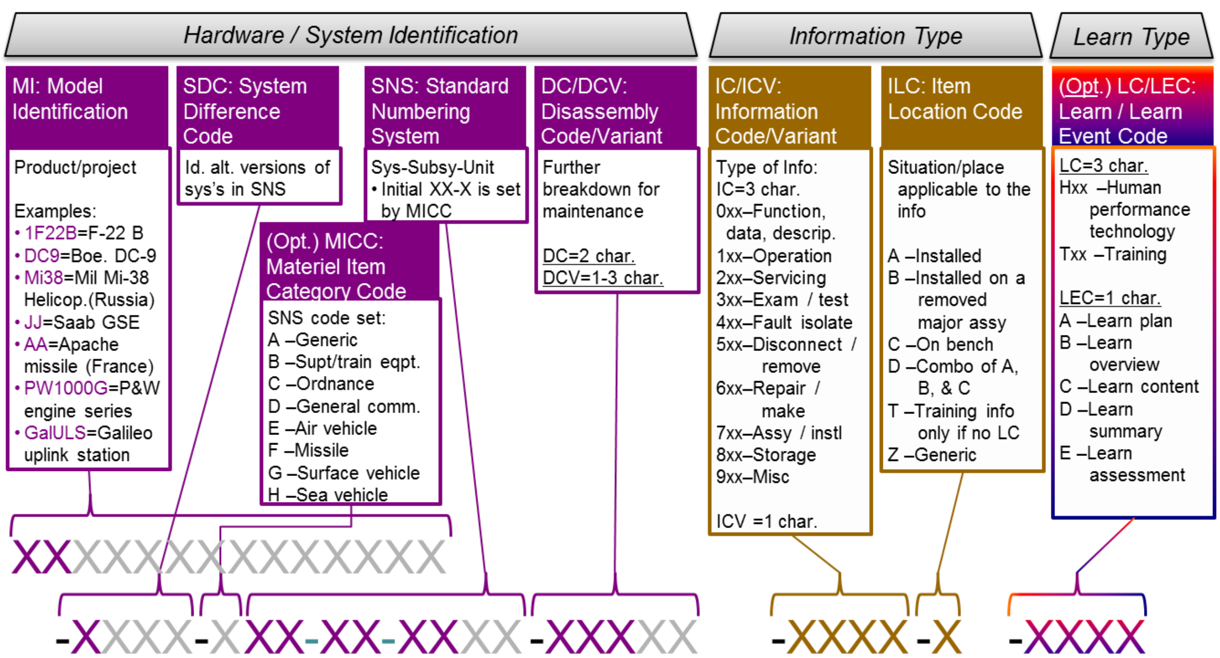
S1000D was produced to establish standards for the documentation of any civil or military vehicle or equipment. It is based on international standards such as SGML/XML and CGM for production and use of electronic documentation. In addition, it defines a Common Source Data Base (CSDB) to provide source information for compilation of the publications and for use in electronic logistics information systems to deliver modules of information direct to the user. S1000D has also been linked to the PLCS development, which enables the compilation of technical documentation direct from the current product structure, and to SCORM, for training materials.

The key business driver is to reduce the cost and complexity of technical documentation by providing a modular structure with components that can be reused for different product versions. The use of a common structure also permits the use of generic viewing tools which are not specific to a particular product. Adoption of S1000D provides a common structure for technical documentation which is interoperable across products and customers. It has also been proved to make the preparation of technical documentation faster and less expensive, and simplifies translation into other languages.

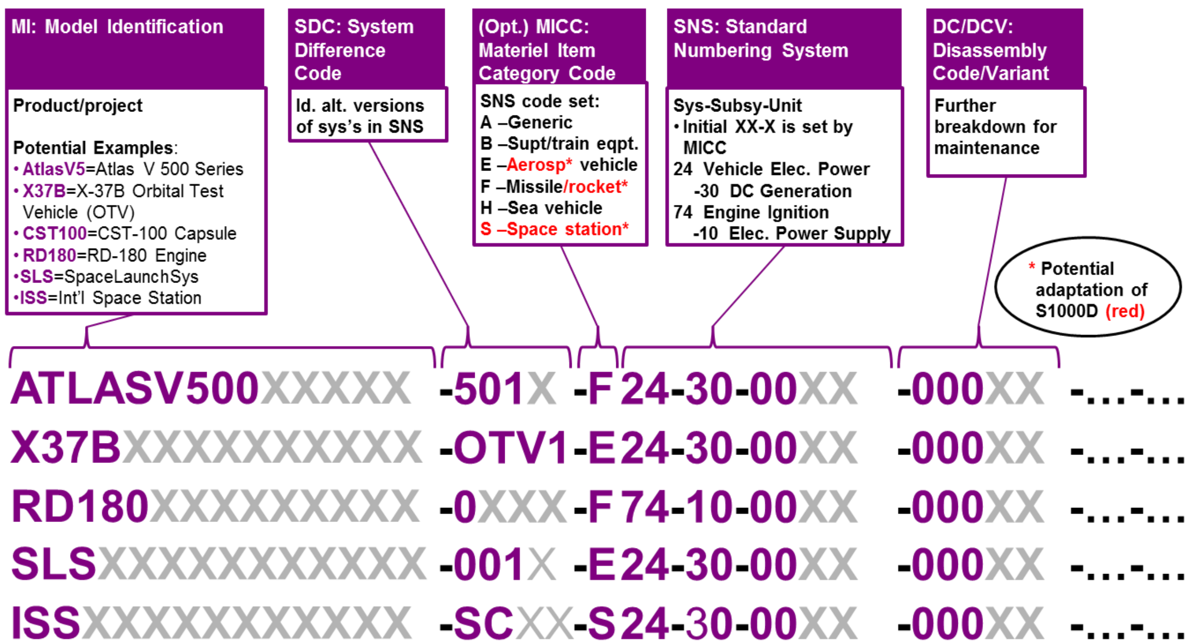
The figure below shows how reusable Data Modules (DM) can be compiled into various forms of tech pubs.



A Data Module Code (DMC) represents each DM, structured with levels of intelligence. The Standard Numbering System (SNS) in the beginning of the DMC is the hardware- or system-based product structure. In the figure below, the light grey X's are optional, for expansion purposes. NATO maintains the MI for those who register.



S1000D was designed for air, land, and sea vehicles, as well as support equipment. There are predefined SNS sets for these product/project types in the standard, and various others have been added as well. They are not mandatory, but they represent industry best practices. There are no SNS sets for the space industry, but S1000D could easily be adapted to space vehicles and facilities, too. See the potential example usage in the figure below. Note how commonality can be achieved across types of data sets.



SCORM (Sharable Content Object Reference Model)

SCORM began in 1997. It is a collection and harmonization of specifications and standards that defines the interrelationship of content objects, data models and protocols such that objects are sharable across systems that conform to the same model. This specification promotes reusability and interoperability of learning content across Learning Management Systems (LMSs). SCORM is compatible to work with S1000D in developing tech pubs for training. The International S1000D – SCORM Bridge Project Team defined requirements for a specification that integrates authoring environments for SCORM-based learning content with S1000D Common Source Databases (CSDBs) used for technical manuals.

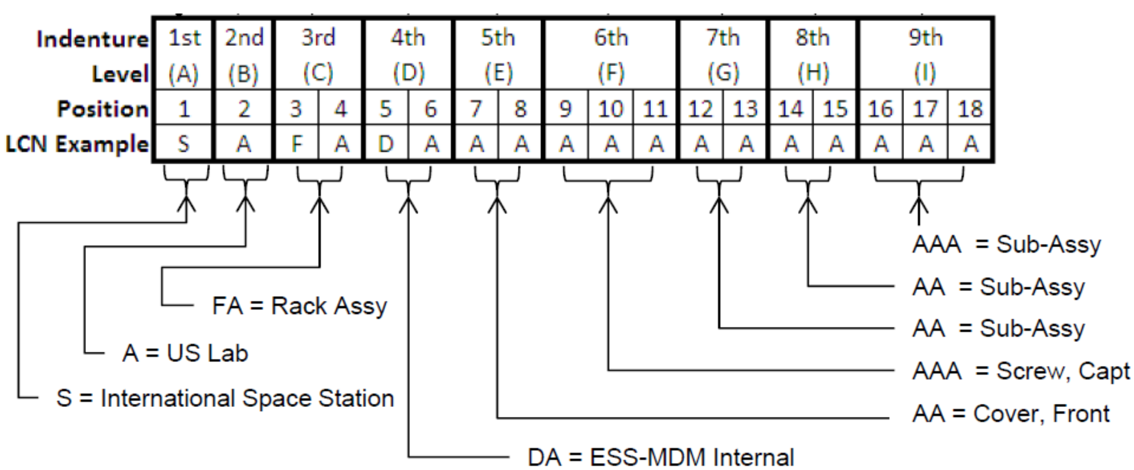
Logistic Support Analysis (LSA)

LSA is encompasses a key set of supportability tools which are typically initiated during design and development for purposes of supporting the O&S life cycle phase. The term "Logistics" has often been used by NASA only for functions like inventory management.

DoD uses the term more broadly, covering essentially all needs of O&S, but starting often during the design phase. Other industries have the same functions integrated into what they call systems engineering, product support, etc. DoD's recent change of terms from ILS to IPS helps describe the broader scope better.

The analyses performed with LSA methods need to be documented. DoD developed LSA standards in the 1980s to best organize LSA information and manage in a data system, MIL-STD-1388-1 and MIL-STD-1388-2. These have been since used by many global industry users. The most recent version of the LSA data standard was MIL-STD-1388-2B. It was cancelled in 1996 during DoD reforms, yet it is still used today by many in industry. Replacement standard MIL-PRF-49506 was developed by DoD, and the UK developed DEF STAN 00-60. The MIL standard was then replaced in 2007 by the industry standard GEIA-STD-0007. ASD developed S2000M, S3000L, and S4000M (now S4000P) to accommodate LSA needs, and the AIA joined them in developing these with the whole S-series suite of specifications (standards).

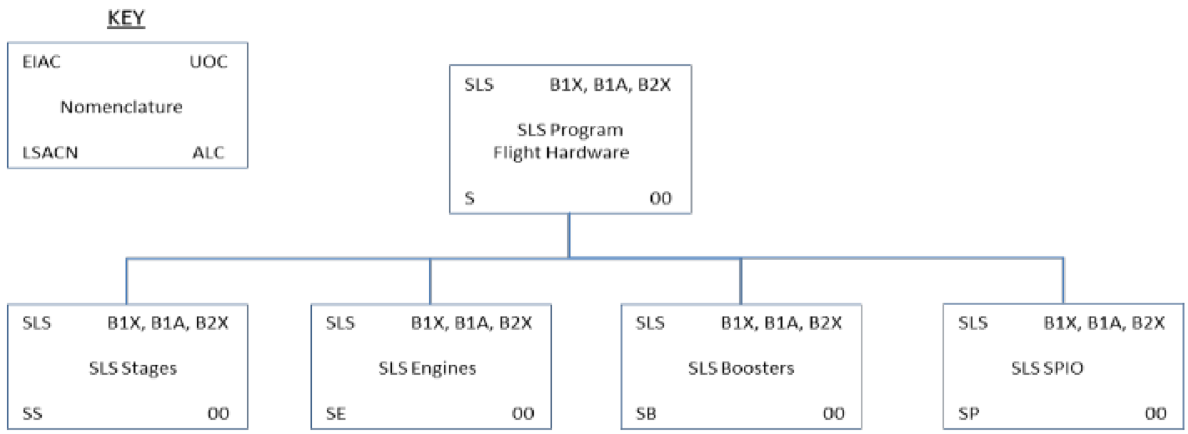
One of the key data elements in an LSA is the LSA Control Number (LCN). LCNs are key fields in LSAR databases which define a unique part application and have served to provide a visual indicator as the indenture level of a part. LCNs are limited to 18 characters. The figure below shows the ISS LCN structure.



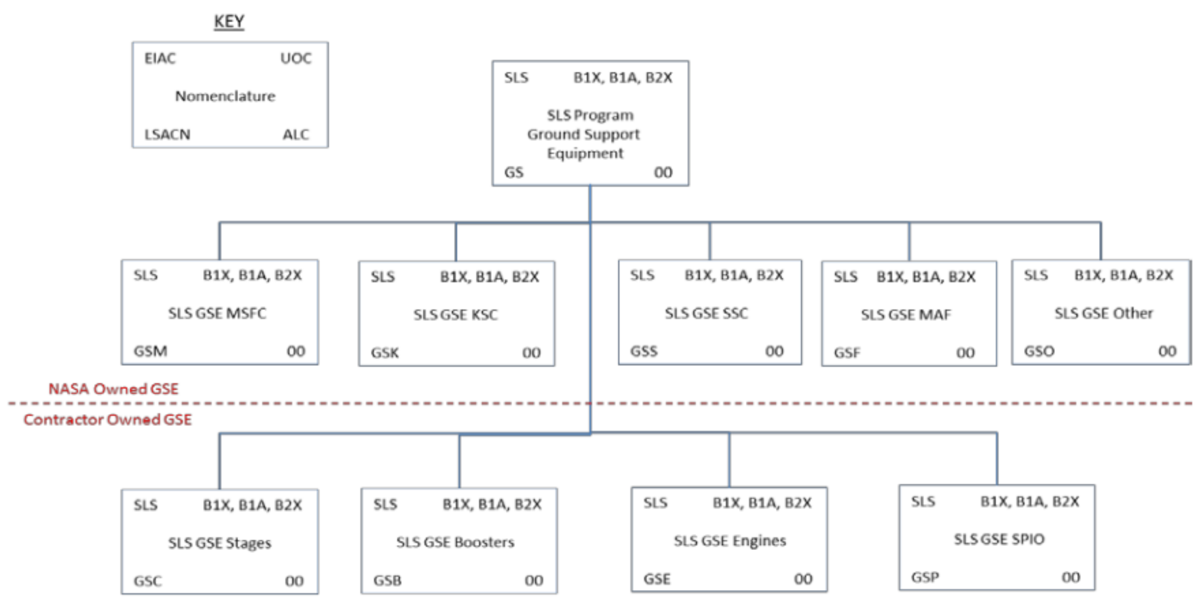
Alternate LCN Codes (ALC) are used to define variants of an LCN item.

NASA's Space Launch System (SLS) LCN structures are shown in the figures below.

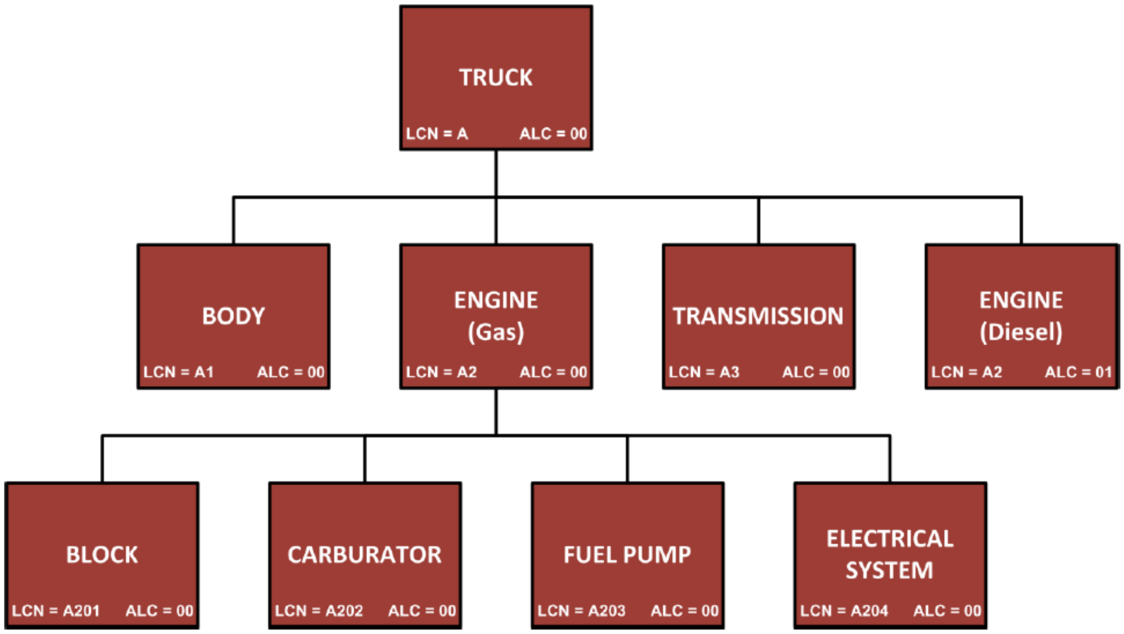
SLS Program Flight Hardware LSACN Structure



SLS Program Ground Support Equipment LSACN Structure



The **MIL-STD-1388-2B** standard requires defining each parent child relationship for each unique part application. In other words, despite the use of the same subassembly or NHA, each child must be linked to each new instance of the subassembly and unique LCNs must be assigned. Changes to one instance of the assembly require manual synchronization among all instances. An alternative data structure to the 1388-2B standard is a parent child table. This data structure requires indenturing a subassembly's components once and changes to the subassembly's BOM propagates through all part applications immediately. An example product breakdown structure using LCN's is shown below.

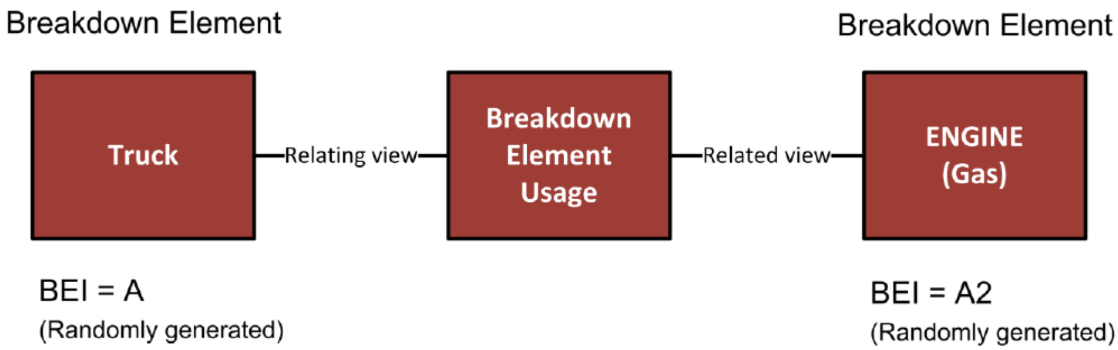


GEIA-STD-0007 standard is very similar to the MIL-STD-1388-2B. Like MIL-STD-1388-2B, it defines the data elements, structure, and business rules for logistics product data, but GEIA-STD-0007 does not prescribe how the data must be managed (e.g. relational tables). Instead, it specifies the requirements for the exchange/delivery of the data in an Extensible Markup Language (XML) format as prescribed by an XML Schema Definition (XSD). It requires defining each parent child relationship for each unique part application. Changes to one instance of the assembly require manual synchronization among all instances. An alternative data structure to the 1388-2B standard is a parent child table. This data structure requires indenturing a subassembly's components once and changes to the subassembly's BOM propagates through all part applications immediately. GEIA-STD-0007 established a common DoD baseline for Logistics Product Data (LPD), allowing DoD to progress towards an ISO 10303 solution.

In comparing older LSA standards with GEIA-STD-0007, see the table below.

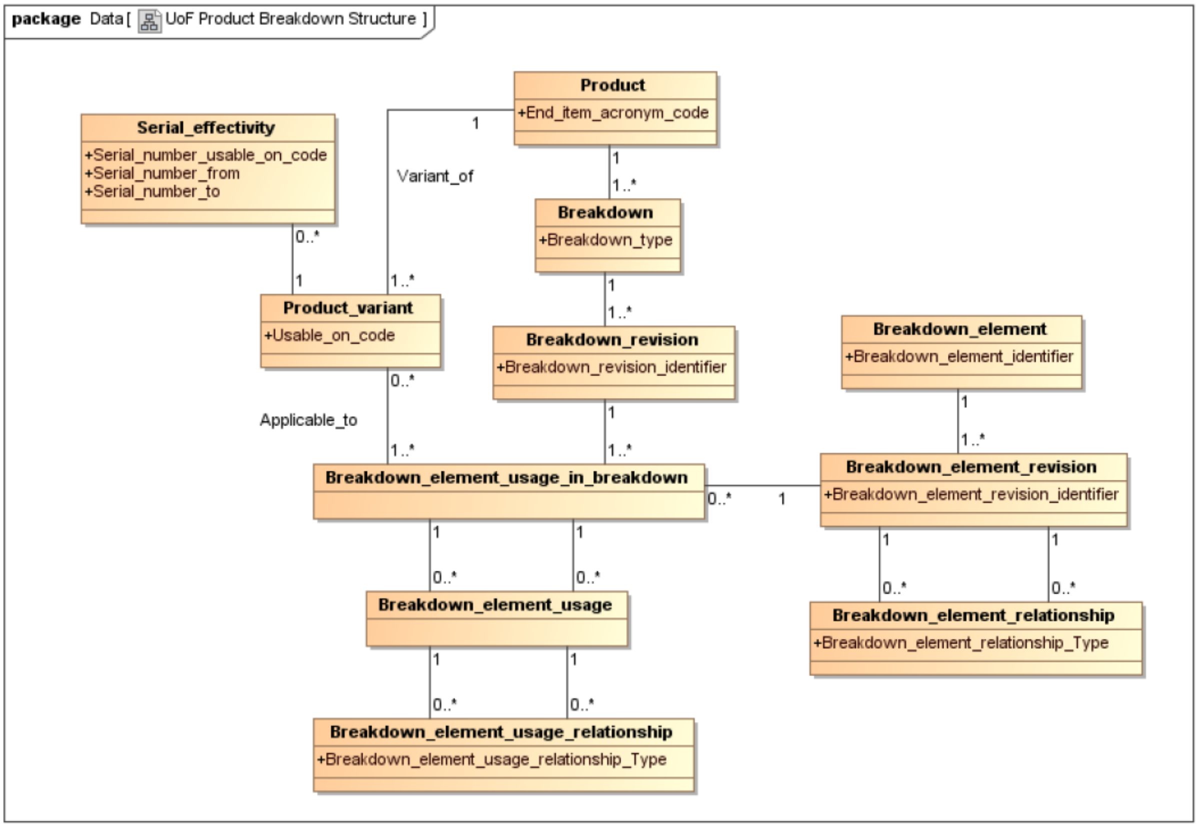
MIL-STD-1388-2B	**MIL-PRF-49506**	**GEIA-STD-0007**
518 Data Elements	159 Data Products	600 Data Elements
104 Relational Tables	No Relational Tables	110 Entities
9 Functional Areas	No Functional Areas	9 Functional Areas
48 Reports	8 Summaries	24 Reports
1 Master File (Full File) for Data Exchange	No Master File	1 Master File (XML Full File) for Data Exchange
1 Database Repository	User Defined Database Repository	User Defined Database Repository

GEIA-STD-0007 has been working toward data exchange compatibilities with ISO 10303 AP239 PLCS. The PLCS product breakdown structure is an equivalent approach to an LCN, but parallels usage in the design engineering and PDM domains. Each breakdown element contains a Breakdown Element Identifier (BEI). The figure below shows a PLCS approach compared to the LCN example used earlier.



In comparing to newer LSA standards, GEIA-STD-0007 can be structured as sets of Units of Functionality (UoF) that incorporate Unified Modeling Language (UML) diagrams for representing LPD business information requirements. This structure is similar to the approach used in the S-Series specifications (e.g. S2000M and S3000L standards). Each UoF, or functional area subset, contains a UML graphical representation along with set of associated definitions for each UML class.

The Product Breakdown Structure UoF describes the information necessary to define a product, its variants, its breakdown constituents, and associated revisions (design iterations). The business information requirements are represented graphically in the figure below using a UML Class Diagram.

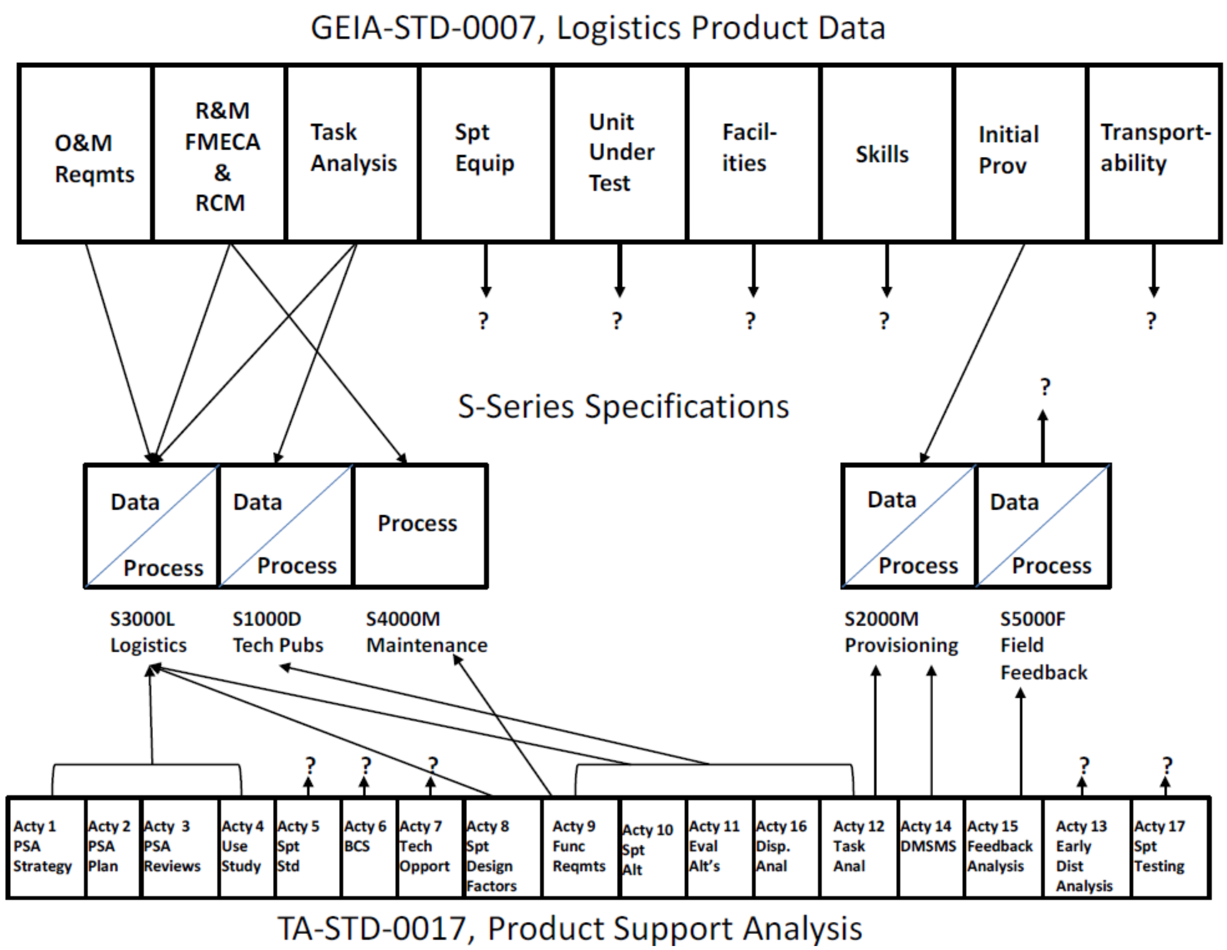


S3000L is a more generic standard than GEIA-STD-0007 and MIL-STD-1388-2B. It is closer in structure to the UK's standard, DEF STAN 00-60. It gives good overall LSA information, but does not provide full support for all identified candidate item analysis activities. The data model covers just the LSA data elements that will typically be exchanged between a contractor and his subcontractors, partners, and customers. The scope of the data model includes:

- Definition of LSA program and products to be supported.
- Support early phases of LSA selection of candidate item and analysis activities.
- Support LSA Failure Mode and Effect Analysis (FMEA), Special Events, and Damage Analysis.
- Document results from Maintenance and Operational Task Analysis (MTA/OTA).

It still requires defining each parent child relationship for each unique part application. Changes to one instance of the assembly require manual synchronization among all instances. An alternative data structure to the 1388-2B standard is a parent child table. This data structure requires indenturing a subassembly's components once and changes to the subassembly's BOM propagates through all part applications immediately.

The U.S. DoD's LOGSA white paper described a comparison between GEIA-STD-0007 Logistics Product Data (LPD) and the S-series Specifications, as of 2013. They also compared SAE's TA-STD-0017 Product Support Analysis (PSA), adopted for DoD use in 2013, which is relatable to MIL-STD-1388-1A and MIL-HDBK-502A. The figure below shows how they correlated the content in each standard.



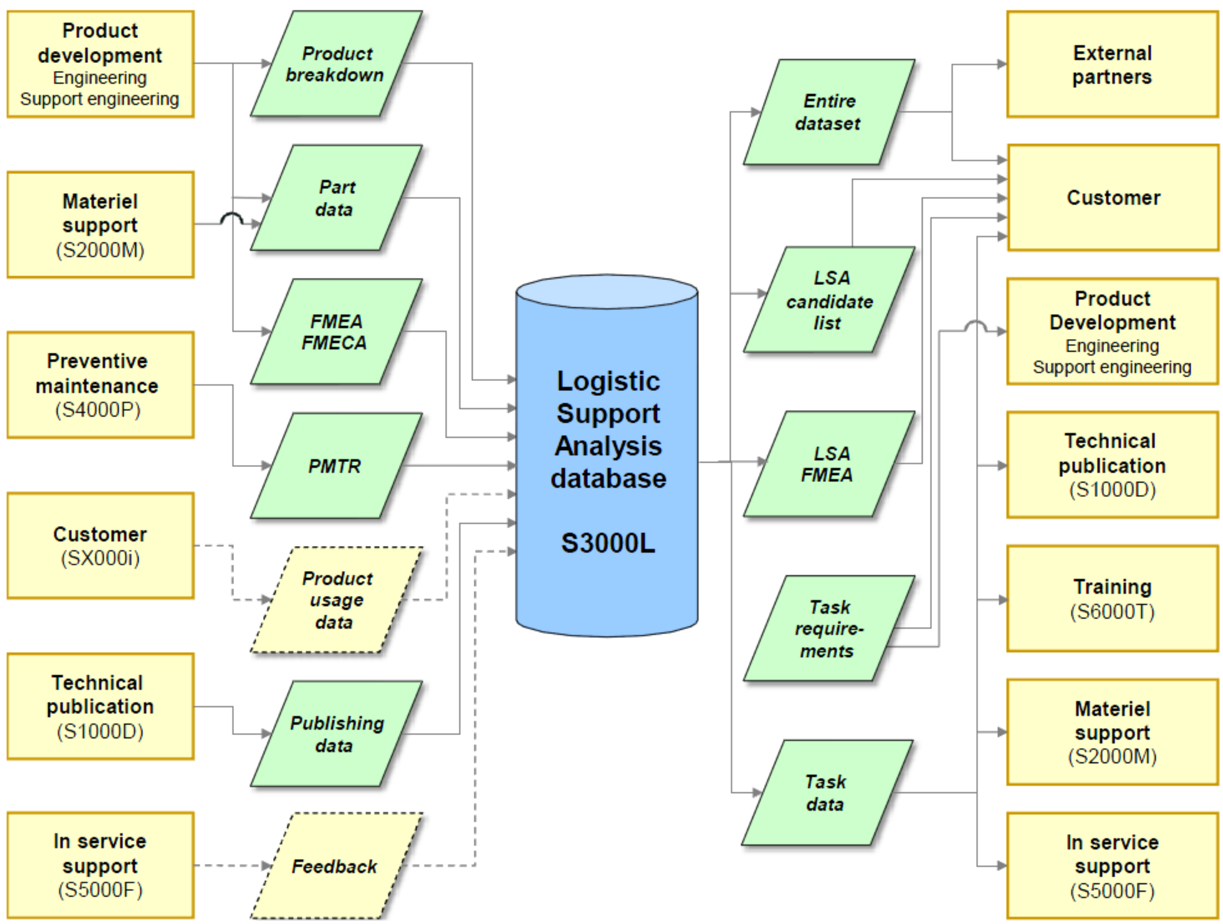
S3000L Issue 1.0 used ISO 10303-239 PLCS edition 1 as the method for data exchange. To support this, the S3000L team published two Data EXchange Specifications (DEXs) using OASIS DEXlib. The two DEXs were published in 2011 and included:

- **DEX1A&D** - Aerospace and defense business DEX for exchange of product breakdown for support
- **DEX3A&D** - Aerospace and defense business DEX for exchange of a task set.

Issue 1.1 just came out in July 2014. It is fully compatible with the new SX002D Common Data Model, which will form the core of the S-Series ILS specifications,

making them interoperable with each other. Thus, the new specification versions (such as the new S5000F, due out early 2015, or S2000M issue 6.0) will be able to exchange data with S3000L with no data conversion issues.

The exchange of data for S3000L issue 1.1 is defined using XML and XML schema, which will be published on the S3000L website. An overview of the types of data exchanges supported by S3000L XML schemas is summarized in the figure below.



The method of mapping the S3000L data model to the S3000L XML schemas is done in accordance with the XML Schema Authoring Rules defined by the DMEWG. An added feature for LSA data exchange is the option to only exchange updates to complete (baseline) data, and it can accommodate minor and major changes.

S3000L XML schemas will provide mappings to ISO 10303-239 PLCS edition 2 or OASIS PLCS PSM, in order to support continued use of the ISO PLCS standard. The rationale for introducing S3000L XML schemas as the basis for supporting S3000L data exchanges is to allow for organizations that do not have the required PLCS skills to still support the S3000L specified data exchanges.

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

STEP provides a comprehensive set of internationally-agreed integrated information models to address the problem of exchanging product information between dissimilar computer applications throughout the lifecycle of the product.

Deployment of the STEP standard enables companies to have a proven single definition for all the product-related information related to individual products throughout their lifecycle, independent of changes in process and information technology. The standard will enable suppliers to deliver and receive support information in a consistent form, irrespective of the source. Interoperability is facilitated by the adoption of common subsets of the standard, known as Application Protocols to support particular information flows.

In order to support specific business functions, STEP contains a number of subsets known as Application Protocols (APs), which constrain the standard to a particular business context. STEP also supports a wide range of IT services, ranging from simple file exchange through databases and language bindings to XML and schemas. STEP does not constrain the process modeling tools which can be used to express the context of the information exchanges. Of the few hundred STEP Aps, these are examples of those relevant to aerospace:

- AP203 for configuration controlled 3D data, including full PDM information and parametrics (a common 3D “STEP” file neutral format)
- AP209 for composite and metal structural analysis and related design
- AP210 for printed circuit assemblies
- AP212 for electrotechnical design and installation
- AP214 for core data for automotive mechanical design processes (another common 3D “STEP” file neutral format)
- AP219 for dimensional inspection
- AP224 for process planning
- AP232 for Technical Data Packages (TDP)
- AP233 for systems engineering data representation
- AP237 for computational fluid dynamics
- AP238 for NC machining
- **AP239 for Product Life Cycle Support (PLCS)**

Given MIL-STD-31000 lacks the depth and berth to address a Digital Product Definition Package, guidance comes from the ISO 10303 STEP standards. The scope of STEP offers a “cradle to grave” standard that is a modularized architecture consisting of several Application Protocols (APs), each defining data from a specific business viewpoint of the integrated STEP information model. This is intended to provide software developers the flexibility of claiming conformance to specific domains of STEP. Two of the first APs developed were AP 203 – Configuration Controlled 3D Design and AP 214 – Core Data for Automotive Mechanical Design Processes. They served as improvements over IGES in the area of 3D mechanical design. These protocols are being merged into one AP called AP 242 – Managed Model Based 3D Engineering, just released in 2014. Tangentially related to the work mentioned above, AP242 is being harmonized with AP239 edition 2 and other standards and this harmonization process could impact the AP239 edition 3 specification.

ISO 10303-239 Product Life Cycle Support (PLCS) was first published in 2005 and allows STEP to accommodate the product support and configuration management domains. A key component of PLCS is the Activity Model defined in the IDEF0 modeling language, a language used to illustrate decisions, actions, and activities from a functional perspective. The Activity Model specifies the activities and the information flows between activities that the AP supports through data exchange.

ISO 10303-239 Product Life Cycle Support (PLCS) was first published in 2005 and allows STEP to accommodate the product support and configuration management domains. The “PDM_Schema” created in 1999 as part of AP214 is what was brought forward to become ISO 10303-239 DEX1. A key component of PLCS is the Activity Model defined in the IDEF0 modeling language, a language used to illustrate decisions, actions, and activities from a functional perspective. The Activity Model specifies the activities and the information flows between activities that the AP supports through data exchange.

The PLCS Activity Model provides the foundation for the PLCS information model. The information model defines the entities and structures, or application modules, defined within the scope of the AP. It is represented in a language called EXPRESS and serves as the master PLCS schema. EXPRESS is a formal information requirements specification language (ISO 10303-11) used to specify the requirements of the various ISO 10303 application protocols. The EXPRESS language focuses on the definition of entities, which represent objects of interest. The definition of an entity is in terms of its properties which are characterized by specification of a domain and the constraints on that domain. See a simplified subset of the PLCS EXPRESS schema to the right.

```
ENTITY Product
SUPERTYPE OF (ONEOF (
    Breakdown_element,
    Document,
    Part));
  id : STRING;
  name : STRING;
  description : OPTIONAL STRING;
END_ENTITY;

ENTITY Breakdown_element
SUPERTYPE OF (ONEOF (
    Functional_element,
    Physical_element,
    System_element,
    Zone_element))
  SUBTYPE OF (Product);
END_ENTITY;

ENTITY Document
  SUBTYPE OF (Product);
END_ENTITY;

ENTITY Part
  SUBTYPE OF (Product);
END_ENTITY;
```

The EXPRESS example contains an entity called Product with the subtypes Breakdown_element, Document, and Part. The Product entity also contains the id, name, and description attributes which are inherited by its subtypes. The Breakdown_element entity has the subtypes Functional_element, Physical_element, System_element, and Zone_element. The PLCS EXPRESS information model contains over 150 modules, 500 entities, and 1200 attributes and enables the functionality described in the figure below.

For data exchange, PLCS utilizes two primary file transfer options defined by STEP:

- **ISO 10303-21 (Part 21)** - ASCII exchange file format
- **ISO 10303-28 (Part 28)** - XML exchange file format

The Part 21 data files are validated with the EXPRESS schema and the Part 28 files are validated with an XSD derived from the EXPRESS schema. Both schemas contain the same basic content and are composed of generic entities such as Product, Breakdown, Part, Task, and Organization for example. Because the information model defined by PLCS is generic in nature to support the entire life cycle of a product, it has a scope that is wider than most applications, business processes, or data exchange needs. Therefore, the concept of Data Exchange Specifications (DEXs) was created for narrowing the scope of PLCS.

In most circumstances, it would be impractical for organizations to contract for the entire range of data specified in ISO 10303-239 PLCS. A DEX identifies a subset of the overall PLCS information model and allows organizations to acquire PLCS compliant data adapted to their unique business processes and activities. A DEX contains a schema, derived from the overall PLCS schema, containing only those PLCS entities required to support a specific business need. To aid organizations in DEX development and to promote the uptake of PLCS, the OASIS PLCS Technical Committee (TC) created an open source development environment called DEXlib. The TC also developed a set of templates, or predefined business objects, that specify collections of ISO 10303-239 entities required to exchange a specific concept. Though these templates were created to assist in the DEX development, they are often viewed as complex by those not involved in their initial development. Nonetheless, DEXs can be developed using alternative methods to OASIS sponsored templates. PLCS DEXs are simply specifications on how to exchange information requirements in a manner compliant with ISO 10303-239. The figure below illustrates the relationship between the major PLCS components and STEP.

The OASIS PLCS TC more recently created a second edition of DEXlib, called PLCSlib, focused on the development of Systems Modeling Language (SysML) based DEXs. The committee has derived a SysML Platform Specific Model (PSM) from the ISO 10303-239 EXPRESS information model. An XML Schema was then derived from the SysML PSM to allow for XML implementations.

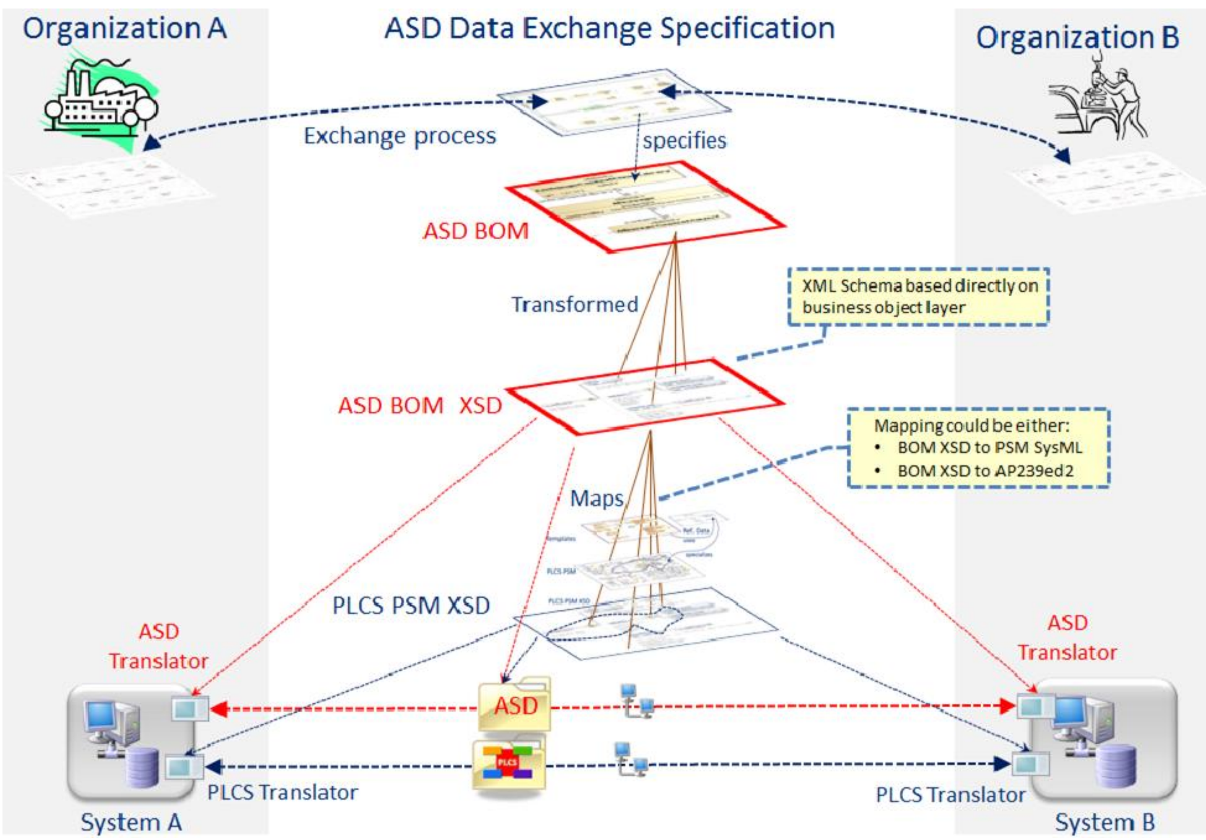
The OASIS PSM appears to deviate from the ISO 10303-239 EXPRESS information model in several areas to improve the efficiency of the information model, thereby improving the efficiency of the end product (i.e. exchange file). However, these changes also appear to result in a split from the core STEP architecture resulting in a file structure that is not compliant with current STEP implementation methods.

DEXlib versus PLCSlib

DEXlib (DEX edition 1) is based on the ISO 10303-239 Edition 1 schema while PLCSlib (DEX edition 2) is derived from ISO 10303-239 Edition 2 schema (does not directly support the schema of ISO 10303-239 Edition 2). There is no direct compatibility between DEXlib and PLCSlib so DEXs developed using DEXlib must undergo extensive re-work to be migrated to PLCSlib. Since TDI project proposal, industry and government entities have taken positions on PLCS and its different DEXs. All are waiting for how 10303-239 edition 3 will resolve the differences.

S-series ILS Specifications Schema and PLCS

In awaiting ISO AP239 PLCS edition 3 and its associated data exchange development environment, all future S-series ILS specifications will follow the same XML schema approach as described in S3000L. The figure below illustrates how S-series ILS specification XML schemas are viewed with respect to ISO 10303-239 PLCS and OASIS PLCS PSM.



The S-series ILS specifications XML schemas are targeted to support data exchange at the Business Object Model (BOM) layer. However, each XML schema will also include the mapping details required for an unambiguous mapping of each element and attribute to PLCS in order to enable PLCS-based data exchanges and/or PLCS-based data consolidation.

LOGSA Schema and PLCS

In a 2013 LOGSA white paper on PLCS and LPD, they describe an alternative to AP239 DEXs similar to the ILS Spec Council's schema for the S-series. Rather than developing a DEX composed of OASIS templates, this approach primarily consists of a direct mapping from the GEIA-STD-0007 source elements to ISO 10303-239 target entities and attributes. This approach reflects a precise mapping and removes the potential for ambiguity among data exchange partners. The DEX mapping can be documented in HTML and included as an appendix to a future revision of GEIA-STD-0007, therefore providing a medium for publication. While OASIS templates and development environments such as DEXlib and PLCSlib play a valuable role in formulating generic DEXs standardized and published at the OASIS level, they lack substantive value in the development and standardization of an LPD business DEX. In addition, there is no method for publishing business DEXs in OASIS.

CAD Data Exchanges

Many people think of STEP as merely a neutral CAD file conversion format which can be exchanged between different CAD vendors. As this report's section on the overall ISO 10303 STEP standard describes, STEP covers much more. That CAD conversion is covered by AP209 and AP214. Recently, AP242 was released, which combines the other two and updates these conversions. IGES and JT are other common neutral CAD exchange formats (not part of STEP), and there are some less common ones. These exchange tools are typical in vendor software and provide needed capabilities for programs using multiple CAD tools. However, the neutral conversions always have a risk of some loss of integrity. These risks have been accepted for years in industry. These must be considered again when performing CAD data exchanges using the TDI concept to pass data to entities outside of the design life cycle phase. PLCS is one method which may aid this exchange, whether from CAD to CAD environment or from CAD to non-design environment.

Due to the need to exchange CAD to CAD in many formats, and the issue of exchange integrity, NASA is currently drafting NASA-HDBK-0009, Engineering Model Maturity Levels (EMML): Model Definitions. This draft states that definition of model maturity is missing in both the models being shared and the Data Requirements Descriptions (DRDs) representing the contracted deliverable. EMML is intended to enhance the integrity and definition of the model itself with regard to digital integrity and definition.

Efforts to exchange CAD data to entities outside design have been attempted, but challenges have been discovered due to many variations in CAD model definition or product structure. Some proprietary vendor solutions have been developed for exchanges using certain scenarios or vendor tools. NASA's EMML handbook could aid this issue for programs who use it effectively for contracting.

On industry white paper described the production of Computer-Based Training (CBT) using S1000D and SCORM standards. They reused CATIA 3D models in S1000D data modules (DM). 3D models were reduced and converted to 3D XML. Next, scripts were developed to generate a mapping between the 3D XML from CATIA and the XML from the S1000D DM's. Mechanics working on an aircraft can now perform Computer-Based Training and Simulation Scenarios in a web-based system. Any changes to aircraft design are reflected in the CATIA models and those changes are mapped (via the 3D XML) to the S1000D based work instructions. This means that aircraft mechanics can now easily update their Training and Simulation environments with minimal effort.

Evaluation of industry standard data exchanges of CAD data directly with S1000D data is available, but appears to be not well developed yet. PTC described to the TDI team that they have a vendor solution based on about half proprietary and half industry standard methods. The recently-formed S1000D Model-Based Enterprise Task Team (MBETT) is currently gathering all known methods of getting CAD data into S1000D and evaluating best recommendations to update the S1000D standard for this.

LOng Term Archiving and Retrieval (LOTAR)

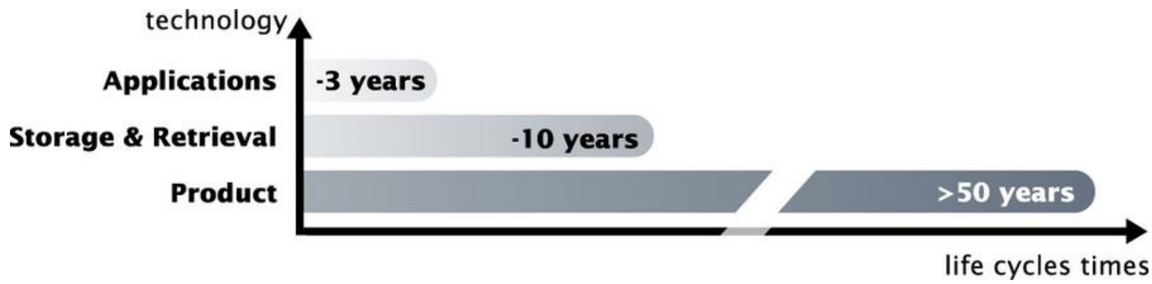
The LOTAR project is designed to provide a capability to store digital product information in a standard neutral form that can be read and reused throughout its lifecycle, independent of changes in the IT application environment originally used to create it. The multi-part standard covers both the information content and the processes required to ingest, store, administer, manage and access the information.

LOTAR brings together the work started under the AIA Manufacturing Maintenance and Repair Committee with similar work in ASD-Europe, under the auspices of the International Aerospace Quality Group (IAQG). Standards with identical technical content represented by LOTAR are:

- NAS9300 series standards in the US.
- EN9300 series standards in Europe.

The European and the American aerospace industry associations (ASD and AIA) selected EXPRESS as the open, maintained standard information language for the purpose of digital archiving. LOTAR allows the re-use of existing designs in both new products and updates to existing products and ensures successful retention of data for legal purposes.

The life cycle of applications and storage technologies hast to be considered by setting up a long term archiving and retrieval standard. Approximately every three years a change in the application technology and every ten years in the technology of storage and retrieval happen. In comparison with an archiving period of fifty up to one hundred years in the aerospace and defense industry the technology life cycle plays a major role.



H-4 Policies/Positions on TDI Standards

This section describes the various policies and positions of industry and government organizations, including NASA, in reference to the standards evaluated by the TDI project. General interoperability requirements are also referenced.

AIA's Engineering Data Interoperability Group (EDIG) recommended in a 2008 position paper and 2009/2013 guide that AIA Member companies and Suppliers transition to a Standards-based interoperability solution utilizing PLCS (ISO 10303-239) and its associated DEXs. NASA is an AIA member.

The ASD/AIA ILS Spec Council's DMEWG came out with a new direction in 2014 on a standard exchange mechanism between the S-Series specifications. In the DMEWG Charter, the ILS Spec Council had directed the use of ISO 10303-239 PLCS, but had not specified which edition to use nor the Data EXchange (DEX) method to be used. After PLCS DEX changes, they decided to put in place a new DEX development capability, and it is believed that this will be harmonized with a future Edition 3 of the ISO 10303-239 PLCS data model environments. Their decision included reviews of similar evaluations and conclusions of the PLCS AP239 differences by the following various standards communities:

- **SAE Life Cycle Logistics Supportability (LCLS) Committee**, who manages GEIA-STD-0007
- Europe's **ASD Strategic Standardization Group (SSG)**
- **Airbus Group Standards Steering Committee (SSC)**
- **The OASIS PLCS TC** also presented their evaluations at meetings with the DMEWG, but the DMEWG still chose to depart from PLCSlib.

In 2014, the ASD/AIA ILS Spec Council's new short term direction is to implement S-Series specifications data exchange using a "bespoke" (i.e. "custom") XML schema approach with a direct mapping to ISO PLCS edition 2. As a long term objective, they support development of ISO PLCS edition 3 and support the eventual re-integrating of the S-Series specification data exchange with an anticipated ISO PLCS edition 3.

Various NASA policies have begun to touch on TDI and related standards in the last 5-10 years.

NPR 7120.10 "Technical Standards for NASA Programs and Projects" (rev. 2012): NASA is required to use industry standards where no comparable NASA standard exists.

NPR 7120.9 "Product Data & Life-Cycle Mgt (PDLM) for Flight Programs & Projects" (rev. 2011): Requirements promote interoperability for PDLM goals.

NASA-HDBK-0009, "Engineering Model Maturity Level (EMML): Model Definitions", (draft in work): Presents practices and procedures to define a consistent approach for exchanging critical program and digital project data (3D models and simulations), inclusive of maturity and states, across multiple NASA centers and domains.

NASA-HDBK-0008, NASA Product Data and Life-Cycle Management (PDLM) Handbook; Applicable & Ref Documents:

- **ISO 10303-239** Product Life Cycle Support (PLCS)
- **ISO 10303-203 & -214** (3D CAD neutral STEP exchange files)
- 6.5.1 Exchanging and Distributing 3D Models: The most important requirement relating to the documentation and archiving of engineering data is that all relevant information be stored in a format that can be read irrespective of a specific IT infrastructure and after a long period of time; in the aerospace industry, for example, the **Long Term Archiving and Retrieval (LOTAR)** activity that addresses archiving of data for long life-cycle programs.

NPD 7500.1, Program and Project Logistics Policy; Applicable & Ref Documents:

- **GEIA-STD-0007**, Logistics Product Data
- **ASD S3000L**, Int'l Procedure Specification for Logistic Support Analysis
- GEIA-STD-927, Common Data Schema for Complex Systems
    - Uses **ISO 10303-239 PLCS** as one of the integration models.
- Designing and Assessing Supportability in Department of Defense (DoD) Weapon Systems: A Guide to Increased Reliability and Reduced Logistics Footprint, (2003)
    - Superseded by Defense Acquisition Guide, & Product Support Manager Guidebook, 2011.
    - Product Support Manager Guidebook refers to **S1000D** for IETMs.

GSDO-PLN-1024, GSDO Integrated Logistics Support Plan; Applicable & Ref Documents:

- **GEIA-STD-0007**, Logistics Product Data
- **ASD S3000L**, Int'l Procedure Specification for Logistic Support Analysis

CEV-T-011, “Project Orion, Integrated Logistics Support Plan”; Applicable & Ref Documents:

- NPD 7500.1A, Program and Project Logistics Policy
- Designing and Assessing Supportability in Department of Defense (DoD) Weapon Systems: A Guide to Increased Reliability and Reduced Logistics Footprint, (2003)
- 3.1 TECHNICAL DOCUMENTATION/INTERACTIVE ELECTRONIC TECHNICAL MANUALS & 3.2 LOGISTICS SUPPORT ANALYSIS TOOLS AND DATABASES: “To ensure commonality, Orion Integrated Logistics and all subcontractors will use …applications compatible with **EAGLE**”

In 2004, the **U.S. Navy** issued policy on the procurement and delivery of digital product and technical data. The policy requires product data, engineering design and manufacturing data (CAD/CAM/CAE), 3-D vector data, and product model data be delivered in accordance with International Organization for Standardization (ISO) 10303, Standard for the Exchange of Product Model Data (STEP). The Under Secretary of Defense for Acquisition, Technology, and Acquisition (USD (AT&L)) highlighted this policy in 2005 and requested the Army and Air Force to implement a similar approach that adopts ISO 10303 to enhance interoperability between Services, depots and contractors. As a result, the Air Force issued Air Force Instruction (AFI) 63-101, Acquisition and Sustainment Life Cycle Management in 2009, which requires Program Managers to use STEP Application Protocol (AP) 239 for acquiring engineering data on acquisition programs

ISO 10303 AP239 PLCS was ratified as a **NATO standard** in February 2008 under Standardization Agreement (STANAG) 4661, which states that member nations agree to apply AP239 for product data management in cooperative NATO acquisition programs. NATO Guidance on Life Cycle Costing (ALCCP-1) recommends use of PLCS for data collection.

Although the **U.S. Army** does not have an official policy on STEP implementation, it does require the use of interoperability standards for data exchange. In addition, AR 700-127, Integrated Product Support (IPS) requires the use of SAE GEIA-STD-0007, Logistics Product Data as the contractual method for acquiring and documenting data logistics product data resulting from the product support analysis process. GEIA-STD-0007 was developed as an intermediate strategy for codifying a logistics product data exchange mechanism for DoD and industry partners.

The U.S. Army Logistics Support Activity (LOGSA) has been involved with various working groups and boards for the Aerospace and Defence Industries Association of Europe (ASD) S-series specifications, PDES Inc., the Organization for the Advancement of Structured Information Standards (OASIS), and SAE International standards. After conducting an analysis, LOGSA determined that the functional areas and data elements contained in SAE GEIA-STD-0007 clearly fell within the scope of ISO 10303-239 PLCS. The functional areas of the standard were used as building blocks for creating a logistics product data DEX that could be tailored to organizational needs. The preliminary DEXs were completed using the OASIS DEXlib methodology which utilizes templates based on ISO 10303-239 Ed. 2. However, during this time, another OASIS DEX development methodology emerged called PLCSlib. This methodology was a labeled as a replacement for DEXlib but it was not based on ISO 10303-239 Ed 2, but a new schema called the OASIS Platform Specific Model (PSM) that deviated from the formal ISO 10303-239 Ed 2 schema. This work became an OASIS committee specification called Product Life Cycle Support Version 1.0. Despite the PLCS name, it still remains an OASIS committee specification and has yet to be introduced as a basis for developing an ISO 10303-239. Ed 3.

As a result of the instability and lack of direction within OASIS, LOGSA developed a new independent alternative for creating an ISO 10303-239 PLCS based DEX. Rather than developing a DEX composed of OASIS templates, the LOGSA approach removes the abstraction and primarily consists of a direct mapping from the SAE GEIA-STD-0007 source elements to ISO 10303-239 target entities and attributes. This approach reflects a simple and precise mapping and removes the potential for ambiguity among data exchange partners. The mapping can be documented in HTML and included as an appendix to a future revision of SAE GEIA-STD-0007, therefore providing a medium for publication. This method eliminates the risk posed by the changing DEX development methodologies within OASIS. The method is also ISO 10303-239 Ed. 2 based, not OASIS committee specification based.

However, due to the many challenges and uncertainties surrounding OASIS and ISO 10303-239 in the near term, LOGSA recommended to the SAE International Life Cycle Logistics Supportability (LCLS) technical committee (the committee that governs SAE GEIA-STD-0007) that short term efforts should be focused on enhancing SAE GEIA-STD-0007 as an intermediate step in migrating to an ISO 10303-239 solution (presumed to be ISO 10303-239 PLCS Ed. 3) in the future. In 2013, the SAE LCLS committee agreed with LOGSA's recommendations to shelve ISO 10303-239 PLCS efforts for the short term and focus on improving the existing SAE GEIA-STD-0007 data exchange structure by making it more compatible with ISO 10303-239 PLCS.

According to LOGSA, as currently written, each S-Series specification will require an additional DoD standard (and possibly multiple standards to support each of the different services) to appropriately contract in accordance with DoD guidance and regulations. They cite the example of the required MIL-STD-3031 and MIL-STD-3048 in order to implement for S1000D. This similar pattern would have to be followed in order to contract for any of the S-Series specifications. They also note that S1000D is widely used by industry and has a well-organized support structure. The U.S. Army/Marine Corps and Air Force have developed implementation standards that adapt S1000D to their requirements. In LOGSA's April 2014 white paper, they recommend that the DoD continue to use the SAE and U.S. DoD standards and handbooks for product support analysis and LPD, and that DoD implementation of S-series specifications should be based on policy and guidance of each DoD service. Future development of the S-series may influence future DoD usage.

The requirement for long-term retention of data varies by industry. The U.S. Federal Aviation Administration (FAA) for the commercial aviation industry has a regulatory requirement to retain the original design data for 50 years or more. This requirement can be found in Order 8110.4, which is available at www.faa.gov. The defense industry has an incentive to retain data for the life of a deployed weapon system. In other industries, the requirements for product liability require the retention of data for the life of the product plus 7 to 10 years depending on industry.

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