SIEMENS

Ingenuity for life

Realizing a Digital Enterprise driven by standards

This document refers to the Digital Enterprise as a business that not only creates and uses digital representations of the products and environment in which it operates; but aspires to trace an entire digital thread of its products as digital twins through their product lifecycle.

Standards are an axiom for common enterprise understanding and the longevity of the digital thread used in Siemens product lifecycle management (PLM) solutions. These standards-driven solutions cover a breadth of industries, including discrete manufacturing, construction, marine and energy.

This document addresses standards used in Siemens products that are principally aimed at discrete manufacturing across a wide range of domains, including automotive, aerospace and consumer products.

A white paper issued by: Siemens PLM Software

www.siemens.com/plm

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Executive summary

As our customers join us on the frontier of a Digital Enterprise business transformation, the question arises, "How can open standards, industry standardization and best practices support my digitalized business model?"

A fully digitalized business model is accomplished by connecting or integrating all phases of the product lifecycle with a digital thread whereby traditional paper-based business processes are transformed and optimized to take advantage of a digital twin. This transformation has an impact across many operations, such as sales, information technology (IT), marketing and engineering. To support this transition, global and industry standards play a key role in merging the virtual world with real production. With standards describing key interfaces and communication protocols, Siemens PLM Software strongly believes that our openness is one of the major drivers behind the successful adoption of our products as the foundation of the Digital Enterprise.

In this paper Siemens PLM Software presents our vision and strategy for the use of standards across the Digital Enterprise. It is worth noting that the Digital Enterprise is not comprised of just PLM, but rather encompasses PLM, manufacturing operations management (MOM) and factory automation. Although some software providers focus on only engineering and design, Siemens PLM Software looks at the use of standards in a holistic fashion across the entire value chain.

With Siemens' experience both as an original equipment manufacturer (OEM) and as a global powerhouse for product lifecycle management and manufacturing operations management software, we are uniquely able to equip your organization with an integrated toolchain for PLM, MOM and factory automation. Our offering makes use of open standards, industry standards and best practices to establish portfolio integration as well as enabling collaboration with your supply chain, development partners and customers.

Siemens implements standards by working closely with customers to understand their specific requirements. In addition, we are guided by the acceptance of standards in the community, the implementation of standards by other vendors, and the viability of standards in supporting workflows across the value chain. In addition to developing direct support for key standards, Siemens has opened up its technology to an extensive partner network to efficiently expand the standards that it supports.

Figure 1.1: Expanding scope for global standards and industry standardization.

Facing critical challenges

Background

As we look into the details of what it means to operate as a Digital Enterprise, one notices that challenges around process, data and tool integration begin to surface. Instead of integrating a business through a hybrid of connected IT and manual operations or paper-based processes, the Digital Enterprise is characterized by the integration of business processes through digital formats and protocols. As part of the required IT integration, it is worth calling out the demand for standard protocols given the desired integration between PLM, manufacturing execution systems (MES) and factory automation. Factory automation is driven by real-time systems integration, so taking a traditional view of enterprise transactional integration is not sufficient.

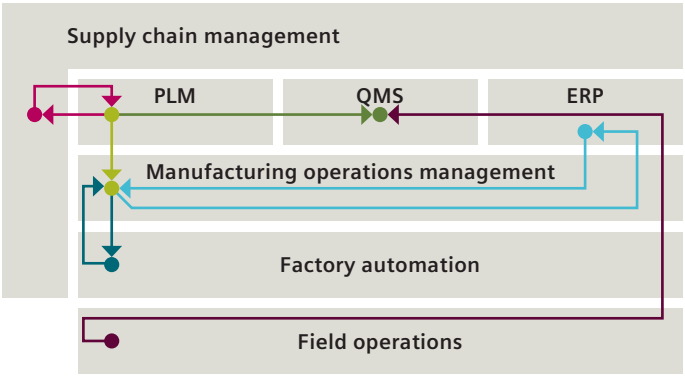


Figure 2.1: The integration challenge across PLM, MOM and factory automation.

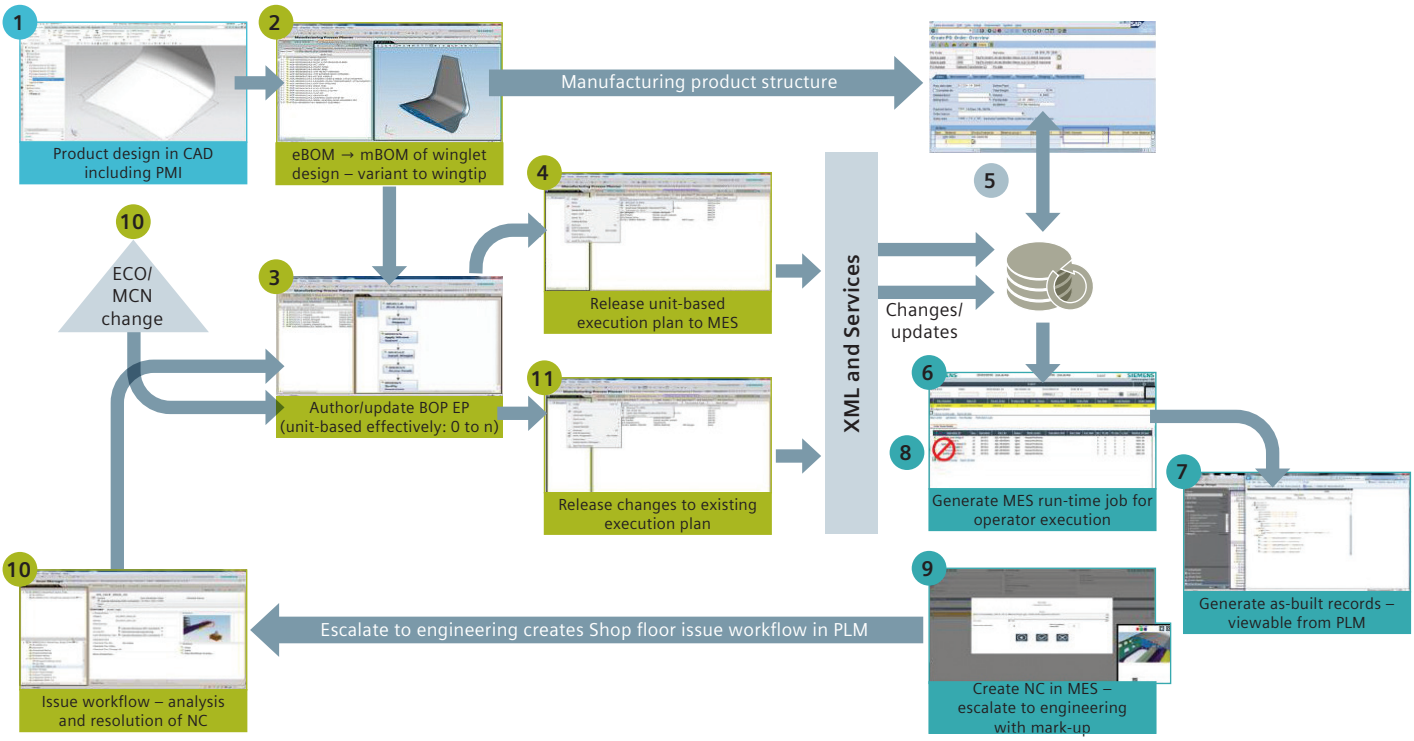


Figure 2.2: Closed-loop integration of PLM with MOM.

As illustrated in Figure 2.1, the profile of a Digital Enterprise includes a few important concepts that ought to be considered in terms of the integration across enterprise systems, factory automation and field operations.

- The foundation of the Digital Enterprise for engineering, manufacturing and operations management starts for many OEMs with PLM, MOM and enterprise resource planning (ERP). Because ERP is typically the master for business domains like procurement and order management, it is important for any customer starting the Digital Enterprise journey to plan out the proposed interoperability between PLM, MOM and ERP

  This is why, for example, the Teamcenter® software Gateway for Enterprise Applications is an integral element of Siemens' Active Integration product suite, and is a powerful solution for the seamless integration of almost any enterprise application with Teamcenter PLM software. Teamcenter Gateway for Enterprise Applications helps you coordinate your product development processes using data from a variety of systems, including ERP, MES and customer relationship management (CRM), to make sure the right data is available at the right time wherever it is needed across your information technology landscape

- Many data exchange and enterprise integrations involve feedback loops among these systems. A good example is the ability to record nonconformity in MES and use this to track engineering issues in PLM (as illustrated in step 9, Figure 2.2). Accordingly, when starting your Digital Enterprise journey we recommend planning for these feedback loops since they enable you to provide products with superior quality and operational performance

- Many organizations recognize that an integration between PLM, MOM and ERP forms a foundation for the Digital Enterprise. However the Digital Enterprise goes beyond these systems. The Digital Enterprise includes, for example, connecting MOM with factory automation, and PLM with field operations. It is important to plan for how the operations of your plant and the use of the final product by the customer will be integrated into the Digital Enterprise. A good example is the ability to provide predictive maintenance on assets in the field and pursue corrective maintenance where needed. This obviously requires integrating service lifecycle management with the Internet of Things (IoT) and operational data analytics

- As manufacturing OEMs have adopted a partner and supply chain that is now truly global, it is important to consider how to include suppliers and partners in the Digital Enterprise. One piece of the solution may be an integrated data ecosystem that allows open collaboration with third parties. Standards typically form a good foundation for these collaborative ecosystems. For example, a major automotive OEM demonstrated that using the International Organization for Standardization (ISO) standard, the JT™ data format for supply chain collaboration, improved their business efficiency; building on their success, collaboration based on JT among suppliers and OEMs is becoming a standard practice across the automotive industry

A final point worth making is that any Digital Enterprise has to deal with heterogeneous IT systems and data sources. As you prepare for a Digital Enterprise transformation, it is important to strategically plan for loose couplings wherever possible, to reduce the cost of integrating heterogeneous systems. A good example is the integration of PLM with MOM, given that PLM and MOM are typically not provided by the same software vendor. Standards like International Society of Automation (ISA) ISA95 provide a reference model for how to create common semantics between PLM and MOM that can be used to create a loosely coupled integration, avoiding major modifications to either system.

Business opportunities

Siemens recognizes that using standards across your enterprise comes with business benefits at multiple levels. Siemens takes a holistic view of standards and looks at the potential use of standards beyond enterprise integration; including using standards to capture, communicate and verify the quality of data in many different systems, and ultimately verify how your customers use your product.

Specifically, Siemens recommends the use of industry standards to support:

- Improved communication and collaboration
- Practical application of expert knowledge
- Knowledge capture that represents years of experience
- The advancement of new technology/architectures while preserving existing service level agreements (SLAs)

Additionally, it is important to look at how standards help realize a direct return-on-investment (ROI) for the products you engineer and sell. Siemens recognizes that the use of standards helps:

- Lower installation and startup costs
- Reduce the need to maintain large inventories
- Enable interchangeability of components, improving design with less custom effort
- Increase safety through the use of relevant standards like ISO 26262

In general, standards should help you achieve operational excellence by:

- Improving the performance of your operations
- Lowering maintenance costs of your products
- Reducing downtime and enhancing operability of your products

Siemens is strongly focused on enabling and supporting operational excellence for our customers, and accordingly, typically seeks to engage with customers at various levels and across many domains relative to the practical use of standards. A good example of this is our continued engagement with an automotive OEM customer on supply chain collaboration based on JT. Not only did we work to enhance their internal engineering processes based on JT, but we also used the JT ISO standard as a means to efficiently integrate their supply chain. Practical use of standards requires strategic business alliances to be successful!

Key considerations

Siemens recognizes the journey to realizing a robust Digital Enterprise is not an experience to be taken lightly. Accordingly, as you plan for an adoption approach that fits your organizational needs and constraints, Siemens recommends the following best practices:

- Establish a Digital Enterprise office responsible for the governance of tool chain integration, semantics and best practices
- Focus on digital threads with high ROI for your business, such as model-based engineering and electronic work instructions. Building on success is key
- Use industry state-of-the-art technology and data formats for critical and value-add business processes. Siemens clearly understands the value of standards, but also recognizes that the business demands best-in-class solutions. Hence a balanced approach is needed in a strategic partnership
- Leverage industry-driven standards via consortia. Standards driven by an industry are simply more focused than most open standards, and facilitate solutions to problems in a specific domain
- Use open standards when semantics are comprehensive, mature and broadly supported, and hence, the least common denominator is not a problem; for example, product and manufacturing information (PMI), geometric dimensioning and tolerancing (GD&T) and model-based definition (MBD)
- Make sure to define a subset of common semantics between the virtual and physical world to accelerate your IoT adoption

In general it is worth noting that strategic alliances for standardization offer the best rate of success. Alliances enable the evolution of open and industrial standards adherence that may be mutually monitored in the context of ever evolving strategic business objectives. Siemens places openness at the core of our corporate culture, and this places Siemens in a favorable position to form standardization alliances.

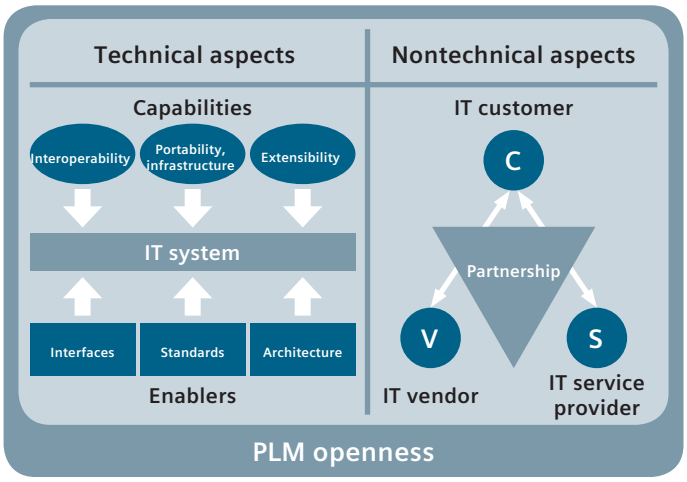
Strategic standards for the Digital Enterprise

PLM

As one of the key pillars of the Digital Enterprise, our PLM products support the entire digital product lifecycle, from requirements management all the way to service lifecycle management. As part of this process many aspects of collaboration and exchange are required; not only to efficiently execute internal business processes, but more importantly, to facilitate collaboration with partners and the supply chain. As a result, Siemens PLM Software has for many years ingrained openness in our company's culture. This is the driving force behind our accessible and engaging business model, effective participation in steering groups and the delivery of open software technologies. For example, our policy of licensing PLM components to other software vendors on a level playing field has nurtured interoperability with third-party PLM solutions.

Code of PLM Openness

To start the conversation about the relevance of open standards in PLM software, it is worth highlighting the Code of PLM Openness (CPO) initiative driven by the ProSTEP iViP association.



CPO was initiated by ProSTEP iViP in 2011 together with BMW, Daimler, Volkswagen and others. The aim was to establish a common understanding on the importance of openness for IT systems being used in product development, and define measurable criteria for openness to assess their fulfillment.

The following major areas of openness are addressed: interoperability, infrastructure, extensibility, standards, architecture and partnerships. By signing the CPO statement, IT vendors evaluate their products against the CPO criteria. With its signature, Siemens PLM Software emphasizes its obligation to develop interoperable systems and fair business models.

Model-based definition

One of the fundamental pillars of the Digital Enterprise is the ability to leverage model-based definition (MBD) practices. Historically, government and industry used drawings to communicate requirements for manufacturing components and systems. Meanwhile, many in industry have moved away from a reliance on drawings to using 3D computer-aided design (CAD), including GD&T, to design, price and manufacture items. This evolution has also allowed the design to be modeled in 3D CAD and for those design models to be annotated to replace a traditional drawing. Using these 3D annotated models as part of a technical data package (TDP) enables the design engineer to formalize the design intent using geometry, as well as annotations regarding specs, dimensions, tolerances and materials.

3D design and PMI based on ASME Y14.41 and ISO 16792

The American Society of Mechanical Engineers (ASME) publishes a standard (ASME Y14.41) to establish requirements for model-based definitions in CAD software and among those who use CAD software to create product definitions within 3D models. ASME issued the first version of this industrial standard on August 15, 2003 as ASME Y14.41-2003. It was immediately adopted by several industrial organizations, as well as the United States Department of Defense (DOD). ASME Y14.41 was revised and republished in May, 2012 as ASME Y14.41-2012.

Subsequently, ASME Y14.41 served as the basis for the standard ISO 16792:2006 Technical product documentation – digital product definition data practices. Both standards focus on the presentation of GD&T together with the geometry of the product.

Both ASME Y14.41 and ISO 16792 are good examples of when mature standards can truly provide business value. Hence, Siemens continues to use both standards at the foundation of our NX™ software PMI offering. PMI authored through NX complies with the standards for 3D part definition (ASME Y14.41, ISO 16792 and the Japan Electronics and Information

Technology Association). As a result, 3D models can legitimately join 2D drawing as a fully sanctioned means of conveying product and manufacturing information.

ISO JT and JT Open

JT provides the common language for facilitating collaboration, visualization and interoperability with 3D product information. Extensively adopted by the PLM community, JT serves as a unifying technology for 3D communication in:

- Traditional product design
- Manufacturing
- Supplier collaboration
- Documentation
- Data archiving

JT enables a broad range of users to access and work with intuitively understandable visualization data (even if they possess minimal engineering knowledge).

JT is supported through an industry initiative known as the JT Open Program, which is an organized community driven by global leaders in the PLM industry.

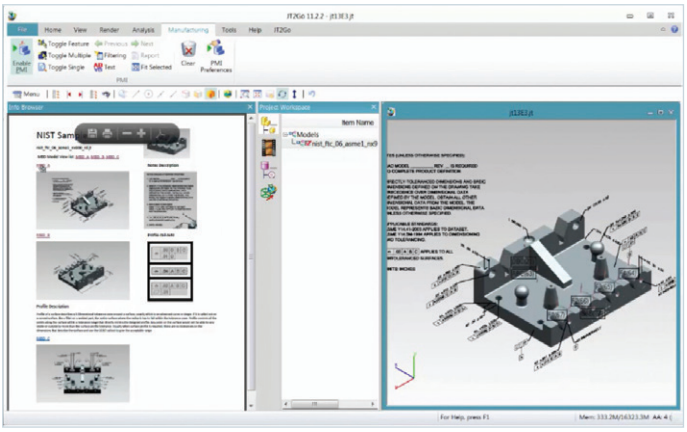
The JT Open Program membership was instrumental in Siemens publishing the JT file format reference. This reference was accepted by the ISO in December 2012 as the world's first international standard (IS) for viewing and sharing lightweight 3D product information in the PLM domain.
The JT file format reference is ISO 14306:2012.

Boeing	Caterpillar	Daimler
Approximately 700,000 JT files in just one site's database	Creates over 250,000 JT files per month, over 10 million managed files	Daimler has over 10 million managed JT files
Ford	**Siemens**	**Volkswagen / Audi**
Approximately 4 million JT files par car program dating back to 1993	JT is the corporate-wide standard for long-term data retention	Every released CAD dataset is automatically converted into JT

JT adopters actively promote ISO acceptance in part because of the amount of JT data that exists in their managed environments and is being created daily. Having an international standard for JT protects users' investments in JT data.

Electronic disclosures based on ISO JT and PDF

As part of model-based definition practices, our customers expect Siemens PLM Software to deliver on their need for publishing technical data packages (TDPs).



While we will support 3D PDF in our product portfolio through partners such as Tech Soft 3D, we have also developed low-cost complementary solutions for TDP workflows, such as innovatively enabling the use of JT and PDF through a simple attachment protocol. This process makes use of traditional PDF files as defined in ISO 32000-1:2008 using PDF Reference 1.7 and the long-standing data attachment policies for PDF documents without the need for 3D data translations to a native PDF representation.

As part of our free JT2Go product we have released the capability to link JT directly to corresponding references in the PDF document. These PDF references provide access to: PMI entities, geometric entities, model views and the assembly component structure. Siemens believes this is an effective technology for creating TDPs for the following reasons:

- Direct access to JT as part of the PDF avoids another translation step to the Product Representation Compact (PRC) format
- Better alignment of TDPs with the ASME Y14.41 standard; for instance, information captured as part of JT is equal to the source CAD PMI representation.

Model-based systems engineering

Through our systems-driven product development portfolio initiative, Siemens is driving a comprehensive integration of model-based systems engineering (MBSE) practices and workflows into our PLM offering. As part of this effort we are not only enhancing MBSE native capabilities in our products, such as systems and interface modeling in Active Workspace, but also continuously expanding our coverage for modeling solutions and toolchain integration based on open standards.

ReqIF

Requirements Interchange format (RIF/ReqIF) is an XML file format that can be used to exchange requirements, along with associated metadata, between software tools from different vendors, including Siemens PLM Software. This exchange format also defines a workflow for transmitting the status of

requirements between partners. Although developed in the automotive industry, ReqIF is suitable for lossless exchange of requirements in any industry.

The Teamcenter support for the RIF/ReqIF standard enables you to bridge the requirements gap between you and your customers and suppliers. Teamcenter is able to receive and send requirements data across an entire program to ensure that all components of your projects are aligned and working as a collective.

The RIF/ReqIF standard has become increasingly important to integrate the voice of the customer into deliverables managed by Teamcenter. With a variety of different requirements tools in existence, the disparate nature of project stakeholders and an increasing need for efficiency, it has become integral to a project's success that requirements be integrated and changes to requirements be reflected. The Teamcenter RIF/ReqIF standard exchange understands the schema, version and content of the RIF/ReqIF documents and enables you to map and import the data into your own Teamcenter schemas.

Siemens PLM Software supports the integration of requirements data based on RIF/ReqIF through our partner, Asaro Systems (http://www.asarosystems.com/).

SysML
Systems modeling language (SysML) is a general-purpose modeling language for systems engineering applications. It supports the specification, analysis, design, verification and validation of a broad range of systems and systems-of-systems.

SysML was originally developed as an open source specification project initiated in 2003 in response to an request for proposal (RFP) from the Object Management Group (OMG): "UML for Systems Engineering." SysML contains nine diagram types, seven of which it shares in common with its parent language, along with one tabular notation (allocation tables). The SysML specification is publicly available for download, and includes an open source license for distribution and use. The most recent revision is OMG SysML v. 1.4.

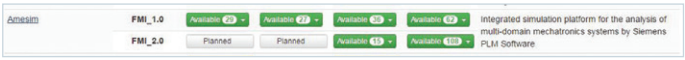
As OMG UML 2.0 profiles, SysML models are designed to be exchanged using the XML Metadata Interchange (XMI) standard. In addition, architectural alignment work is underway at Siemens to support ISO 10303 (also known as STEP AP-233, a standard for exchanging and sharing information between systems engineering software applications and tools).

Siemens provides native systems modeling as part of its Teamcenter Active Workspace capability and while it follows a subset of the SysML constructs it also goes beyond what SysML has been able to support. For instance, in the context of Teamcenter, Active Workspace systems modeling provides integrated PLM functions supporting configuration management, change management and traceability across modeling domains for large and complex product lines. In addition, Teamcenter provides an advanced system interface management capability to address closed loop integration systems modeling with multiple engineering areas such as Software, Electrical, Mechanical and Electronics.

Siemens is partnering with No Magic (https://www.nomagic.com/) to complement our system modeling capability with SysML behavior modeling and for the integration of SysML models with Teamcenter Mechatronics Model Management.

Functional mock-up interface
The functional mock-up interface (FMI) defines a standardized interface to be used in computer simulations to develop complex cyber-physical systems. Siemens is an active member of the FMI Steering Committee and the FMI Design group, and has contributed extensively to the specification of FMI 1.0 and FMI 2.0. In addition, Siemens PLM Software continues to be the voice of its industrial customers for FMI evolution, focusing on compatibility, simplicity, reliability and neutrality of the standard and its specification.

Specifically worth highlighting here is the FMI support provided by LMS™ Imagine.Lab Amesim™ software, the multi-domain modeling and simulation platform provided as part of the Siemens PLM Software LMS Imagine.Lab™ software product suite.



In support of the LMS Imagine.Lab product suite, Siemens PLM Software continues research activity on advanced co-simulation.

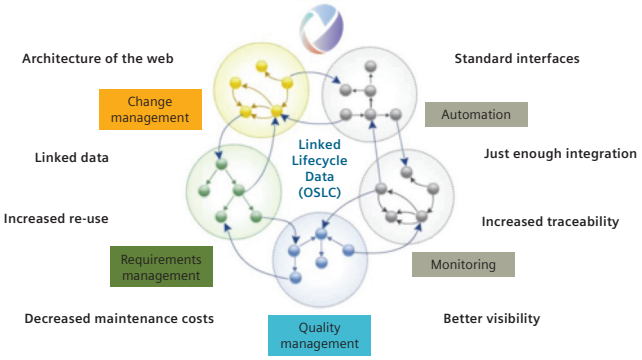
Open Services for Lifecycle Collaboration
Open Services for Lifecycle Collaboration (OSLC) is an open community creating specifications for integrating tools. These specifications allow conforming independent software and product lifecycle tools to integrate their data and workflows in support of end-to-end lifecycle processes. Examples of lifecycle tools in software development include defect tracking, requirements management and test management.

The OSLC community, of which Siemens is a member, is organized into workgroups that address integration scenarios for individual topics such as change management, test management, requirements management and configuration management. The topics that have OSLC workgroups and specifications are called domains in OSLC. Each workgroup explores integration scenarios for a given lifecycle topic and specifies a common vocabulary for the lifecycle artifacts, needed to support the scenarios.

OSLC is based on W3C Linked Data, which builds on four primary rules of linked data, authored by Tim Berners-Lee and documented on the W3C web site:

- Use Uniform Resource Identifiers (URIs) as names for things
- Use HTTP URIs so that people can look up those names
- When someone looks up a URI, provide useful information, using the standards
- Include links to other URIs.

Users can work seamlessly across their tools
(complex and fragile synchronization schemes not required)



Siemens supports enterprise integration based on OSLC as part of PLM. Through enhancements of the Teamcenter service oriented architecture (SOA), customers can now take advantage of OSLC for both data and user interface integration. Most recently, Siemens uses OSLC as part of its integration of PLM with application lifecycle management (ALM) tools, including Polarion ALM.

Manufacturing, metrology and tolerance variation analysis
Geometry and PMI stored in the model-based definition feeds Siemens manufacturing process software with the information required for intelligent analysis of manufacturing tolerances and comparison data for metrology.

Siemens products observe two critical standards in its MBD and metrology products:

ASME Y14.5 Dimensioning and Tolerances
ASME describes the Y14.5 standard as establishing "uniform practices for stating and interpreting GD&T and related requirements for use on engineering drawings and in related documents. GD&T is an essential tool for communicating design intent – that parts from technical drawings have the desired form, fit, function and interchangeability. By providing uniformity in drawing specifications and interpretation, GD&T reduces guesswork throughout the manufacturing process – improving quality, lowering costs, and shortening deliveries."

Siemens uses the ASME Y14.5 standard as the basis of metrology analytics in its variation analysis (VSA) product for simulated measurements and NX CMM Inspection Programming for analysis of actual measurement data.

ANSI 105.2-2009, Part 1 Dimensional Measuring Interface Standard
The American National Standards Institute (ANSI) defines the Dimensional Measuring Interface Standard (DMIS) as "a neutral language for communication between information systems and dimensional measurement equipment (DME). DMIS is an execution language for measurement part programs and provides an exchange format for metrology data such as features, tolerances, and measurement results. DMIS conveys the product and equipment definitions along with the process and reporting information necessary to perform dimensional measurements that employ coordinate metrology."

Siemens uses the ANSI 105.2-2009 standard to communicate measurement programs from NX CMM Inspection Programming to coordinate measurement machines executing those measurement programs.

Additive manufacturing
Additive manufacturing is an important pillar of the Siemens product portfolio, and we continue to explore the potential use of standards for modeling, data exchange and collaboration. The following standards are worth highlighting in this space.

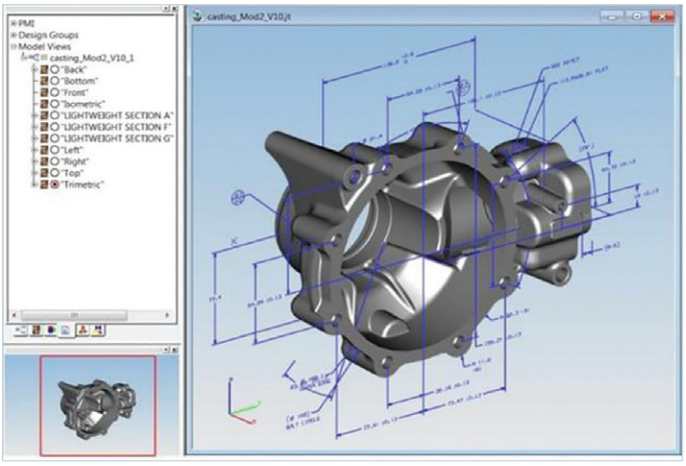
3MF
3MF is an open packaging convention file format that fully describes a solid model as a Cartesian mesh, retaining materials, texture, color and other characteristics. Files can be read by printer preprocessing software, like Microsoft® 3D Builder to generate printer-specific instructions; or read directly by a new generation of 3D printers capable of printing directly from 3MF. Siemens PLM Software is one of core members of the 3MF consortium. As part of our product development plans we are looking forward to further integrate the 3MF standard with NX, Solid Edge® software, as well as JT2Go.

JT interoperability with 3MF
JT to 3MF links the 3D digital model with additive fabrication tools and techniques. The JT to 3MF Translator from Siemens PLM Software is of interest to JT adopters wishing to extend the value proposition of their JT asset by 3D printing physical mockups, functional prototypes, and, when applicable, production parts; by sintering functional prototypes from the 3D model, or by developing an additive manufacturing production workflow. The translator processes JT format geometry, assembly structure, part/assembly instances, transforms, attributes and color/material of bodies. A configuration file lets the user specify the JT entities to read and processing parameters to use.

STL
The STL file format was invented by the Albert Consulting Group for 3D Systems in 1987 to support the stereolithographic 3D printer invented by Chuck Hull. The STL file format made it possible to transfer three-dimensional CAD models to 3D systems' very first commercial 3D printer, the StereoLithography Apparatus. Since this initial release, the technical specifications of the STL file format have remained virtually unchanged. This file format is supported by many other software packages, including NX and Solid Edge. It is widely used for rapid prototyping, 3D printing and computer-aided manufacturing (CAM). STL files describe only the surface geometry of a three-dimensional object without any representation of color, texture or other common CAD model attributes. Even though Siemens PLM Software supports the STL file format we expect this format for 3D printing to be superseded by 3MF at some point.

Long-term archival and exchange of data
Switching your business to a Digital Enterprise business means further considerations regarding long-term archival, both for data retention and retrieval. Siemens offers either solutions for both based on JT or STEP.

JT
The JT file format is used extensively by industry in a broad range of use cases and work flows, including data exchange and archiving. Siemens first published the specification for JT in January 2007. The primary driver for publication of the JT file format specification was to support long-term data archiving. JT Open Program members performed an extensive vetting of the content stored in a JT file to verify it retained the content necessary for archival.



In 2008 an assessment was completed in accordance with a set of criteria defined by a major automotive OEM taking into consideration standards from the German Automotive Industry Association (VDA) and aerospace industry requirements. The JT file format met 100 percent of the geometry requirements specified for archiving. Since that time, JT has been adopted in the automotive industry as the preferred format for long-term data retention. Siemens also adopted JT internally as a corporate-wide, long-term data retention format in March, 2008. JT can be used to fully represent product manufacturing information, which has been a primary consideration in the decision to use JT for archiving.

JT data is typically created at the same granularity as CAD content and is stored as managed data. Because of this, JT is preferred for long-term date retention as it does not require an additional process or workflow to generate content for archiving.

JT file format content
The JT file format provides coverage for the following domains. It is worth noting that these domains are not exclusive to 3D geometry only.

Advanced 3D compression	Product structure (BOM)
Precise - B-Rep & B-Spline	Layers
Non-precise - facetted shapes and primitives	Metadata
Solids, wires and points	Computer-aided engineering (CAE) graphics
Levels of detail (LODs)	CAE results
Transforms and materials	Graphic product manufacturing info
Textures and lights	Semantic PMI

Siemens PLM Software supports read and write of JT across the product portfolio.

Data exchange based on STEP
The STEP AP concept was first envisioned to combine STEP building blocks, such as geometry and assembly, to collectively solve a particular industry workflow issue. STEP AP203 was developed primarily by the aerospace community for their shape and assembly structure interchange workflows through PDES, Inc. in the United States, and STEP AP214 was primarily developed by the automotive community through ProSTEP in Europe.

Groups like PDES, ProSTEP and LOTAR saw the need to progress what had been started with STEP AP203 and STEP214, and agreed to initiate new development in the context of STEP AP242, which combines AP203 and AP214 to reduce complexity and introduce missing support for PMI.

Since AP242 is new it is recommended to check that the destination system supports the required content before embarking upon AP242-based exchange. The most recent content is in the area of semantically-defined PMI, which should allow receiving systems to interpret the PMI definition beyond just a graphical representation. Other areas being developed in the STEP community include more extensive validation properties important for long-term archival (LOTAR), the technical data package (TDP) and any process that relies on the fidelity of data exchanged in the STEP format.

AP242 also provides a means to use JT and STEP together in an effective way. The standard makes use of both formats for data exchange and archiving through STEP XML output. In STEP XML the product structure information is stored as xml formatted text and the geometry descriptions are stored as binary 3D JT. The JT files are accessed through URI strings.

Siemens actively participates in the STEP development activities of the consortia and continues to advance its STEP coverage across the PLM product portfolio.

The NX STEP AP203 and STEP AP214 translators provide two-way data exchange between NX and STEP AP203 edition 2. These translators exchange assemblies, facetted and precise b-rep solids, color and layer, external references, basic wireframe and basic product id, product version, product information configuration management data, and AP203 edition2 PMI as a polyline representation.

The NX STEP AP242 translator supports two-way data exchange between NX and STEP AP242 edition 1 using NX file import/export and file open/save as capability. The translator can also be executed from the command line. The translator provides an exchange for solid, surface, wireframe and tessellated geometry. Part PMI support includes graphically- and semantically-defined representations, and there is interoperability between NX Assemblies and AP242 XML business objects.

JT interoperability with STEP

Siemens PLM Software has developed the JT Bi-directional Translator for STEP, which translates STEP AP242 edition 1, AP203 Edition 2 and AP214 ISO format files to and from JT. The product operates in either of two ways:

1. From command line as a standalone Bi-Directional Translator. The product translates JT files to and from the file system without needing to install Teamcenter visualization, and independently from the installed version of Teamcenter visualization
2. STEP file open and export for Teamcenter visualization 11.1 onwards and the Lifecycle Viewer 11.1 onwards. The product will open STEP AP242, AP203 and AP214 files and save JT files from within the viewer to any of these specified STEP formats

The JT Bi-directional Translator for STEP translates precise surface and solid geometry as XT b-spline and analytic forms. It translates wireframe, assemblies, polyline PMI, supplemental geometry coordinate systems, facet boundary tessellation, attributes and geometric validation properties. With the STEP 242 format the translator also supports semantic PMI, tessellated geometry and 242 XML files.

LOTAR NAS 9300

The objective of LOTAR International is to develop, test, publish and maintain standards for long-term archiving (LTA) of digital data, such as 3D CAD and product data management (PDM) data. These standards will define auditable archiving and retrieval processes. Use of the standard series by other branches of industry, such as the automotive or shipbuilding industry, is possible. For instance, the results are harmonized with recommendation 4958 for long-term archiving of the German Association of the Automotive Industry (VDA) and are based on ISO 14721, the Open Archival Information System (OAIS) Reference Model. The documents for the standard are published as the EN9300 series and, in cooperation with the Aerospace Industries Association (AIA), also known as the National Aerospace Standard (NAS).

EN/NAS 9300-110 2014	JT Inspector Design Authority
Geometric validation properties: volume, surface area, centroid within 1 percent	Calculates geometric properties and compares against stored CAD values in the JT file to a user defined tolerance (1 percent or more or less if desired)
Empty model	Reports all topological entities
Surfaces replace solid	Reports all topological entities
Set of 12 SASIG data exchange tests with recommended threshold values	Reports against the 12 EN/NAS 9300-110 SASIG tests using adjustable threshold values
Invalid solid	Use Parasolid® software to check whether the XT model is valid for applications based on Parasolid
Cloud of points within 1E-4m	Compares point cloud source against surfaces and reports against user defined tolerance down to 1E-8m

Siemens PLM Software supports NAS9300 validation of JT data with the JT Inspector product. JT Inspector Design Authority is able to validate geometry and PMI against the current draft standards for NAS 9300-110:2014 and NAS 9300-125:2016.

Technical data package MIL-STD-31000A

MIL-STD-31000A is a United States Department of Defense standard practice for technical data packages. It provides technical guidance to the government and its contractors about validating digital 3D models prior to their distribution to agencies and subcontractors during the design, manufacturing and product lifecycle. MIL-STD-31000A has much in common with NAS9300-110 and Siemens supports validation of JT data to the military standard with its JT Inspector Design Authority product.

JT Inspector Design Authority

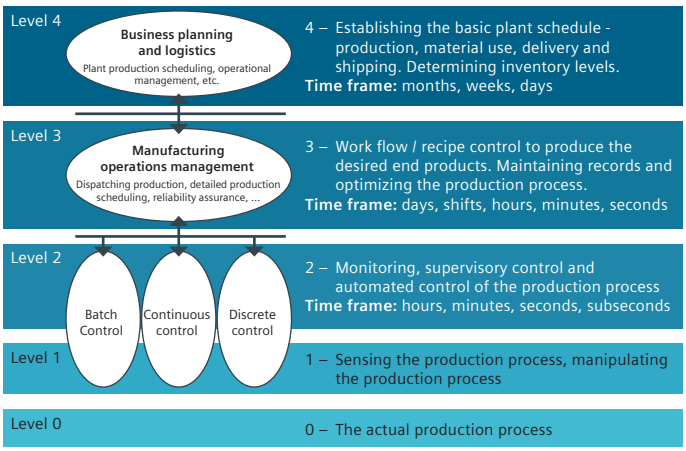
JT Inspector Design Authority is an inspection tool available from Siemens PLM Software that reports the content and integrity of a JT file and determines its fidelity relative to the original CAD data or another validation source used as a cross-reference. JT Inspector Design Authority implements the validation requirements for precise geometry and PMI set out by the MIL-STD-31000-A and NAS-9300 standards. Geometry tests include a comparison of geometric properties; checks for a valid Parasolid model; 60 Security Awareness Special Interest Group (SASIG) tests and point cloud comparisons. PMI tests include comparison of PMI type counts, polyline centroid and curve length, associated and attached area, Unicode string comparison and a check on whether it's a valid JT PMI definition. The tool can run within an automated environment, such as Teamcenter dispatcher, or interactively in Teamcenter visualization with user-defined tolerances.

MOM and automation

As the second key pillar of the Digital Enterprise, our manufacturing operations management and factory automation products support the digital manufacturing lifecycle from production scheduling and capacity planning all the way to integration with shop floor automation and Industrial IoT. As with product lifecycle management, our customers in this space expect to efficiently execute internal business processes and, more importantly, facilitate collaboration with and their supply chain.

ANSI/ISA95

ANSI/ISA95, or ISA95 as it is more commonly called, is an international standard from the International Society of Automation for developing an automated interface between enterprise and control systems like MES.

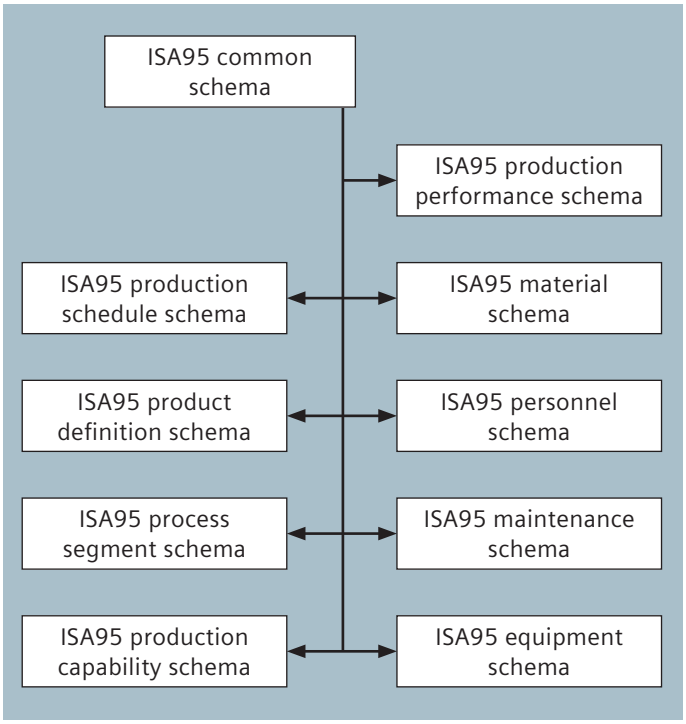


The ISA95 standard has been developed for global manufacturers. The standard was developed to be applied in all industries, and in all sorts of processes, like batch processes, continuous and repetitive processes.

The objectives of ISA95 are to provide consistent terminology to form a foundation for supplier and manufacturer communication, information and operations models. Together these clarify the boundaries between the functionality of the applications to be integrated, and show how information flows among them. Siemens supports the ISA95 specification as part of the integration of SIMATIC IT MES with the enterprise. In addition, the product architecture of SIMATIC IT is founded on the ISA95 MES international standard.

B2MML

Business to Manufacturing Markup language (B2MML), is an XML implementation of the ANSI/ISA95 for enterprise to control system integration. B2MML consists of a set of XML schemas written using the World Wide Web Consortium's XML Schema language (XSD) that implement the data models in the ISA95 standard.



The objectives of B2MML are to enable companies that would like to leverage standard mechanisms by integrating ERP and supply chain systems with manufacturing systems.

SIMATIC IT MES has a built-in integration mechanism that adheres to B2MML industry standards.

OPC Data Access

OPC Data Access (OPC DA) defined by the OPC Foundation describes how real-time data can be transferred between a data source and a data destination (for example: a programmable logic controller and human machine interface or a programmable logic controller and MES) without getting into the native protocols used on either side. It provides a standard data exchange mechanism, avoids building custom drivers on both sides and focuses on continuous communication of data.

OPC DA is relevant only for real-time data and not for historical data. Typically, OPC DA associates three attributes to the data field – value, quality of value and timestamp. OPC DA uses distributed component object model (DCOM) communication between the client and server. OPC DA can be used successfully in a variety of different environments – from discrete to batch to continuous processing automation. Siemens currently supports the use of OPC DA as a communication interface option across disparate automation systems. SIMATIC IT MES has a built-in OPC client and fully supports OPC DA.

OPC Unified Architecture

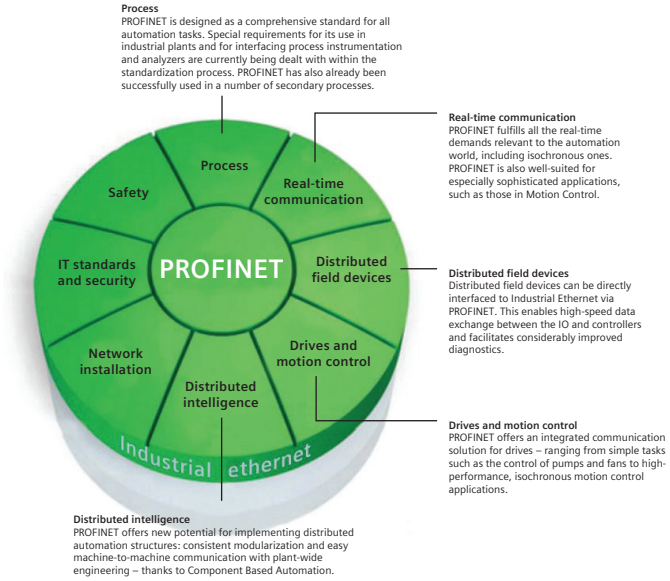
OPC Unified Architecture (OPC UA) is an industrial machine-to-machine communication protocol for interoperability developed by the OPC Foundation. It is the successor to OPC Data Access. Although developed by the same organization, OPC UA differs significantly from its predecessor. The foundation's goal for this project was to provide a path forward from the original OPC communications model (the Microsoft® Windows® operating system only process exchange COM/DCOM) to a cross-platform service-oriented architecture (SOA) for process control, while enhancing security and providing an information model.

Unlike OPC DA, OPC UA is designed to be independent of operating system platforms and features standard internet and Internet Protocol (IP) based protocols, built-in security features, generic object models, extensible-type systems and scalability through profiles.

Siemens currently provides support for the use of OPC UA as the communication interface across the automation levels of SCADA, Control and PLC. By implementing OPC UA as either a server or client we can offer access to data, alarms and diagnostic information from the SIMATIC S7 controllers.

PROFINET

PROFINET (an acronym for Process field net) is an industry technical standard for data communication over Industrial Ethernet, designed for controlling and collecting data from equipment in industrial systems, with a particular strength in delivering data under tight time constraints, which you will find in the field of industrial automation. The standard is maintained and supported by PROFIBUS and PROFINET International, an umbrella organization headquartered in Karlsruhe, Germany.



Siemens continues to be a strong supporter of standard communication protocols supported by PROFIBUS and PROFINET through various standards. With the totally integrated automation portal (TIA Portal), Siemens offers an engineering framework that combines all automation engineering tools. In the TIA portal, PROFINET represents the communications standard for all new products such as SIMATIC S7-1500. This combination creates the basis for integrated data management and maximum consistency.

Industrial IoT protocols

Open ecosystems are also a rapidly rising trend in the Industrial IoT world, and Siemens is jumping on board with its latest innovation: MindSphere, a cloud offering that links physical products and production facilities with digital data. With MindConnect, Siemens offers numerous possibilities for connecting machines, plants and worldwide fleets to MindSphere, regardless of the manufacturer.

For instance, MindConnect Nano is a plug-and-play solution that enables you to read out data from your industrial asset and preprocess it for transfer to MindSphere. The MindConnect Nano edge device transmits data, encrypted through a secure internet connection, to MindSphere, allowing the creation of cloud-based applications and services. Data defined by the user is connected using the MindConnect Nano, and is then transmitted to MindSphere at fixed time intervals.

MindSphere is designed as an open ecosystem, making it possible to exchange data across company boundaries and connect a wide range of different products. Thanks to open standards and interfaces, data can be gathered from industrial equipment of many different manufacturers and analyzed in MindSphere. Current supported data sources are SIMATIC S7-300 / S7-400 / ET 200S, SIMATIC S7-1200 / S7-1500 and OPC UA. Additional supported data sources, protocols and different edge devices are under development.

For further information, please refer to the supplementary paper on Siemens' vision for Industrial IoT.

Conclusion

As discussed in this paper, Siemens continues to set the trend for how to leverage open and industry standards as part of your Digital Enterprise. Not only does Siemens contribute to open standards like JT, but we also continue to work with our strategic customers to evaluate when standards can be further integrated into our products and industry solutions.

As you plan to realize a Digital Enterprise that fits your organizational needs and constraints, we reiterate the following best practices:

- Establish a Digital Enterprise office responsible for the governance of toolchain integration, semantics and best practices. Transforming your organization into a Digital Enterprise requires buy-in from all relevant stakeholders, including partners and your supply chain
- Focus on digital threads with high ROI for your business, such as model-based engineering and electronic work instructions. Even though this paper provides a holistic view to adopting a Digital Enterprise with standards as a keystone, it is important to build on success. Start with an area in which you can make a real difference in current business operations
- Use industry state-of-the-art technology and data formats for critical and value-add business processes. Siemens recognizes the value that standards may deliver to companies as they endeavor to realize and maintain an enterprise-scale digitalization effort, and hence, this is why Siemens is systematically driving broad standards compliance into our products. However, it is also worth highlighting that utilization of proprietary technologies should be considered, and espoused, in those cases when it makes logical business sense to do so. For example, consider proprietary integrations for critical operations when you may want to use PLM, MOM or automation technology as a key market differentiator, or when reliance on immature standards may introduce other unnecessary business risks
- Leverage industry-driven standards via consortiums. Standards driven by an industry simply have a better focus, partly because they represent a specific domain. Our experience tells us that standards driven by industry consortiums typically make a more significant impact on the efficiency of customer operations
- Use open standards when semantics are comprehensive, mature and broadly supported, and hence, least common denominator is not a problem; for example, PMI, GD&T and model-based definition. As mentioned in the previous two bullets, open and international standards often do not represent all the domain semantics necessary to complete an integration. Carefully evaluate them and check their coverage across the business critical tools that form the foundation for your Digital Enterprise
- Consider shared semantics between the virtual and physical world to accelerate your IoT adoption. The Digital Enterprise is all about connecting the virtual and physical world so you should plan for this

The world of standards is very much about creating strategic alliances in which adhering to the evolving open and industrial standards may be mutually monitored in the context of ever evolving strategic business objectives. In this vein, Siemens believes that it is in a most favorable position to form such alliances. Openness is at the core of our company's culture.

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About Siemens PLM Software

Siemens PLM Software, a business unit of the Siemens Digital Factory Division, is a leading global provider of product lifecycle management (PLM) and manufacturing operations management (MOM) software, systems and services with over 15 million licensed seats and more than 140,000 customers worldwide. Headquartered in Plano, Texas, Siemens PLM Software works collaboratively with its customers to provide industry software solutions that help companies everywhere achieve a sustainable competitive advantage by making real the innovations that matter. For more information on Siemens PLM Software products and services, visit www.siemens.com/plm.

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