Model standards interoperability across domains, the life cycle, and the supply chain

Charlie Stirk
stirk@costvision.com
303-539-9312

Dec. 13, 2012
My perspective …

• Cost models need to interoperate with other models
  • Requirements, Arch., Project, CAD, Assembly, Mfg., O&S

• Standards Involvement
  • PDES Manufacturing & Systems Engineering Teams
  • INCOSE MBSE, Tool Integration and Interoperability
  • OMG Model Interchange Working Group
  • CAX Implementor Forum
  • PLCS Implementor Forum
  • AIA/ASD Long Term Archiving and Retrieval (LOTAR)
    – Product Data Management & Metadata Teams
  • AIA/ASD Integrated Logistics Support (ILS S-series)
    – Data Modeling and Exchange Working Group

• Use of other technologies
  • OAGIS, Acrobat/3D PDF, COLLADA, CAD/PLM API’s
Data Across Functional Domains & Life Cycle Stages

Concept
- Requirements
- Volume, Budget, Schedule
- Architecture

Functional Design
- Systems structure & interfaces
- Function & State Behaviors
- Packaging, Test Plans

System Preliminary Design
- BOM, Architecture Layout, Physical Interfaces
- Assembly Sequence, Logistics & Maintenance Plans

Product/Process Preliminary Design
- Solid Model, Kinematics
- Fabrication Processes, Factory Layout, Ergonomics

Detailed Design
- CAD with GD&T, Tooling, CAE
- RFx, ECx, CAM, Process Plans, DFX Rules, Tech Manuals

Manufacturing
- Factory: Materials, Quality, Utilization, Factory Layout
- Supply Chain: Network, Buffers, Lead Times, Schedules, Orders

Operations & Support
- Spares, Upgrades
- Maintenance Records, MTBF, MTTR
- Maintained Configuration

Security
Configuration & Change Management
STEP Modular Architecture (STEPmod)

- Modular Application Protocol (AP) Benefits
  - STEP Module and Resource Library (HTML on CD) for CHF 352
    - Faster revision process (months rather than years)
  - Interoperability of implementations through module & code reuse
    - requirements, assembly structure, geometry, PMI etc.

- Two implementation levels
  - ARM domain-specific entities map to MIM entities from integrated resources

- Modular STEP AP Domains
  - AP209 CAE (FEA and CFD)
  - AP210 EDA/MCAD (electrical and mechanical assemblies)
  - AP233 Systems Engineering
  - AP239 Product Life Cycle Support (PLCS)
  - AP242 Mechanical CAD (parts & assemblies)
Program and Project Management

• Earned Value Management (EVM)
  • UNCEFACT based XML Schemas for Cost and Schedule
  • Cost classification by Work Breakdown Structure
    – MIL-STD-881 for systems (but hybrid breakdown)
    – Operations & Support WBS (functional breakdown)
  • DoD requiring on all large programs for EVM baseline and reporting to Central Repository

• NATO Guidance on Life Cycle Costing (ALCCP-1)
  • Recommends use of PLCS for data collection
  • Recommends standard Cost Breakdown Structure
  • Recommends standard activity and resource classification

• Collaborative Project Management (CPM)
  • Usage Guide, Data Exchange Model, Implementation Guide
  • By ProSTEP iViP with German auto industry
  • XML schemas and WSDL transport
Systems Engineering Model Standards

- **SysML = Systems Modeling Language**
  - Diagram language based on UML/OMG MOF
  - XMI = XML Model Interchange format
    - Written specification for OMG MOF (interpreted!)
    - Canonical XMI is restricted specification (NIST Validator)
    - OMG MIWG testing conformance, but not interchange yet
    - Need UID for diagram/data management
    - Without diagram exchange, limited to libraries or manual model re-building
  - Partial mapping with AP233 needs completion

- **ReqIF = Requirements Interchange Format**
  - XML schema for spec hierarchy, data types, attributes
  - Several versions in use
  - Vendor implementations not interoperable
  - ProSTEP iViP setting up an implementers forum
  - Early version mapping with AP233 needs updating/validation
SysML/AP233 Data Overlaps

- AP233:
  - Lifecycle Stages
  - Eng Config Mgmt
  - Organizations
  - Schedule
  - Change Management
  - Approvals, Security, Status
  - Requirements Management
  - Property-based Requirements
  - Issue Management
  - Risk Management

- SysML:
  - Classification
  - System Structures/Blocks
  - V & V
  - Activities
  - Text-based Requirements
  - Function Models
  - State Machines
  - Property & Units
  - Model Organization
  - Views and Viewpoints
  - Diagrams
  - Parametrics
  - Allocations
  - Interfaces/Ports & Flows
Model Transformation Technologies

• **XSLT (Extensible Stylesheet Language Transformations)**
  • Between XML documents, HTML, PDF, relational databases, …
  • Many proprietary and open source implementations
  • E.g. STEPmod publishing system for STEP AP’s

• **EXPRESS-X (ISO 10303-14)**
  • Data between EXPRESS schemas
  • NIST Expresso open source and commercial tools
  • E.g. implement STEP ARM to MIM/AIM mapping

• **Meta Object Facility (OMG MOF)**
  • Typically between UML derived languages and models
  • Ecore variant in Eclipse Modeling Framework commonly used
  • Transformation languages: QVT, ATL, VIATRA
  • E.g. ReqIF to SysML Requirements
Use of AP233/239 in Systems Engineering

- Early version of AP233 used for
  - Data Migration between Slate and TeamCenter SE
  - Mapping of CADM 1.5 format for DoDAF

- AP233 and AP239 Convergence
  - AP239ed2 contains all but 233’s Issue and Behavior Models (State Machines and Enhanced Functional Flow Block Diagrams)
    - Roll them into modules or reference data

- AP239 PLCS used to manage mapped objects
  - PLCS supports relationships & configuration management
    - Like earlier work with CADM, IFC, SysML
    - Add ReqIF, UPDM, EVM, CPM, etc.
  - PLCS provides links to other domains (PDM, LSA, provisioning, scheduled maintenance, tech pubs, field data ..
PDES Systems Engineering Projects

- Requirements Traceability
  - Decomposition from Capabilities to Specifications
  - Across supply chain
  - Across tools (DOORS, ReqIF, SysML, etc.)
  - To verification & validation artifacts
  - Engineering change processes

- Systems Model Interoperability
  - Architecture, Behavior, …
  - Across lifecycle (Architecture, Systems, Design, Test, etc.)
  - Across languages (UPDM, SysML, UML, AADL, domain specific, …)

- Sharing info with ProSTEP iViP Smart Systems Eng.
  - Initial focus on Modelica Functional Mockup Interface (FMI)
  - Have advantages over Matlab/Simulink S-Functions
Convergence of AP203 (Aero) and AP214 (Auto)

• Create single superset standard for MCAD
  – 203 x 214 = 242 and upwardly compatible
  – Modularization for interoperability across domains
  – Already harmonized for geometry (translators handle both)

• 214 adds the following capabilities
  – Manufacturing process planning
    • Relate plans, operations, tools, raw/in-process/finished, projects, other activities, etc.
  – Kinematics
  – Machining Features
  – OMG PLM Services (web services API) for PDM and Engineering Change

• Enable association with 203 unique capabilities
  – Catalog, Composites, Construction History, Requirements
New Functionality for AP242ed1

- **Business Object Model (BOM)**
  - AP214 ARM was higher level than STEPmod ARMs
  - Upward compatibility for AP214 ARM based implementations
  - Harmonization ongoing with AP239 for PDM
  - Mapping from BOM to ARM
    - Enables higher level API
    - Composites then PDM and other areas
    - Eventually kinematics and mfg. process for visualization

- **Shape Data Quality**
- **Access Rights Management**
- **Expanded Kinematics Simulation**
- **Improved PMI**
- **External Element Reference (eg. for Assembly PMI)**
- **Tessellated Geometry**

- **EXPRESS schemas and draft recommended practices available for testing**
Proposed Functionality for AP 242ed2

- 3D parametric / geometric constraints design
- 3D kinematics assembly
- 3D GD&T at assembly level
- Sustainability information
- Software / mechatronics
- 3D electrical harness
- 3D piping
AP242 PMI Subgroup work deferred for lack of funding

- Mapping of screw threads standards to AIC522/AM machining_feature
- Welding standards (ISO 2553, AWS A2.4)
- PMI for ISO assembly documentation, assembly technology, assembly joint
- Support of adhesive standards (ASTM D7447)
- ISO 1101 FDAM1 - Tolerances of form, orientation, location and run-out
- Surface texture (ISO 1306, etc. and ASME B46.1)
- Other items that had been categories as out of scope for PMI-1 e.g. spot-face
- Update for new editions of ASME Y14.41 and ISO 16792
CAX-Implementor Forum

- Joint testing effort of PDES Inc. & ProSTEP iViP

- Participants: AutoDesk, Capvidia, CT Core Technology, Dassault Systemes, DataKit, ITI TranscenData, Kubotek, LKsoft, PTC, Siemens, TechSoft 3D, Theorem Solutions, Vistagy

- JT, 3DPDF, 3DXML, CAP-XML sponsors are active members

- Bi-annual rounds of testing of CAD data exchange
  - Cooperate on implementing STEP
  - Feedback to STEP developers
  - Accelerate translator development
  - Promote interoperability
  - Scope is AP203, AP214, AP242
  - Capability & Validation

Semantic PMI Representation Test Model
CAX-IF Benefits

- Individual results covered by non-disclosure
  - Publish only aggregate results

- Test Suites
  - Instructions on building test models
  - Test, production models in file repository (STEP & native)

- Draft Recommended Practices
  - Model Styling & Organization
  - User Defined Attributes
  - External References
  - PMI
  - Tessellation
  - STEP File Compression

- LOTAR provides requirements and test models

- 3D PDF Generator

3D Tessellated Geometry
Synthetic Test Model
CAX-IF Implementation Coverage Matrix

• Purpose is to coordinate vendor testing
  • Organized by major sections of Recommended Practices

• Self-reported Vendor Status
  • Categories: Production, Customer Tests, Development, Future Plans, Not Supported
    (Only Production status made public)
  • Can compare implementations

• Total of 6 Vendors testing 242 implementations
  • Sufficient to have schema and recommended practices
# Public Implementation Coverage Example (CATIA V6)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geometry</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wireframe</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Geom. Bounded Surface Model</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>BREP Solid</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3D Tessellated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Assembly Structure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assembly Structure</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mapped_Item</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>Composite Material</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Composite Material</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Model Styling</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid Color</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Face Color</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Overriding Face Color</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Edge / Curve Color</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Overriding Edge Color</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Composites

- Composite meta-data
  - Ply orientation angle and thickness
  - Material specification

- Shape
  - 2½ D wireframe and surfaces
  - Explicit solids
  - New tessellated geometry

- Going forward in AP242 and AP209
• Combines CAD, CAE, PDM capabilities
  – Superset of AP203ed2
  – Finite Element Analysis (FEA)
  – Computational Fluid Dynamics (CFD)
  – General numerical analysis
  – Shares base analysis models with AP233 Systems Engineering

• Developing binary format
  – Based on open source HDF5 toolkit
  – New ISO 10303-26 (part26)

• New API specification
  • BOM to ARM to AIM mapping
  • Web services implementation
Simulation Data Management (SDM)

• SimPDM project of ProSTEP iViP
  • Business process diagrams
  • Business process between SDM, Multi-Body, FEM, CFD, PDM
  • Not an interchange data format, it is a metadata model

• CAE Services project of ProSTEP iViP
  • Successor to Collaborative CAD/CAE Integration (C3I)
    – Successor to SimPDM
    – XML schemas and WSDL
    – Mapping to AP209 entities

• SimDM project of PDES Inc.
  • Uses AP209ed2 and 242-style Business Object Model

• CRESCENDO project of EU
  • Based on EU VIVACE, AP233/239 and PLCSlib
  • Behavioural Digital Aircraft (BDA) Model …
BDA Business Object Model defines common language exposed as web services based on 233/239

BDA PLCSlib DEX’s to be publicly released soon
- Many base PLCS templates already available as OASIS templates
- Not specific to aircraft, can be used for other types of products

Web services to create, update, read and search data
- WSDL interfaces implemented against
  - Share-a-space collaboration hub
  - Clients: MSC SimManager/SimXpert, Siemens TeamCenter/NX, Scilab, Proosis, Dassault CATIA/Enovia/iSight/Dymola, Altair/Optistruct
Benefits of PLCSlib

- New DEX development environment
  - Recommended by OASIS PLCS Technical Committee on all new DEX development
  - Replaces DEXlib and based on AP239ed2 International Standard (IS)
  - Generate DEX XML schema from SysML model
  - Reference data in semantic web technology (OWL2 DL)
  - Uses new templates (due to AP239ed2 and other lessons learned)

- Benefits
  - Can transform data for legacy DEX to new DEX’s (no DEX transform)
  - Re-use DEXlib business information requirements/entity mapping
  - Faster DEX development (SysML IDE & encapsulation/abstraction)
  - SysML integration to Enterprise Architecture and Systems Engineering
  - Smaller file sizes and schemas
  - Better re-use and fewer base templates
  - Better quality due to built-in object and type checking
  - Software code and Web service generation
Rich model designed to enable traceability from customer expectations through to certification
SysML Block Definition Diagram of PLCS Requirements
A CRESCENDO example (simplified)

A typical example case in CRESCENDO:

• Airbus (France and UK) start to develop a new plane based on an analysis of customer expectations leading to requirements
• Cranfield (UK) are asked by Airbus to develop engine properties to match the requirements
• DLR analyse power off-takes
• The requirements and engine properties are passed by Airbus to Rolls Royce (D and UK) to propose a type of engine with more properties and requirements for which RR then simulate
• The results of the simulation are passed to NLR (Netherlands) who produce a “surrogate model” which is passed back to RR and then made available to Airbus
• Iterate taking into account thermal, noise, pylon structures,…
Multiple Visualization Formats

• New LOTAR visualization team
  • Provide requirements to other consortiums
  • Interoperability testing with 3D tessellation in STEP

• JT and 3D PDF working on PMI

• COLLADA from Khronos Group
  • Harvesting by ISO TC184/SC4 like JT
  • XML schema with an extension method
  • Open source toolkits available
  • Used in Digital Content Creation industry
    – CGI, gaming, training …
  • New version includes BREP, kinematics (little support yet)
  • Khronos also provides WebGL (3D model in browser)
  • Open source for COLLADA to WebGL (three.js, scene.js)
3D CAD in a Web Browser

• WebGL in HTML5
  • Embedded in most browsers, or plug-in to Internet Explorer
  • Runs on desktop and Android, RIM mobile browsers (not iOS)
  • Uses GPU for 3D acceleration

• Examples using WebGL
  • PythonOCC – STEP through OpenCascade to browser
  • Sketchfab – publishing system from CAD to web pages
  • Tinkercad – parametric 3D CAD in browser and STL interface
  • 3DTin – modeller with STL, OBJ, DAE (COLLADA) export
  • ShapeSmith – parametric NURBS open source
  • Sunglass.io – collab. viewer, parts/assemblies, CAD formats and plug-ins

• X3D plug-in for browsers
  • Collaborating with COLLADA and WebGL teams
Tessellated Geometry Interoperability Testing

**CAD authoring application**
- **Catia V5-R21**
- **NX V7**

**STEP Converters**
- **STEP 3D tessellated geometry**
  - **EXP**
  - **IMP**
- **STEP file checker**
- **STEP 3D tessellated geometry**
  - **IMP**
- **STEP 3D tessellated geometry**
  - **EXP**
  - **IMP**

**Creation of prototypes by stereolithography**
- **VRML browser**
  - **Right Hemisphere**
- **Deep Vision 3D viewer**
- **Adobe Acrobat 3D**
- **Adobe**

**STEP 3D tessellated geometry**
- **to STL**
- **to VRML**
- **to Deep Vision**
- **to PDF 3D**
PLCS and Logistics

• ASD/AIA Integrated Logistics Support S-series
  • SX000i Guide for Use of S-series: writing chapters
  • S2000M Material Management: issue 5.0 on May 3
  • S3000L Logistics Support Analysis: issue 1.1 Q1 2013
  • S4000M Scheduled Maintenance: working on issue 1.0
  • S5000F Operational & Maintenance Feedback: early draft handbook, data
  • S6000T Training Needs Analysis, TBD
  • S9000D Dictionary: issue 1.0 under development

• GEIA-0007 Logistics Product Data
  • Some DEXlib DEX’s developed
  • Handbook Rev B Ballot Draft released August 20
  • Draft MIL-HDBK-502A Acquisition Logistics on Oct. 1

• Other MODs developing PLCSlib DEXs
  • France, Norway, Sweden, UK, USMC/NATO
Convergence on Maintenance Feedback

- Spec 2000 from Airlines for America (A4A) (A4A formerly known as Air Transport Association (ATA))
  - E-business Specification for Material Management
  - For Maintenance, Repair, Operation (MRO) of civil aircraft
  - Strongly recommended by airframers in procurement
  - Chapter 11 Reliability Data Collection/Exchange
    - Eg. LRU Unscheduled Removal Record
  - Chapter 13 Performance Metrics Standards
    - Eg. To compute MTBF

- ASD Strategic Standardization Group (SSG) Plan
  - Analyze Spec 2000 and prepare adjustment proposals to A4A to fit with ASD S5000F requirements

- Challenge: Input to ASD indicates that A4A is not open to adoption of AIA/ASD S-series standards
Transglobal Secure Collaboration Program (TSCP)

- **Members**: MoD’s, DoD, and A&D contractors

- **Secure E-mail Specification v1 (SE v1)**
  - Check sender/receiver for EAR and ITAR rules
  - PKI certificates for digital signature and encryption
  - Certificate Authority and cross-certification

- **Identity Federation v1 Assertion Profile (IdF v1)**
  - Security Assertion Mark-up Language (SAML) profile for A&D
  - Attributes also passed through WS-Fed Protocol

- **Communicating with OASIS PLCS TC on Information Rights Management**
Based on legacy NIST STEP Class Library
- BRL-CAD Open Source Reference Implementation
- BRL-CAD used Coverity for static code analysis to find and fix defects and security vulnerabilities

Current STEPcode functions
- Generates p22 SDAI class library in p23 C++ binding
- Compiles p21read/write executable
- Works on major EXPRESS schemas and p21 files

www.stepcode.org
- scl-dev Google group discussions on STEP
- Used by SCView: EXPRESS-G, tree & text viewer
- Github: Notepad++ plug-in for EXPRESS schemas
Conclusions

• Many complementary interoperability standards for models across domains and the life cycle
  • Need to define interfaces (map overlaps and fill gaps)
  • Need to portfolio manage collections (like LOTAR & ASD SSG)

• Technology is available, but needs investment
  • Standards development infrastructure (eg. STEPmod)
  • Share implementer forum resources and best practices
  • Tighten implement/test/feedback/modify cycle like CAX-IF
  • Need open source reference implementations
  • Sharing best practices (Validation, UIDs, Testing …)