DIGITAL ECOSYSTEM FOR ENGINEERING

Recently, there has been a lot of discussion about sharing data across the various primary engineering communities of practice (COPs), and the software tools used by them. This paper provides our perceptions of some of the various digital COP domains and the typical software tools they use. It also offers some thoughts on the subset of shared data used to synchronize across these life cycle engineering COPs.

THE PRIMARY LIFE CYCLE ENGINEERING COMMUNITIES

We would suggest there are five primary engineering COPs that perform work across the life cycle of equipment-centric systems. An integrated system-of-systems view - with an associated shared/agreed data set – between these COPs is needed to ensure not only that the equipment assets meet each customers needs, but also that the support for these systems ensures they are sustained within the tailored and correct support solutions for each customer/asset.

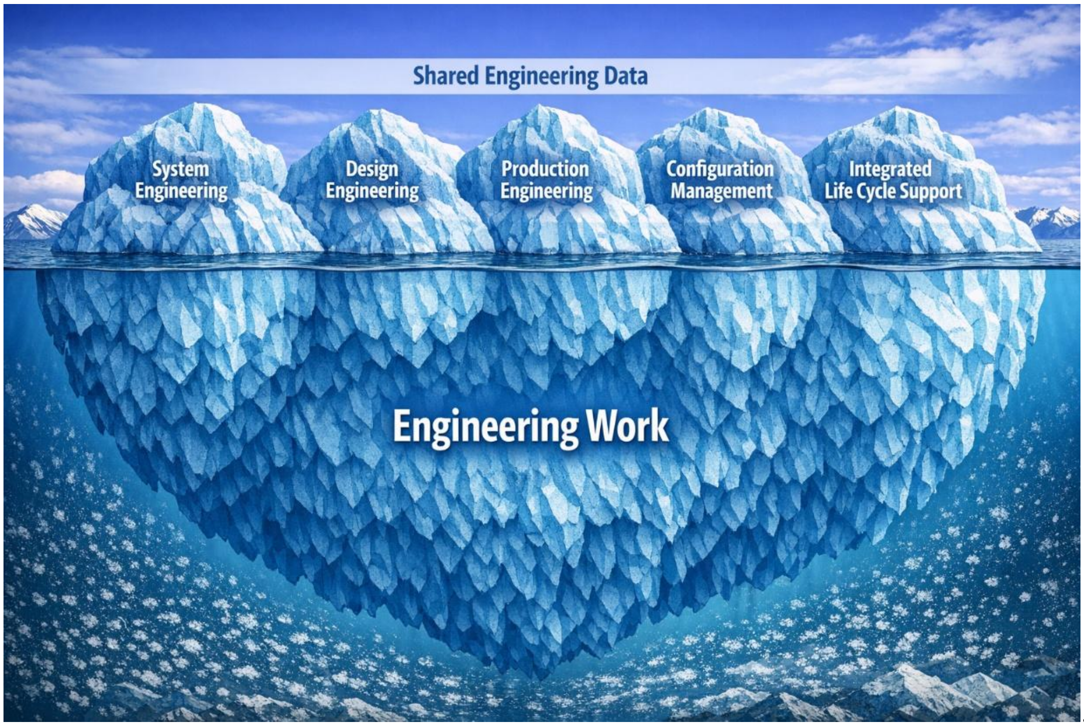
We suggest these primary life cycle engineering COPs are:

- **System Engineering** – which defines, analyzes, and manages complex systems across their lifecycle. Focuses on requirements, architecture, interfaces, and integration.
- **Design Engineering** – which develops physical or digital designs of components and systems including mechanical, electrical, and software aspects
- **Production Engineering** – which translates designs into manufacturable processes, focusing on tooling, workflows, and quality assurance
- **Configuration Management** – which controls product configuration baselines, versions, changes, and documentation across the lifecycle.
- **Integrated Life Cycle Support** – which ensures systems are supportable and maintainable throughout their lifecycle, including designing and managing support solutions encompassing a wide range of support processes and resources.

THE DIGITAL & DATA CHALLENGE

Fundamental to successful and integrated engineering of such a system-of-systems is the synchronization of common data across the whole engineering workspace, and throughout the full life cycle for each customer – from early concepts through design and build phases to in-service use and even in disposal. However, as depicted below, we need to recognize that the shared common engineering data is only the top layer of a very complex digital engineering ecosystem needed to perform and capture the work within each engineering COP.

Each COP has a wide range of software tools and data they use to complete their work, but they also rely on data originating and developed with the other COP “silos”. Each COP is a very large engineering work “thinking box” which in some respects needs to connect across to the “thinking” in other COPs.



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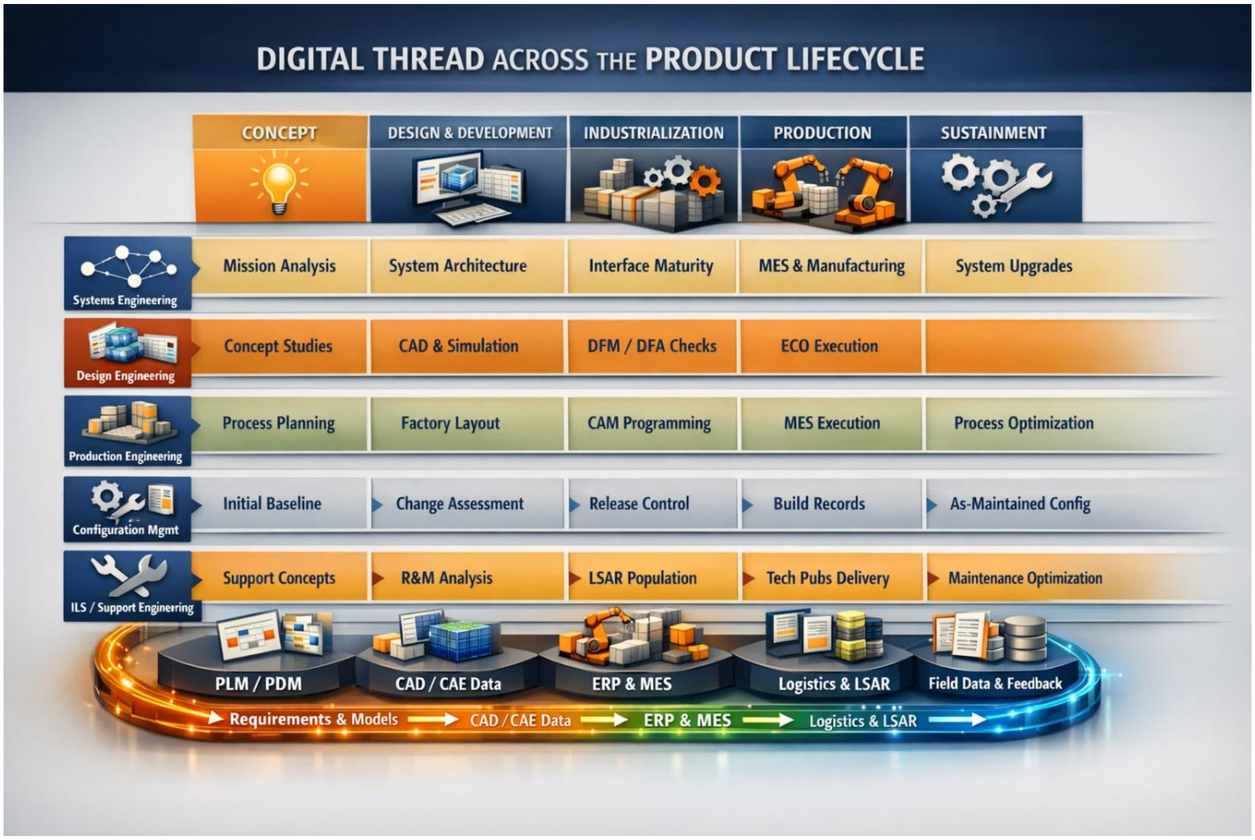
Configuration Management can and does play a key role in synchronizing common engineering data, by, for example, mapping **System Engineering** requirements, **Design Engineering** drawings and **Integrated Life Cycle Suppor**t data to a common configuration item structure and the associated evolving approved baselines.

As depicted below, across the life cycle, the work within each engineering COP should contribute to a common engineering digital thread, enabled by some of the primary types of software shown.



NOTES:

1. New acronyms are **MES** (Manufacturing Execution System), **CAD** (Computer Aided Design), **DFM** (Design for Manufacturing), **DFA** (Design for Assembly), **ECO** (Engineering Change Order), **CAM** (Computer Aided Manufacturing), **R&M** (Reliability and Maintainability), **LSAR** (Logistics Support Analysis Record), **PLM** (Product Lifecycle Management), **PDM** (Product Data Management), **CAE** (Computer Aided Engineering), **ERP** (Enterprise Resource Planning).
2. During the **Sustainment** stage, additional engineering changes may drive the recycling/reworking of engineering activity shown in earlier stages, to create and integrate digital content for any changed datasets across all engineering COPs.
3. The ILS COP should repeatedly re-optimize the holistic “support solution” during the **Sustainment** stage.

LIFE CYCLE ENGINEERING SOFTWARE ENABLERS

The table below offers a glimpse at some of the software enablers used by these five engineering COPs across the life cycle. The identified software tools should be considered indicative and do not represent a complete list. Rather, they highlight the diverse types of software tools needed to enable the work.

Engineering Area	Core Responsibilities	Typical Software Enablers
Systems Engineering	Requirements definition, system architecture, interface control, verification & validation, lifecycle governance	**MBSE tools** (Cameo, Rhapsody), Requirements tools (DOORS Next, Jama), **Architecture modeling** (SysML, Simulink), **PLM** (Windchill, Teamcenter)
Design Engineering	Mechanical/electrical/software design, analysis, simulation, prototyping, design optimization	**CAD** (CATIA, NX, SolidWorks), **ECAD** (Altium, Mentor), **Simulation** (ANSYS, Abaqus), **PDM/PLM** (ENOVIA, Windchill)
Production Engineering	Manufacturing process design, tooling, factory layout, digital manufacturing, quality engineering	**MES** (Opcenter), **CAM** (NX CAM, Mastercam), **Digital manufacturing** (DELMIA, Tecnomatix), **QMS** (Minitab, PLM QMS modules)
Configuration Management	Baseline control, change management, versioning, traceability, documentation governance	**PLM CM modules** (Windchill, Teamcenter), **Version control** (Git, SVN), **Change systems** (Jira, ServiceNow), **Document control** (SharePoint)
ILS Engineering	Reliability/maintainability, supportability analysis, LSAR, technical publications, training, lifecycle cost	**R&M tools** (Reliasoft, Isograph), **LSARs** (GenS, OmegaPS, Eagle, Slicwave), **S1000D authoring** (R4i, Eagle EPS, HiCo, Arbortext, Oxygen), **MBPS tools** (Analyzer, Opus Suite), **Training systems** (Unity/Unreal, LMS platforms)

TOWARDS AN ENGINEERING SW ECOSYSTEM ARCHITECTURE

Our review suggests that a software architecture for life cycle should include the following:

1. **Engineering Shared Data Layer** - An integrating top layer to share common data created by the engineering program of work across the five COPs. This layer would be centered on:
    a. **Requirements** – tools for top-down management from effective System Engineering of requirements decomposition across and to the COPs;

synching requirements with actions/product/data produced within each COP.

   b. **Configuration Management –** tools to manage mapping to configuration items of **approved requirements, design/production engineering and ILS data**, managed as evolving baselines across the life cycle, making use of PLM and PDM tools

2. **Design Engineering Layer –** tools to enable design analyses and creation of design data, such as MBSE models, CAD designs and specifications. Some approved data is mapped into the shared data layer for each approved baseline.
3. **Production Engineering Layer -** tools to enable manufacturing analyses and creation of production data, such as CAM, MES and QMS tools. Some approved data is mapped into the shared data layer baselines.
4. **ILS Engineering Layer** - tools to enable supportability/sustainment analyses and creation of support data, such as LSAR, MBPS, Reliability, Publications authoring and Training development tools. Some approved data is mapped into the shared data layer baselines.

All of these engineering-centric layers are enabled by the associated:

1. **Enterprise Integration Layer** – tools to enable integration of engineering data with other enterprise software, such as API and interface tools. These may interface from the shared data layer as well as directly from the other engineering layers. They may integrate within a single enterprise/organization, or out to related enterprises who are stakeholders in the equipment system-of-systems across the life cycle.
2. **Enterprise Resource Planning Layer** – tools that use engineering data to execute enterprise activities and provide feedback data across the life cycle, such as ERP and maintenance/inventory management tools.
3. **User Interaction Layer** – tools that enable and simplify user interactions, such as web portals, visualizations and workflow dashboards.

CONCLUSION

We have tried to present a picture of the overall engineering digital ecosystem, centred on five primary engineering COPs within a life cycle equipment system-of-systems. As shown, there are a very broad range of software enablers and of engineering data objects that enable and define the overall ecosystem.

In many cases, the limited shared data layer is only mapping and representing a small portion of the overall ecosystem dataset, with most of the data held within the separate COPs as they analyze, develop and eventually share approved data objects. Thus, the shared data layer is primarily a ***presentation*** of data objects ***sourced from the COPs***.

However, the mapping of the diverse approved data objects to a set of agreed common configuration baselines is a critical component of effective engineering integration. These baselines will evolve across the life cycle.

Peeking out of our COP “silos” to understand the related engineering activities and the data sources should help create a more integrated engineering effort, and a more accurate related digital ecosystem.

SUPPORTING INFORMATION

Some supporting information is shown below

EXAMPLE SOFTWARE BY TYPE

- - IBM DOORS Next, Jama Connect, Polarion – Requirements Management
- - Cameo Systems Modeler, Rhapsody, Enterprise Architect – MBSE Tools
- - SolidWorks, CATIA, NX, Creo – CAD Tools
- - Altium Designer, Mentor Graphics, Zuken – Electrical Design
- - ANSYS, Abaqus, MATLAB/Simulink – Simulation & Analysis
- - PTC Windchill, Siemens Teamcenter, ENOVIA – PLM/PDM Systems
- - Siemens Opcenter, Rockwell FactoryTalk – MES
- - Mastercam, NX CAM, CATIA DELMIA – CAM & Digital Manufacturing
- - Tecnomatix, FlexSim – Process Simulation
- - Minitab – Quality Management
- - Git, Subversion, ClearCase – Version Control
- - Jira, ServiceNow – Change Management
- - SharePoint, OpenText – Document Control
- - Reliasoft, Isograph – Reliability & Maintainability
- - GenS, OmegaPS, Eagle, Slicwave – LSAR Database
- - R4i, EPS, HiCo, Arbortext, Oxygen XML – S1000D Authoring
- - Analyzer, Opus Suite (SIMLOX, OPUS10), SEER-H – MBPS tools and Lifecycle Cost Analysis
- - Unity, Unreal Engine – Training & Simulation