Multiple View Bill of Materials (BOM)

Problem Statement, Desired State, and Requirements

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AEROSPACE & DEFENSE PLM ACTION GROUP

Abstract

This document states a joint position of major aerospace and defense companies on the topic of Multiple View Bill of Materials (multi-view BOM). Its purpose is to provide the basis for a dialogue between the Aerospace and Defense industry and the PLM providers.

The document introduces the problem statement of the dichotomy between single BOM and multi-view BOM approaches and all their pros and cons. It introduces a set of concepts that form the basis of any BOM solution, as well as a set of use cases that any PLM system must support. Finally, it introduces a solution concept to address the pain points identified throughout the document.

While the discussions presented herein focus heavily on the engineering and manufacturing views of the BOM, the concepts apply to any additional upstream and downstream views of the BOM, such as Sales and Configuration BOM and Support and Services BOM.

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Revision Record

Release	Date	Description
2.0	February 2017	Initial Release
2.1	December 2017	Revisions in response to PLM software providers' review, reorganization of content, and expansion of Introduction and Desired State sections.
3.0	January 2019	Major reorganization of content; addition of sub-project content including preliminary requirements; new *Effectivity* sections; addition of use case classification. Addition of *Appendix A: Glossary* (separate document) and *Appendix B: Concept Definition and Use Cases* (separate technical document for subject matter experts).

Multiple View Bill of Materials (BOM)

Introduction

Over the past few years, a new conversation has been taking place within the aerospace and defense community arising from a growing recognition that certain persistent pain points – points of friction, complexity, or instability – are common across the industry. Those pain points ultimately erode the productivity and quality of product information flow through aircraft and defense systems programs and inflate the cost of systems sustainment.

In March 2016, executives from the Aerospace and Defense PLM Action Group (AD PAG) member companies – Airbus, Boeing, Embraer, Gulfstream, and Rolls-Royce – met with the intent that informal discussions of PLM-related issues would lead to agreement on common objectives, requirements, and plans for remediation of their common PLM pain points.

Since the project's inception, AD PAG membership has increased from five to eleven Original Equipment Manufacturers (OEMs), and the project team has added subject matter experts (SMEs) from Bombardier, Dassault Aviation, GE Aviation, and Safran. The team invited participation from their supply chain, and the project team now includes SMEs from the following major Tier 1 suppliers: FACC, Latécoère, Saab, Spirit AeroSystems, and Triumph. Six of the major PLM software providers have also been heavily engaged by the team in formal review and information exchange sessions.

This discussion resulted in agreement of the member executives to jointly sponsor and staff a select set of projects, each chartered to define objectives, requirements, and roadmaps for eliminating or significantly reducing a key inhibitor to the value potential of PLM. The topic addressed by this particular special project is **Multiple View Bill of Materials (Multi-View BOM)**.

The scope of the team's activity was to compare and contrast single and multi-view BOM, and to agree on a set of standard solution constructs to address the complexities of multi-view BOM while enabling its benefits. Participants and themes from the team's first workshop in early 2017 are shown in Figure 1.

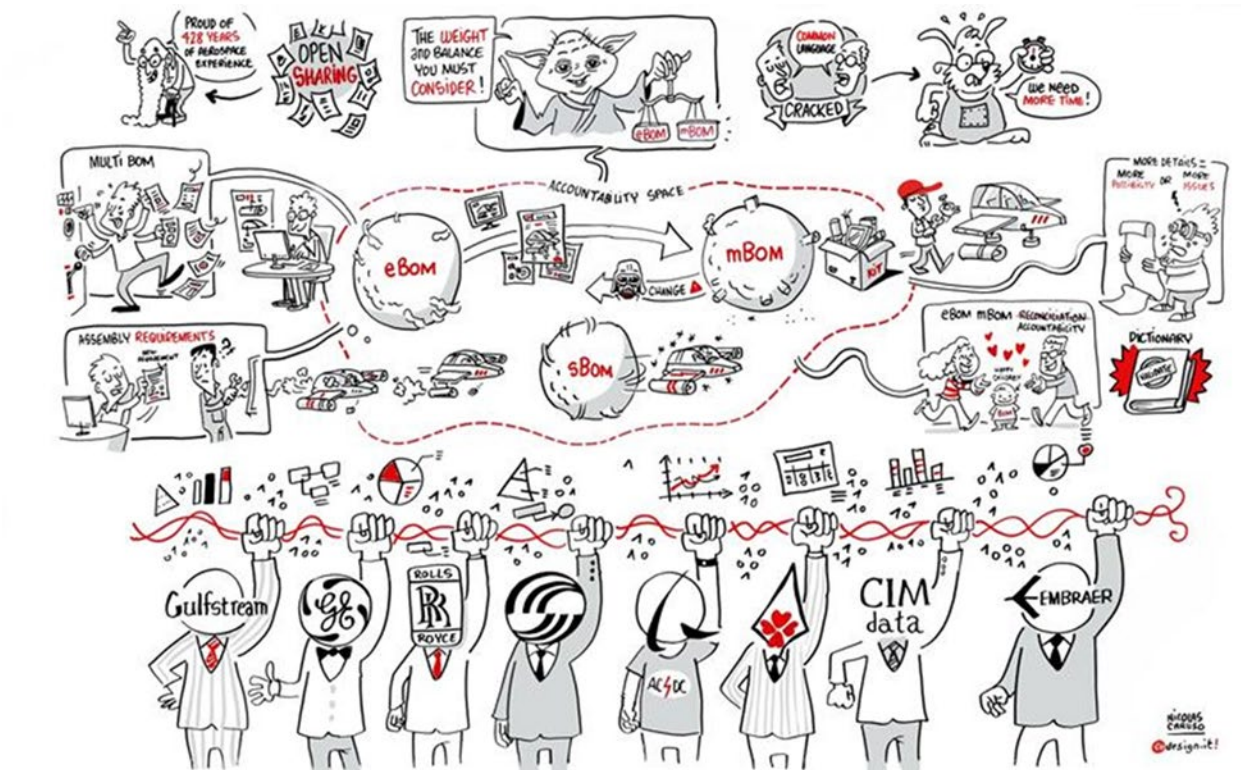

Figure 1 – AD PLM Action Group Multi-View BOM Project Workshop Participants and Themes

This document presents a set of solution concepts for multi-view BOM along with the business context within which the concepts were derived. First, the problem is described, including a characterization of the current negative business impacts. Within this context, business improvement objectives and a set of solution concepts are put forth. This is followed by the team's go forward plan for broadening the contributing industry perspectives, detailing the solution concepts, defining use cases, and deriving requirements. The final section lays out the response requested of the PLM software providers and other relevant entities within the PLM ecosystem.

While the discussion in this document focuses on the Engineering BOM (EBOM) and Manufacturing BOM (MBOM) as the prime multi-view BOM examples, these same concepts apply to any additional upstream and downstream views of the BOM, such as Sales and Configuration BOM Support and Services BOM, etc.

Motivation for the Research

The motivation of the AD PLM Action Group members who are investing in this project work stream is to reduce the pain associated with managing and reusing data in long lifecycle products by defining and adopting industry standards and best practices and avoiding systematic PLM customizations.

The overall goal of this project is to define a desired future state, business improvement objectives, and a set of derived requirements for PLM solution providers that, if implemented, will give each value stream segment owner **custody of the configuration** for which they are responsible, as well as provide a systemic solution between those value stream segments that enables the configuration control requirements of the business.

Purpose of this Document

The intent of this document is to provide the basis for productive dialogue within the AD PLM community. Initial distribution was to a select set of PLM software providers with a request for response and support. However, this was only the first in what was, and will be, a series of position papers that address the topic in ever increasing detail, ultimately resulting in a detailed requirements statement. Through this progression, it is the intent of the AD PAG members to engage the broader PLM community in dialogue.

As project work progresses from problem statement and analysis of current state to definition of desired state and requirements by which that state can be achieved, dialogue with the PLM community will shift from collaboration on solution definition to agreement on requirements and protocols for achieving adoption and compliance.

Note on Authorship and Endorsement

This document represents the work of a project team staffed with SMEs from all AD PAG members and invited Tier 1 suppliers. The content reflects the consensus of member companies with continuing engagements planned to expand the collaboration across the Tier 1 suppliers. Regardless of their level of contribution, member endorsement indicates strong support and agreement with the main points in the problem description, objectives, and solution concepts.

Note About Appendices

The depth of content included in this position paper has been limited to facilitate understanding the main concepts and logical flow that binds them. More detailed description and elaboration of important subject areas have been addressed in separate documents. Those documents are associated with this position paper as Appendices A and B.

Appendix A, a separate document associated with this position paper, is a glossary of terms prepared with strong reliance on publications such as EIA-649, EIA-836, and ATA Spec 2000 and contains precise definitions, the source (in case it was directly adopted or based on a different publication), and a list of synonyms. The goal of the *Glossary* is to support effective communication throughout the A&D industry, as well as be incorporated into future PLM provider offerings and documentation. The *Glossary* will be enhanced to include future subjects and planned updates to the position paper.

Appendix B: Concept Definition and Use Cases, intended for SMEs, is a separate technical document that addresses complex topics and includes numerous diagrams related to the multi-view BOM.

Related Standards

The following publications are recommended reading to gain a thorough understanding of this position paper.

- EIA-649 - *National Consensus Standard for Configuration Management*
- EIA 836 - *Configuration Management Data Exchange and Interoperability*
- ISO 10007:2017 - *Quality management – Guidelines for configuration management*
- CMII-100 - *CMII/IPE Standard for Configuration Management and Integrated Process Management*

Problem Statement

This section introduces the current environment and the complexities and added cost that surface in BOM management.

Context

Many A&D companies or aircraft programs are based on a Design As-Built methodology for the design process. They manage a single representation of the BOM controlled by the engineering design department.

As programs mature from product development, manufacturing priorities take center stage and demand adjustments to the BOM. The constraint of a single BOM forces non-FFF (form / fit / function) changes like work movement in manufacturing or manufacturing process optimization back to the engineering department for implementation.

Other A&D companies or A/C programs are based on a “Design” methodology for the design process to manage a specific representation of the BOM controlled by the engineering design department, with reduced common breakdown with manufacturing activities.

Most A&D companies have deployed PLM solutions for design and manufacturing that are unique. There may be different solutions supplied by the same PLM provider or different solutions supplied by different PLM providers.

Today’s PLM tools allow for multiple views of the BOM and product structures but require reconciliation and complex consumption methods to demonstrate regulatory compliance. Reconciliation mappings are often duplicated, even when most reconciled elements haven't changed, requiring substantial cost to maintain.

Complex manufacturing operations have multiple use cases (e.g., multi-site manufacturing, traveled work, non-conformance, supplier assist, etc.) where reconciliation adds cost.

The complexity surrounding management of multi-view BOM increases with compounding restructuring use cases (refer to the BOM Restructuring section for more details on those restructuring use cases). Managing an alternate part is simple, but when the alternate is used in a manufacturing-only super set assembly with an effectivity start in the middle of the effectivity block of the corresponding engineering definition, the complexity is beyond the capability of today’s commercial PLM solutions.

The core of the issue is that no PLM solution offers any out-of-the-box capability or best practice for managing accountability between BOM structures. That complexity is left to the individual companies to figure out and solutions are then added as customizations and reports. Most OEMs simplify the problems by restricting some of the use cases, thus forcing undue limitations on different organizations (such as forcing a single As-Designed As-Planned structure).

The multi-view BOM concept must facilitate a consistent representation of the same product across its lifecycle, for example, from Design Engineering to Manufacturing Engineering, Procurement, Certification, and post production services.

This concept allows each discipline to have its own references and attributes (common or specific) consistent with upstream or downstream activities to facilitate production.

Current State Comparison Between Single and Dual BOM

This section addresses the BOM concepts, describes the single and dual BOM shared concept, and provides a comparison of single and dual BOM.

Definition of BOM Concepts

The single BOM approach is where the Engineering (As-Designed) BOM is used directly for manufacturing (As-Planned), with corresponding BOM item additions made to support manufacturing and logistic support. This approach is used by Airbus and Embraer.

The dual BOM approach is where the Engineering (As-Designed) BOM is separately reorganized for manufacturing (As-Planned). This approach is used by Boeing, Gulfstream, and Rolls-Royce.

These two approaches are illustrated in Figure 2.

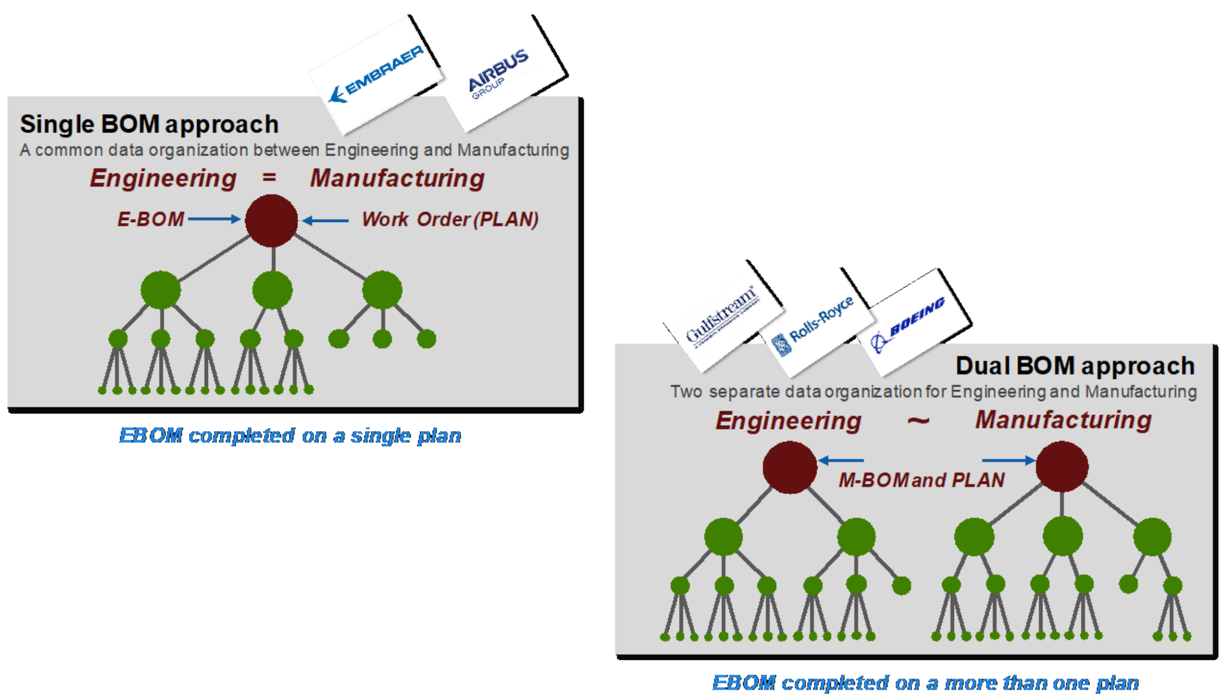

Figure 2 – Single and Dual BOM Approaches

Single BOM

In a single BOM approach, engineering and manufacturing departments need to come to a consensus on a common breakdown of the product structure that cannot be deviated from for the life of the product. Airbus and Embraer apply the As-Designed As-Planned Configuration Item (ADAP-CI) concept, which is an agreed invariant element between manufacturing and engineering. For example, an ADAP-CI could be Installation of the Door as shown in Figure 3.

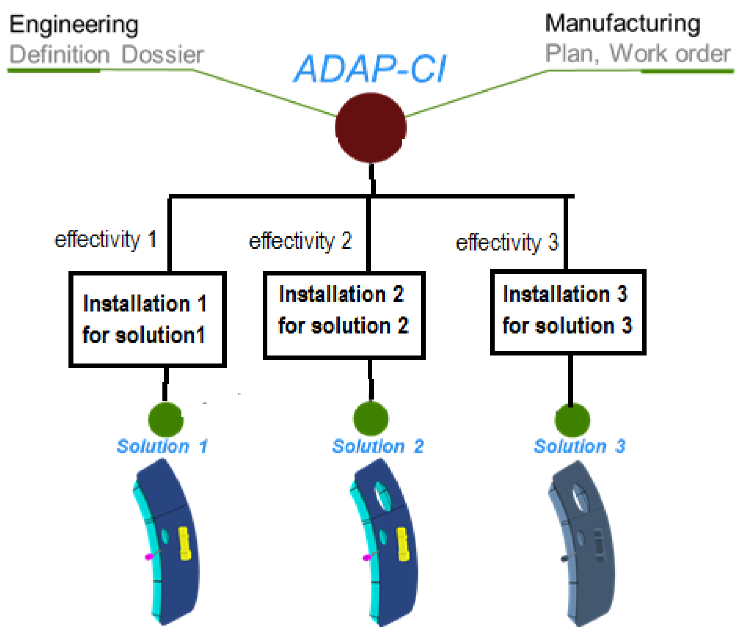

Figure 3 – ADAP-CI Installation of the Door Example

Dual BOM

In a Dual BOM approach, two separate BOM structures satisfy the needs of the organizations that manage them. While engineering organizes the data mainly to facilitate design reuse, manufacturing focuses more on factory optimization. What is crucial is that, at the end, every design element and requirement defined in engineering is accounted for in manufacturing. Boeing employs multiple methods to enforce accountability of this allocation, which will be described further in this paper.

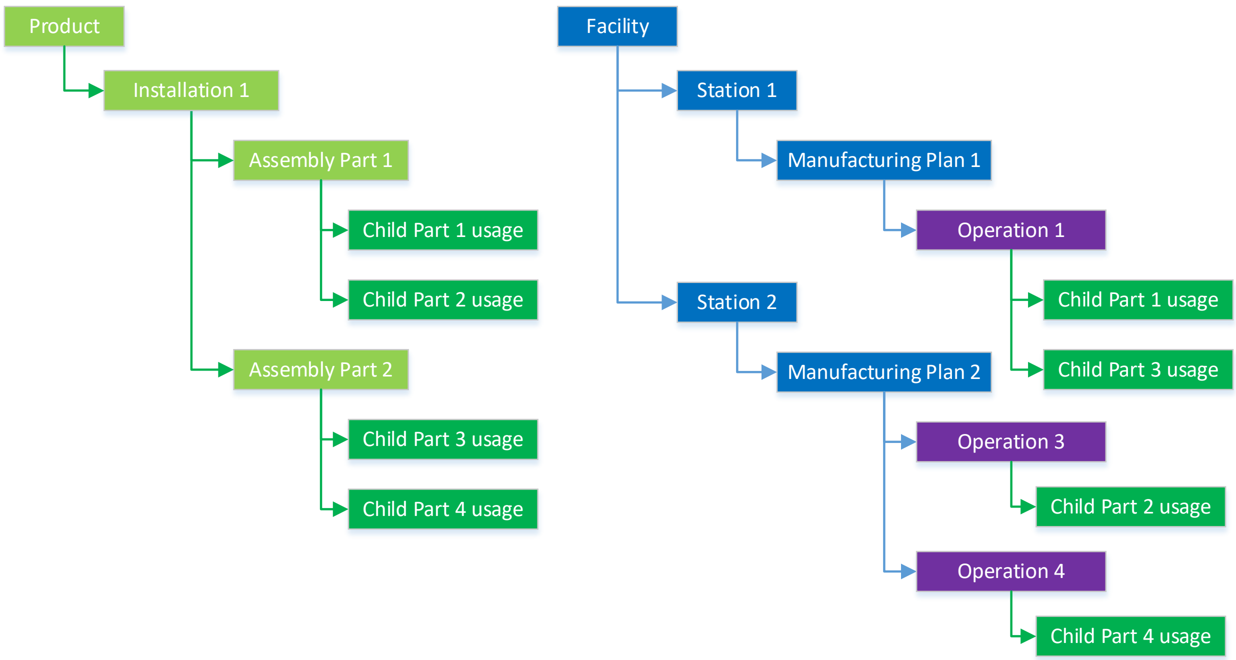

Figure 4 – Dual BOM Example

Shared Concept

The main concept shared between single BOM and dual BOM is effectivity management. In both single and dual BOM scenarios, different layers of effectivity need to be managed, as shown in Figure 4. For example, at Boeing and Dassault Aviation, manufacturing effectivity is different from engineering effectivity. The Airbus, Embraer, and Bombardier work practice is that MBOM effectivity is derived from EBOM effectivity.

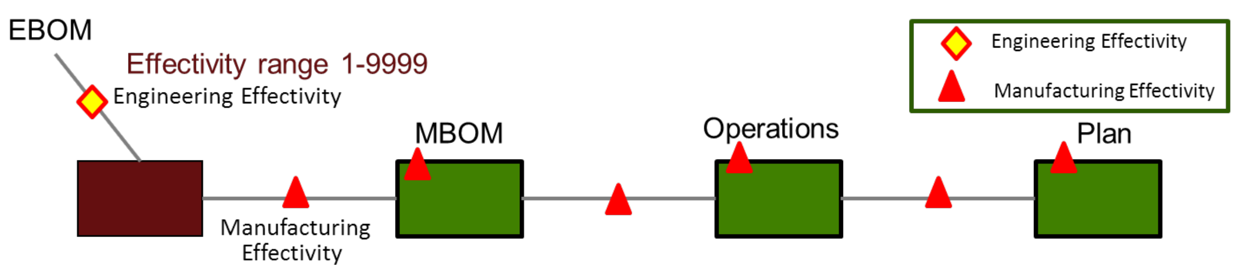

Figure 5 – Engineering vs. Manufacturing Effectivity

Single BOM Dual BOM Comparison

This section addresses single and dual BOM comparison in greater detail by highlighting the advantages and complexities of each approach. Both of those approaches are available using COTS solutions.

Single BOM

Advantages

Conformity—As data are in the same organization from end to end, the conformity and traceability of the deliverable product is done easily.

Communication—Easy communication between engineering and manufacturing is an enabler for task scheduling between both organizations, including across the extended enterprise.

The Complexity

Rigidity—Any change in manufacturing organization requires an update in Engineering. For example, if an equipped pipe has to be installed in another plant to optimize the physical installation, this change (that doesn't change the definition of the aircraft) creates an update to the engineering definition including a Computer-Aided Design/Digital MockUp (CAD/DMU) update in Engineering with all the cost linked to re-release and distribution.

Commitment—To reach a common data organization, the route is long and difficult. This process of committing to a single BOM must be run at each program start or each data reorganization.

Dual BOM

Advantages

Flexibility/Stability—Rapid response is possible for moving parts between work orders to support factory build sequence changes. Dual BOM also isolates the engineering design to define only the fly-away view without requiring interim assemblies.

Simplicity—Organizations downstream of Engineering can use simple change types to optimize manufacturing without impacting the engineering change process.

The Complexity

Configuration Management and Reconciliation—Each type of BOM restructuring requires **extensive** process and tool development to ensure conformity back to the engineering design. ***This complexity is the key business driver for this position paper.***

Integration—Costly integration and PLM tailoring is required to reconcile the Engineering BOM and the Manufacturing BOM

- PLM systems and work processes must be tailored to manage each BOM restructuring type.
- Internal and external supplier systems must be tailored to manage the manufacturing unique processes and data feeds.
- Once created it is very difficult to adapt to new business models.

- With Dual BOM, the internal solution does not integrate with supplier systems.

Opposing Forces

Figure 6 illustrates the opposing forces inherent in a choice between single or dual BOM. This condition leads one to question: Are there any other choices? Is there another model?

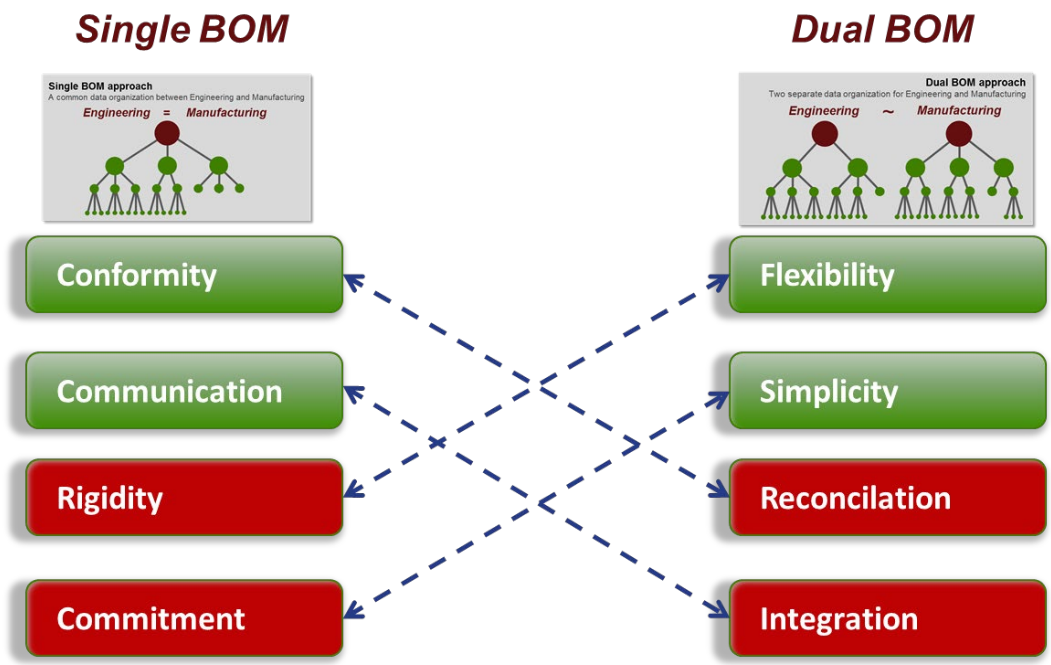

Figure 6 – Single vs. Dual BOM Comparison Illustrating Opposing Forces

Effectivity Schemas

Effectivity management is an area with little standardization among OEMs and suppliers. In most of these companies, current state-of-the-art is to rely mainly on the implementation of an effectivity matrix to link different effectivity schemas used along the entire product lifecycle.

In the following example, OEMs use different effectivity schemas to drive the product definition, depending on the product lifecycle, from the customer requirements to the support and services definition. In addition, effectivity schemas may also differ if used to configure standard features, such as airframe definition, or to configure catalog options and specific customizations, such as the cabin layout.

Effectivity schemas may be completely different from one OEM to another, as illustrated in Table 1. Please refer to *Appendix A: Glossary* (separate document) and the *Key Concepts* section of this position paper for terminology definitions.

Table 1 – Effectivity Schemas and BOM Domains

	Context	Customer definition	Engineering definition	Industrial definition	Support and services definition
OEM 1	Standard configuration	Product Identification Number	Product Identification Number	Production Sequence Number	Product Identification Number
	Option and Customized configuration	Customer Version	Customer Version	Production Sequence Number	Customer Version
OEM 2	Standard configuration	Customer Version	Production Sequence Number	Production Sequence Number	Production Sequence Number
	Option and Customized configuration	Customer Version	Production Sequence Number	Production Sequence Number	Production Sequence Number

These different schemas add complexity to BOM restructuring described in this position paper's *BOM Restructuring* section. This complexity is further increased in the case of outsourcing, where Design and Build or Build to Print suppliers may not use effectivity schemas in the same way as the OEM.

In Table 2, a stream of OEM units is mapped to different component units manufactured by different suppliers. Engines on an aircraft is a typical example.

Table 2 - Effectivity Mapping Between an OEM and Suppliers

OEM 1	Supplier A	Supplier B
Effectivity by Aircraft Identification Number	Effectivity by OEM 1 Production Sequence Number	Effectivity by Supplier B Production Sequence Number
101	107	-
102	099	-
103	-	801
104	102	-
105	-	802
106	-	803

Business Consequences

The increasing cost and complexity of implementing each new generation of PLM is the driving force for the aerospace industry to consolidate common BOM management practices and functionality. Instead of decreasing, the costs, time, and complexity of deploying PLM platforms are **increasing** with subsequent PLM generations.

This is mainly due to the fact that the growing flexibility provided by PLM platforms is not matched by a similar improvement in accountability methods, leaving the burden of ensuring the consistency between BOM structures to end-users. This in turn increases the need for customizations that are not based on any industry standard or best practice.

Business Improvement Objectives

As noted, in a single BOM approach, engineering and manufacturing organizations come to a consensus on a common breakdown of the product structure that cannot be easily deviated from for the life of the product. In the dual BOM approach, the Engineering BOM is separately reorganized for manufacturing. The complexity of both approaches is driving the AD PAG's need to examine the multi-view BOM. The expected outcome of this multi-view BOM project work is to:

- Create an industry-accepted foundation of multi-view BOM capabilities that would allow all companies to use multi-view BOM best practices and standards that are 100% understood, accepted, and supported by PLM.

- Get PLM systems' capabilities to facilitate the management of BOM data across each organization and process with 100% completeness and accountability.
- Ensure that each company has the ability to select various levels of PLM multi-view BOM capability to fit their internal business requirements, using the customization settings within PLM.
- Have zero PLM customization (settings only) to support multi-view BOM; avoid having extensive internally developed processes and system customizations unique to each company.

Key Concepts

The following key concepts are necessary to have an understanding of the desired PLM system behavior for managing objects, attributes, and relationships.

Multi-View BOM Accountability

Multi-view BOM is a process that allows separate BOM structures to be derived from an authority BOM (typically EBOM) with a degree of revision independence. This independence allows changes to be made to individual BOMs (e.g., MBOMs) by the responsible organizations if those changes do not impact the certified design (Type Design). Typically, such changes (e.g., manufacturing changes) are assembly sequencing changes, kitting, and temporary exceptions to the design that are necessary to support cost, quality, and schedule improvements in production.

Multi-view BOM accountability is a process that ensures equivalency between an authority BOM and one or more of its associated derivative BOMs. Accountability is driven by governmental regulations that require manufacturers to have quality management systems in place for the business to achieve production certificates. When manufacturing deviations are defined in the BOM, items such as manufacturing only assemblies, alternate parts, and other manufacturing deviations make the accountability process more complicated. Typically, there are combinations of process and system controls to ensure BOM accountability and to manage the allowed deviations between the authority BOM and any of its derivative BOMs. These deviations are classified as BOM restructuring types.

Effectivity

Effectivity management is an extensive topic that has deep implications in any BOM approach. It defines the validity of a specific component within a product configuration based on several criteria (listed below). It is used to drive product configuration (airframe, systems, etc.) while keeping coherency of baseline requirements to what is requested by the customer and what is defined, manufactured, certified, and delivered during the product's life in service.

As such, effectivity supports:

- **Customer definition,** based on selections of standard features and catalog options offered by the manufacturer and specific customizations requested by the customer.

- **Engineering definition**, such as airframe definition, which covers product description to fulfill regulatory and customer requirements, and systems definition, which ensures aircraft systems coherency and their integration with the airframe definition.
- **Industrial definition** from each produced and installed assembly or section up to the final manufactured product.
- **Support and services definition** and associated products, such as operational and maintenance documentation, spares, interchangeability, service bulletins, and ground support items.

Currently no International Standard or aircraft industry best practice exists to define common effectivity schemas. In addition, effectivity is usually managed and expressed in different ways due to the particular needs to consolidate each above–mentioned definition along the lifecycle. However, effectivity definition is generally based on the following concepts:

- Product family (linked with Type Certificate)
- Product model (covering commercial aspects and based on major aircraft options, such as extended fuselage, important systems change, etc.)
- Product standard definition (“baseline” definition regardless of customer)
- Product identification number (in the case of an airplane, that would be the Airplane Identification Number or AIN)
- Production sequence number (order in which the product goes through the final assembly)
- Customer configuration identification
- Options (offered by the OEM for customers and further customizations for specific customer requests)
- Product batch (for industrial purposes)
- Date
- Service bulletins (to integrate in-service modifications)
- Waivers/Deviations (for out of sequence changes in production)

Those effectivity definitions can be applied at different levels and views of the product structure:

- Aircraft (top level product)
- System (generally considered for coherency of systems at aircraft level)
- Component (to enable component definitions independent of top level configuration context)

There are also different ways of defining sets of configurations, which is how reuse is achieved for a single component definition across multiple product configurations. Those are typically:

- Discrete lists (5,6,7,9,10,15) – number designates any kind of effectivity definition above, not necessarily product identification number or production sequence number.
- Intervals (5-15) – can also be defined by implementation point (5) with a superseding next version (16).

Moreover, those effectivity definitions are often confined into specific product definitions. For example, option-based effectivity could be specified in the engineering definition but not necessarily in the manufacturing definition. What is important is that no matter which effectivity schemas are defined in which product definition, they need to be reconciled so that the different product definitions are consistent with each other.

Manufacturing Planning

Manufacturing planning is performed when a manufacturing engineer assigns the parts, engineering specifications, requirements, and notes from an Installation EBOM to one or many manufacturing plans in the production sequence. Each job or manufacturing plan is then performed independently over time within the assembly line. Installations introduce EBOM/MBOM configuration complexity because each part and process becomes part of the end item as they are installed. There is no interim EBOM definition of an installation that can be inspected. **This limits the physical factory inspection processes to only inspecting the parts within the MBOM of the plan relative to the EBOM**.

Each plan is inspected incrementally as a manufacturing package of work. This is necessary because of the gaps in time and flow in the build process from the time the first part or process of the installation design is started to when the last part or process of the installation design is completed in the assembly line.

As the inspection activities are done incrementally along the manufacturing stages, the As-Planned and As-Built accountability process is how the A&D industry proves each plan is the correct configuration and that the sum of all the plans' MBOMs are equal to the EBOM at the end of production. This is the key to allowing incremental inspection of installation designs so when all work instructions are complete, it is recognized that the As-Built configuration is equivalent to the As-Designed.

When the MBOM projects the EBOM across a large time phased production flow, accountability becomes very difficult if the accountability must be defined from the complete manufactured product backwards into the EBOM.

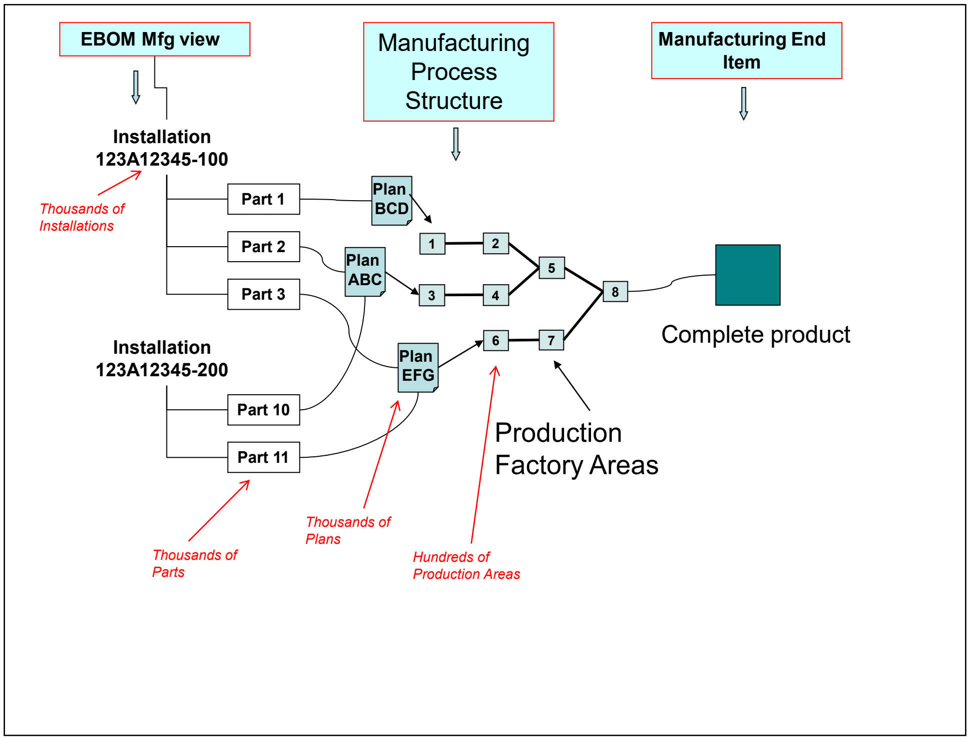

Figure 7 – Installations Completed Incrementally Over Time

Allocation Map

An allocation map is a data structure enforcing a set of rules that evaluates the EBOM authority effectivity and ensures that manufacturing effectivity changes are always within the authority effectivity. Accountability rules also cover effectivity, quantity, substitute and optional parts checks, and manufacturing-only changes to ensure compliance between the authoring BOM (e.g., EBOM) and the downstream BOM (e.g., MBOM).

Change Actions

Change actions fulfill a role that is similar to allocation maps. Unlike a persistent map that manages the entire structure at all times, change actions only manage changes to authority and downstream structures. Any change action performed on the authority structure produces a set of actions that need to be performed on downstream structures to account for upstream changes.

Change actions can be linked directly to effectivity that is then applied to all affected objects. Change actions specific to downstream structures only cannot affect the relationships to the authority structure.

Configuration Control Zones (CCZ)

Please refer to *Appendix A: Glossary* (separate document) for terms definitions.

The configuration control zone (CCZ) concept is intended to facilitate the understanding of business rules embedded within the computing technology to manage configured items. This is achieved by establishing system-controlled business rules specific to a configuration control zone that must be fulfilled prior to a state change of an object. These business rules are where **system enforced accountability rules can be created downstream of the EBOM**. Figure 8 presents the elements and relationships between elements that define the Configuration Control Zone concept.

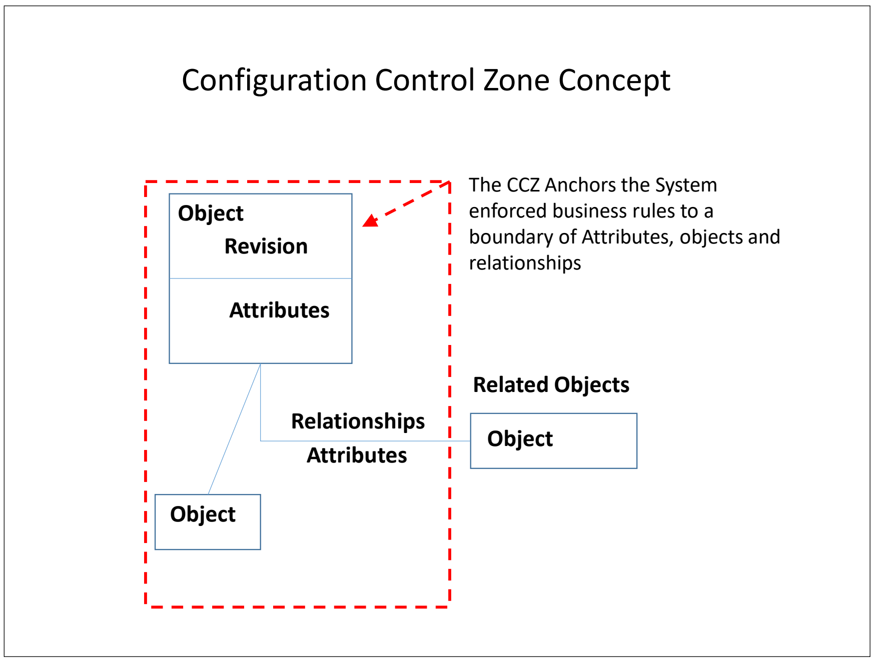

Figure 8 – Configuration Control Zone (CCZ) Elements and Relationships

In Figure 8, the CCZ is the boundary within which the business and computing technology define the configuration management rules that are system enforced.

A more specific example (in Figure 9) would be that of an assembly, with its component parts and a standard library of work instructions that are referenced by it.

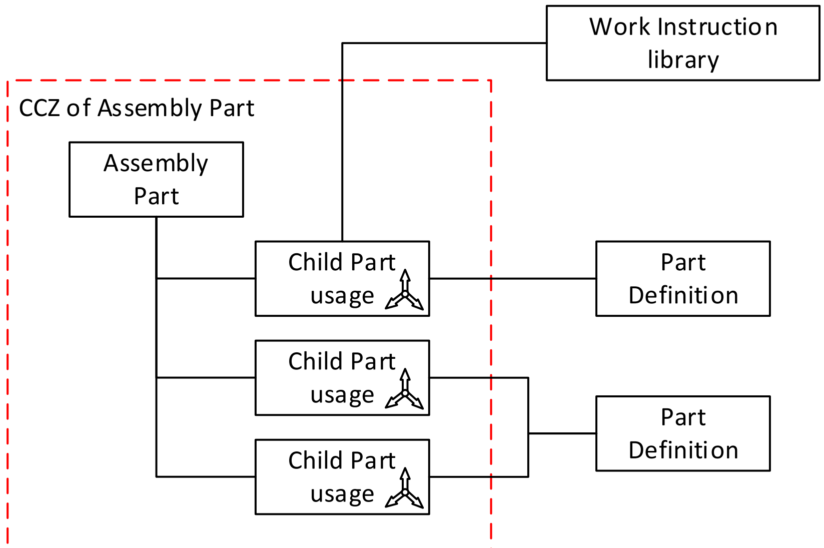

Figure 9 – Specific Configuration Control Zone Example

In this example, an assembly part owns the position of its children but not their definitions. In other words, to revise the position of a child, the assembly part needs to be revised because the lifecycle of the child part usages is tied to the lifecycle of the parent assembly. To revise the definition of the part within the assembly though, both the assembly and the part definition need to be revised (the usage needs to be revised in order to point to the revised definition). The same applies to the Work Instruction library that is shared across many different engineering elements. Hence, its lifecycle is managed outside of the assembly part's CCZ.

The computing technology that manages configured items also:

- Defines the user-selected actions for completeness checks and quality checks prior to a state change or approval
- Defines the automated system enforced rules:
  - Rules that prevent state changes if not correct
  - Rules that trigger downstream processes and interfaces

BOM Restructuring

BOM restructuring is a computing system capability that controls the allowable BOM deviations with configuration accountability. This capability ensures that when a downstream BOM is approved, the system enforces the equivalency automatically and minimizes the need for additional (manual or process driven) accountability checks. It is viewed as a critical component in the overall quality management system that a PLM system must facilitate because it builds accountability into the process automatically as each downstream BOM (as well as all changes applied to it) is approved, rather than relying on users to run reports or system-generated error messages after the BOM has been released. Corrections are difficult and time consuming and can involve disassembly, rework, and/or document effectivity revisions.

The following table is a classification of all the identified restructuring use cases that the PLM system shall handle.

Table 3 - Restructuring Use Cases / Scenarios

Restructuring Class	Restructuring Type
Cardinality	• Merge • Split
Hierarchy	• Make on assembly (layer removal) • Manufacturing assembly (layer addition) – Subset vs. superset – Part number controlled vs. configured
Alternate	• Cardinality: 1-1 vs. 1-N • Usage based vs. definition based
Condition of supply	• Part definition replacement • Kitting and end items

For the following text, "parts" shall be considered as any physical item installed on aircraft, such as a mechanical part, a sheet metal part, a harness, a fastener, a composite part, equipment, and software.

Merge

Merging occurs when two or more engineering definitions (EBOM) are consumed in a single manufacturing plan (MBOM).

Split Design Restructure

A split design restructure is the simplest and most common of all restructures. This is when the EBOM is consumed by more than one manufacturing plan (MBOM).

A special case of a split design restructure is when the items assigned to different manufacturing plans are sub-quantities of a multiuse part or, in other words, instances of the same part definition. This complicates matters, since many PLM systems' BOMs (including some modern ones) are still quantity based with very loose mapping to instance-based CAD systems.

In an instance-based quantity split, it is easy to split quantities of the same part, since each instance of that part is managed as a separate entity. When an engineering change replaces or changes a specific instance, there is no ambiguity about which plan is affected.

It is crucial that for each unit number:

- The part counts between the EBOM and the MBOM are equal at release time
- The part counts remain equal at all times after release[1]

The second bullet item is just as important as the first. Basically, it states that once a design and its manufacturing consumption are released, the system continues to ensure accountability between the two–EBOM and MBOM.

PLM systems have struggled to provide out-of-the-box capability to account for all the deviations in the MBOM when the deviation splits a single EBOM entry into multiple manufacturing BOM items. Quantity splits are good examples of the issue. This is also where judiciously designed CCZ boundaries can become a huge enabler by building the accountability into the foundation layer instead of into reports that rely on a skilled user to interpret, identify, and correct.

Make On Assembly (MOA) Restructure

In most cases, installed parts are called out in the BOM through direct used-on relationships to the installation. Situations exist when an assembly is built at installation time for various reasons, such as when a better fit can be achieved on installation, or when assembly and fabrication steps can be effectively combined.

Very often, manufacturing assemblies and MOAs are both generically referred to as *phantom assemblies*. The difference is that manufacturing assemblies only exist in the MBOM and can be consumed as one item, while MOAs are EBOM items whose lower level components are consumed as independent parts and the assembly is not “recognized” until all the assembly components are installed. In that sense they are actually exact opposites.

This means that multi-view BOM accountability needs to be performed at a more granular level. It is no longer sufficient to ensure that all parts and assemblies directly used on the installation are accounted for, because a portion of an assembly fabricated at installation time might be missing.

Manufacturing Assembly

A manufacturing assembly defines a set of parts that is independently authored in the manufacturing definition. Typically, this is a condition where the deviation from Engineering prevents the use of the engineering part number because the assembly is not “100% per engineering.” To optimize final product assembly, the manufacturing assembly is typically assembled in a back-shop and then consumed into the production line where the exceptions that created the need for the manufacturing-only assembly are accounted for and the product can be completed to original engineering assembly definition.

There are several types of manufacturing assemblies:

- **Subset vs. superset** – a subset manufacturing assembly is composed of elements from a single engineering definition, whereas a superset can contain elements originating from separate engineering definitions. The superset becomes particularly complex to manage when the engineering definitions containing the components have different effectivity.

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[1] This rule excludes MOAs, which don’t exist physically, and manufacturing assemblies, which are not in the EBOM.

- **Part number controlled vs. configured** – A part number-controlled manufacturing assembly has a defined parts list everywhere it is used, whereas a configured one is filtered and results in a different definition based on its usage (such as AIN of parent product).

Alternate Parts

An alternate part can be defined such that it can replace the prime part defined in the engineering definition. An alternate can be defined locally (occurrence specific) or globally (all occurrences).

Condition of Supply

The condition of supply defines the state of the part as it is expected to be received from the supplier. For example, some holes could be omitted and drilled at installation time.

Desired State

The desired state is described here in two parts:

1. An overview of high-level requirements, as well as domain applications with domain-specific requirements
2. A conceptual solution

These two parts in combination present a target state and a high-level understanding of some of the barriers that must be removed from the path.

BOM Accountability

The scope of the multi-view project is focused on the definition of a robust BOM accountability process and enabling software solution that does not rely on a single BOM definition. A set of enabling characteristics apply to any set of BOM structures regardless of use case:

- Accountability is an incremental process during the in-work phase, then validated at release time and enforced forever after.
- Accountability can apply to structures with different effectivity schemas.
- Impacts to accountability are readily visible when performing any change to linked BOM structures.

Domain-Specific Accountability

The following section focuses on specific domain applications where accountability has proven to be of high interest and where it tends to be the most problematic. Each of these domains is being explored as a subproject with the goal of defining a desired state vision and establishing a set of requirements by which the vision would be achieved. This position paper will be updated from time to time as consensus is reached on additional content.

Assembly/Build Level Engineering Requirements

Engineering requirements are specifications for the manufacturing process imposed by Product Engineering and linked to the product definition. This information is typically managed in monolithic containers, such as text files or CAD documents.

This practice inhibits the ability to individually manage engineering requirements downstream after BOM restructuring, requiring some degree of manual actions to ensure their re-assignment to the proper MBOM and to guarantee their full consumption.

Examples of assembly level engineering requirements include:

- Functional tolerances re-assignment and consumption in MBOM after restructuring
- Test requirements in assembly line
- Fastener stack ups
- Sealants, shims
- Torque specifications
- Manufacturing processes linked to specific EBOM
- Manufacturing processes not linked to any specific EBOM (e.g., applicable by default to a complete Section or Aircraft Type)
- Annotations, such as general notes and flag notes
- Protections, not linked to any specific EBOM (e.g., damp-proof paints)

The following list describes a high-level vision for management of assembly-level engineering requirements.

- The PLM toolset enables computer-sensible processes to validate and measure the fulfillment of engineering requirements by manufacturing processes.
  - Ability to have a single source of truth totally shared between engineering and manufacturing for requirement definition and downstream solutions
    - Systematic tracing of requirements to consumption in downstream structures
    - Integrated library to connect requirement definition (engineering) and downstream implementation (manufacturing). Validation and verification with consistent implementation of the solution
  - Accountability of consumption of all the tasks in the right order downstream
    - Timing taken into account for manufacturing to "consume" the requirement (e.g., a hole cannot be inspected if already sealed)
  - Trace evolution of the steps from requirement definition to implementation
  - System provides instructions to properly execute engineering requirements; automated plan creation/intelligence in data to create plans
    - System-provided instructions to properly execute the requirements
    - Ability to drive engineering requirements with contextual help

    - Step-by-step wizard (Turbo Tax-like) for requirement consumption/work instruction creation. Give us the architecture so we can fill in the right information. Also assists with part accountability

- Internet of Things (IoT) is used to perform accountability between physical and virtual, quality assurance and automation.
- Machine learning is applied to adapt delivery of kits (i.e., correct grip length of rivets).

Evolving Configuration for Single Aircraft Identification Number

PLM systems typically manage the engineering configuration of a product through unit effectivity so that it is possible to resolve the latest fly-away configuration of any given physical unit. The management of interim configurations prior to the latest fly-away configuration is difficult. What is lacking is the management of the evolution of that unit and its interim configurations. This capability is necessary in many cases, such as:

- Pre-delivery changes (deviations, out-of-sequence activities, late changes)
- Post-delivery (SBOM) (repairs, service bulletins)
- Non-OEM changes
- Changes to a flight test unit aircraft (e.g., during the flight test campaign)
- Identification of interim configurations, such as “green aircraft” (e.g., for business jets)
- Identification of non-fly-away components (e.g., ferry kits, ground support equipment)

Data Exchange or Sharing with Suppliers and Partners

During the engineering design and manufacturing processes, numerous data exchanges occur between OEMs and suppliers and partners. When suppliers and partners are contracted to assist with design, it is often done within the OEM’s PLM and a data exchange is not typically required. However, if the supplier or partner is engaged to perform Design and Build for the OEM, then some form of data exchange will be required.

Common Design and Build scenarios are reflected in Figure 10.

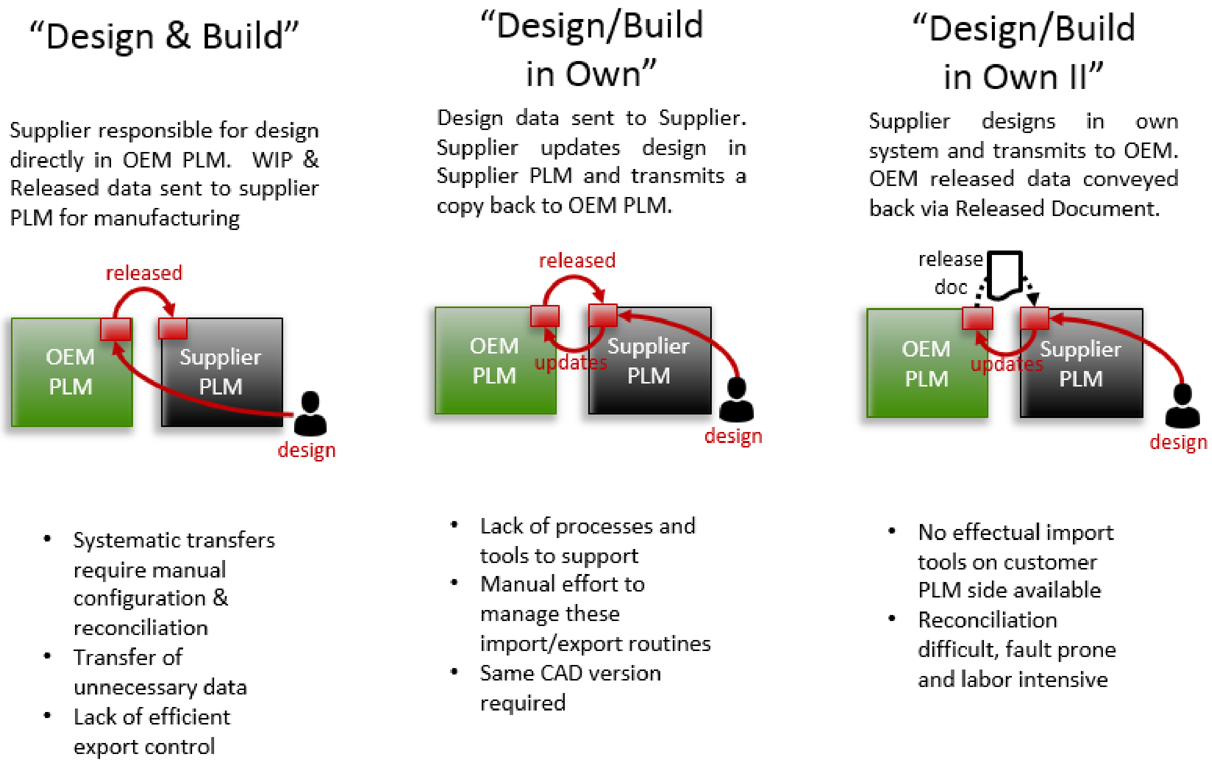

Figure 10 – Common Forms of Design and Build Data Exchange Scenarios

Each required data exchange must be individually defined due to the numerous PLM and CAD systems available, multiple versions actively used, extensive customization to those systems, and varying data formats. The data feeds often include the latest version of an entire structure as opposed to just net change.

As more and more companies convert to Model-Based Definition (MBD), the number of discrete points of data to exchange grows exponentially, only compounding the issues. This quickly becomes overwhelming for suppliers and partners to digest. The data exchange processes start to experience significant failure rates and require highly customized and/or manually intensive reconciliation processes to ensure complete consumption of the data exchanged. Because of this, suppliers and partners are required to staff dedicated specialists to maintain these data exchanges for each OEM with whom they conduct business. This results in significant cost that is ultimately transferred to the OEMs and their customers.

To mitigate data exchange issues, PLM providers commonly recommend that suppliers and partners use the same PLM system as the OEM. This is an unrealistic expectation due to the multitude of systems, versions, and the cost to implement. Suppliers and partners need to be able to run their own PLM systems and manufacturing processes regardless of the source system PLM.

The desired state is that configured BOM information be quickly, securely, and systematically exchanged within a company and between the OEM and its suppliers and partners, regardless of the PLM or Enterprise Resource Planning (ERP) software brand or

version used by each company. The ability to define these data exchanges should be intuitive to configure and any data exchange failures should be quickly identified, resolved, and reprocessed.

Conceptual Solution: Multi-View Approach

The multi-view approach, shown below, is a conceptual solution to the challenges of single/dual BOM implementations today in A&D. In this approach, all product- and manufacturing-related information is stored in a shared repository, with the appropriate view dynamically generated (or via overnight generation), throughout the product lifecycle. To enforce accuracy of views, the shared repository itself must have mechanisms that **maintain integrity** of the multi-view projections. This is where effectivity management in current PLM offerings often falls short.

This shared repository will contain all data types, such as mechanical parts, sheet metal parts, harnesses, fasteners, composite parts, equipment, software, etc.

A Configuration or Engineering View, with appropriate effectivity and level of detail, will be generated by the PLM toolset. Similarly, a Supply Chain View will be generated at point of need for the supply chain usage.

This conceptual solution would apply independently of whether a single or multiple PLM is deployed in a company.

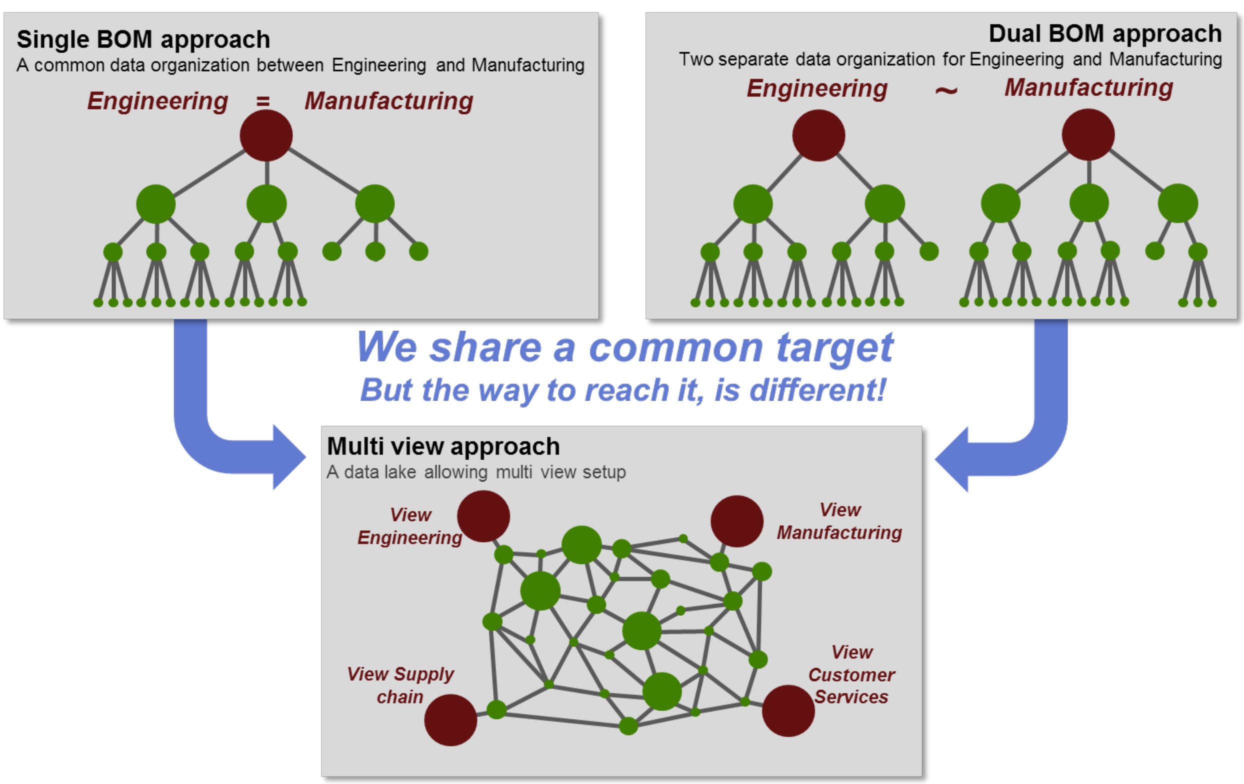

Figure 11 – Multi-View Approach

Requirements

The following requirements define the changes that shall be met to realize the desired state vision and achieve the above objectives.

BOM Accountability

Requirements that are common to all BOM accountability applications include:

1. The system shall enable accountability verification of multiple BOM structures with different effectivity schemas.
2. All restructuring scenarios defined in this document and its appendices shall be supported by the accountability process.
3. The accountability shall be validated before the BOM structures and their components are released as opposed to post-release checks.
4. After the BOM structures and their components are released their accountability shall never be invalidated. To modify the accountability between the BOM structures, one or many must be revised.
5. The system shall provide visibility of all accountability impacts linked to a change.
6. Accountability shall be incremental. If all elements of a product are accounted for, the whole product is accounted for. This requirement is recursive across all product layers.
7. The system shall provide consistency in mapping quantity-based and instance-based structures.

Domain-Specific Accountability

This section focuses on requirements for the domain applications described in the desired state vision where accountability has proven to be of particular interest and/or where it tends to be the most problematic.

Assembly/Build Level Engineering Requirements

The project team has assembled the following set of requirements for this application area:

1. The system shall allow consumption of the engineering definition and requirements at any granularity (based on need) while ensuring total consumption across all manufacturing elements (e.g., pre-torque in one factory location with final torque applied in another).
2. The system shall allow grouping the engineering elements by any arbitrary data element or feature for any of the following use cases: authoring, visualization, consumption, release, etc. (e.g., consume 50 of 100 fasteners with the same definition into one plan with a single operation).
3. The groupings shall persist for future tracking and configuration management.
4. The system shall allow partial definition of a fastener in the engineering BOM through a set of requirements with full implementation in the MBOM.

Evolving Configuration for Single Aircraft Identification Number

The project team has assembled the following set of requirements for this application area:

1. The system shall allow multiple persistent configurations (stages of assembly, pre/post-service bulletins etc.) for each unit number.
2. The system shall allow automatic net-change calculation between the different configurations to facilitate downstream authoring (e.g., removal of flight test instrumentation).

Data Exchange or Sharing with Suppliers and Partners

The project team has assembled the following set of requirements for this application area:

1. There shall be a standard in data exchange for BOM information (including Bill of Process, Assembly Requirements, and Change Information) that all PLM platforms are able to interpret.
2. A product structure for a specific configuration (configured or non-configured), and all the relevant data – metadata, supporting CAD information, engineering intent (i.e., notes, torques, lubes), effectivity, and change information – shall be provided within the data exchange. This can be done for As-Specified, As-Designed, As-Planned, and As-Built configurations.
3. The system shall be easily configurable within the standard product offering, including providing the ability to determine if the exchange is a complete refresh or a net change of differences for the configuration.
4. The system shall support a subscription mentality where recipients have more control to define their data pulls (with OEM approval).
5. The system shall provide timely, relevant synchronization of data, independent of the PLM provider.
6. The system shall enable integration to ERPs for suppliers and partners who might not have a separate PLM.
7. Any errors and/or data exchange failures shall be easily identified, resolved, and reprocessed. There is a closed loop where recipients acknowledge that they have received the exchanged data and successfully processed it into their system.
8. The system shall enable the recipient to augment exchanged data with additional information (i.e., language translation).
9. The system shall provide accountability and audit checking to ensure the exchanged data matches the originating source system.
10. The data exchange shall conform to regulatory and LOTAR (LOng Term Archival and Retrieval) expectations and provides for security and export control.

Go Forward Plan

This section outlines the AD PAG members' approach to achieving their goal.

Three-Step Approach

The project team has defined and followed a three-step approach to pursue their goal and make their solution concept real, as outlined in Figure 12.

1. **Basics**—Perform first level analysis across AD PAG members on BOM usage and product structures. This will be done as a detailed survey sent to all members, concurrent with this position paper's publication (already accomplished for the original topics).
2. **Translate basics into proposed PLM solutions**—Harmonize the survey results, looking for commonality among work methods, business processes, and PLM implementations.
3. **Facilitate A&D collaboration—**Share the common *Multiple View Bill of Materials (BOM)* position paper and *Appendix A: Glossary* with PLM providers for common knowledge and implementation.

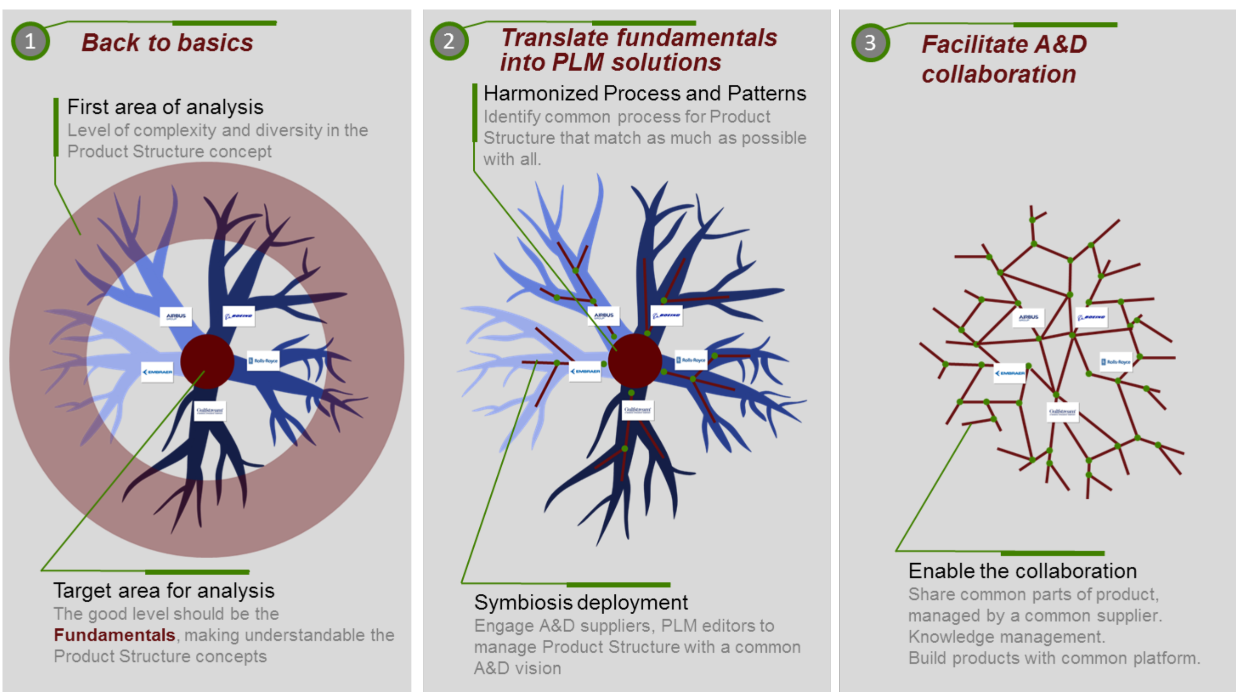

Figure 12 – Proposed Multi-View BOM Solution Roadmap

Requested Response from Industry

The AD PAG wrote this paper to demonstrate an understanding of the issues (i.e., problem statement) and to communicate the group's objectives, desired state strategy, and high-level requirements.

For readers of this position paper who represent manufacturing companies in the aerospace and defense industry as well as other industry segments, the AD PAG team welcomes your feedback and suggestions for future collaborative efforts. To submit comments click here!

For readers who represent a PLM and/or MBSE solution provider to the A&D industry, the AD PAG welcomes your feedback in support of this effort with the following actions:

- Provide comments and suggestions for improvement of the Problem Statement, Objectives, and Desired State as documented in this paper.
- State whether you accept the Conceptual Solution and Preliminary Requirements documented in this paper. For those points that you do not accept, provide an explanation for your position, and if appropriate suggest an alternative.
- Describe in what fashion and to what degree your current products and future product roadmaps comply with the Conceptual Solution and Preliminary Requirements documented in this paper.
- Recognizing that the content of this paper is directional and a work in progress, state whether you will support and participate in further refinement of the requirements and short-term solutions.

About AD PLM Action Group

The Aerospace and Defense PLM Action Group (www.ad-pag.com) is an association of aerospace OEMs and aircraft engine providers within CIMdata's globally recognized PLM Community Program, which functions as a **PLM advocacy group** to:

- Set the direction for the aerospace and defense industry on PLM-related topics that matter to members (*including promoting, not duplicating, the work of standards bodies*)
- Promote common industry PLM processes and practices
- Define requirements for common interest PLM-related capabilities
- Communicate with a unified voice to PLM solution providers
- Sponsor collaborative PLM research on prioritized industry and technology topics

CIMdata administers Group operations, coordinates research, and manages the progression of policy formulation.

About CIMdata

CIMdata, a leading independent worldwide firm, provides strategic management consulting to maximize an enterprise's ability to design and deliver innovative products and services through the application of Product Lifecycle Management (PLM) solutions. Since its founding over thirty years ago, CIMdata has delivered world-class knowledge, expertise, and best-practice methods on PLM solutions. These solutions incorporate both business processes and a wide-ranging set of PLM-enabling technologies.

CIMdata works with both industrial organizations and providers of technologies and services seeking competitive advantage in the global economy. CIMdata helps industrial organizations establish effective PLM strategies, assists in the identification of requirements and selection of PLM technologies, helps organizations optimize their operational structure and processes to implement solutions, and assists in the deployment of these solutions. For PLM solution providers, CIMdata helps define business and market strategies, delivers worldwide market information and analyses, provides education and support for internal sales and marketing teams, as well as overall support at all stages of business and product programs to make them optimally effective in their markets.

In addition to consulting, CIMdata conducts research, provides PLM-focused subscription services, and produces several commercial publications. The company also provides industry education through PLM certification programs, seminars, and conferences worldwide. CIMdata serves clients around the world from offices in North America, Europe, and Asia-Pacific.

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Appendices

Appendix A: Glossary (Separate Document)

Please visit www.ad-pag.com.

Appendix B: Concept Definition and Use Cases (Separate Document)

Please visit www.ad-pag.com.