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# Product Life-Cycle Management for Early Acquisition Programs

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## Abstract

The Department of Defense (DoD) understands the value of the "Digital Thread" that is created during the pre-Milestone A & B activities, but how does one capture and store this information for later use? Up until now, most of this information was collected by program support functions and stored in various stove-piped systems, making retrieval difficult at best, impossible at worst. The U.S. Air Force has created a template for capturing, managing, and controlling this early acquisition data in a Product Lifecycle Management (PLM suite), bringing the same engineering rigor to early acquisition data as to later engineering and technical data and contract deliverables. The Air Force and Siemens funded a trial project to create an "Early Acquisition" PLM-in-a-box template, using Siemens Teamcenter PLM suite, for the purpose of proving out the ability to push the digital thread backward into the DoD 5000 pre-Milestone A & B activities. The goal was a reusable template that can be used for any program of any size. The template produced was adopted by two programs within the Air Force (Ground-Based Strategic Deterrent and Long-Range Standoff) and partially by one program in the Navy (Stingray). The Air Force will use this model to capture and reuse pre-Milestone A & B data for future programs.

Acquisition inside the DoD has been moving rapidly to suppliers relying exclusively on Digitized, Engineering Model-based designs.[1] This causes some friction inside the DoD as many organizations are not set up to receive this digitized data and use it across the acquisition to sustainment process. The reduction of this gap in capability between the vendor and the DoD customer has been recognized as one of the biggest drivers of readiness in the coming decades (DoD, 2009). The DoD Systems Engineering Forum has developed and maintains an Acquisition Modeling and Simulation (M&S) Master Plan (DoD, 2009) with five major objectives:

- Provide Necessary Policy & Guidance
- Enhance the Technical Framework for M&S
- Improve M&S Capabilities
- Improve M&S Use
- Shape the Workforce

Although these objectives are designed to enhance the warfighter's capabilities for current platforms, it also has a fit into the Early Acquisition (pre-Milestone B) process. Chang and Modigliani (2017) pointed out that today, acquisition professionals are expected to tailor

[1] There is some confusion about what constitutes an Engineering Model versus DoD Architectural Framework (DoDAF) model. Table 2 lists the engineering artifact created by manufacturers in the Digital Design Process. DoDAF Models are used for systems design (e.g., a Data Model).

the DoDI 5000.02 on their own. This can be compared to “handing them a map and telling them to figure out the best way to drive from New York City to Los Angeles. If this is their first time traveling this route, it would take a lot of time to study the map, plan the route, talk to others about shortcuts, and encounter traffic and detours along the way. Perhaps they will reach their final destination, but not without wasting significant time and fuel.” To meet this challenge, the U.S. Air Force Life Cycle Management Center worked with the National Center for Manufacturing Sciences (NMCS) to create a workable concept to move Digitalization and Product Life-Cycle Management (PLM) earlier into the acquisition process (Lilu & Uchmanowicz, 2015). Figure 1 shows current uses of PLM inside the Air Force and where it can be used as a support mechanism earlier in the process.

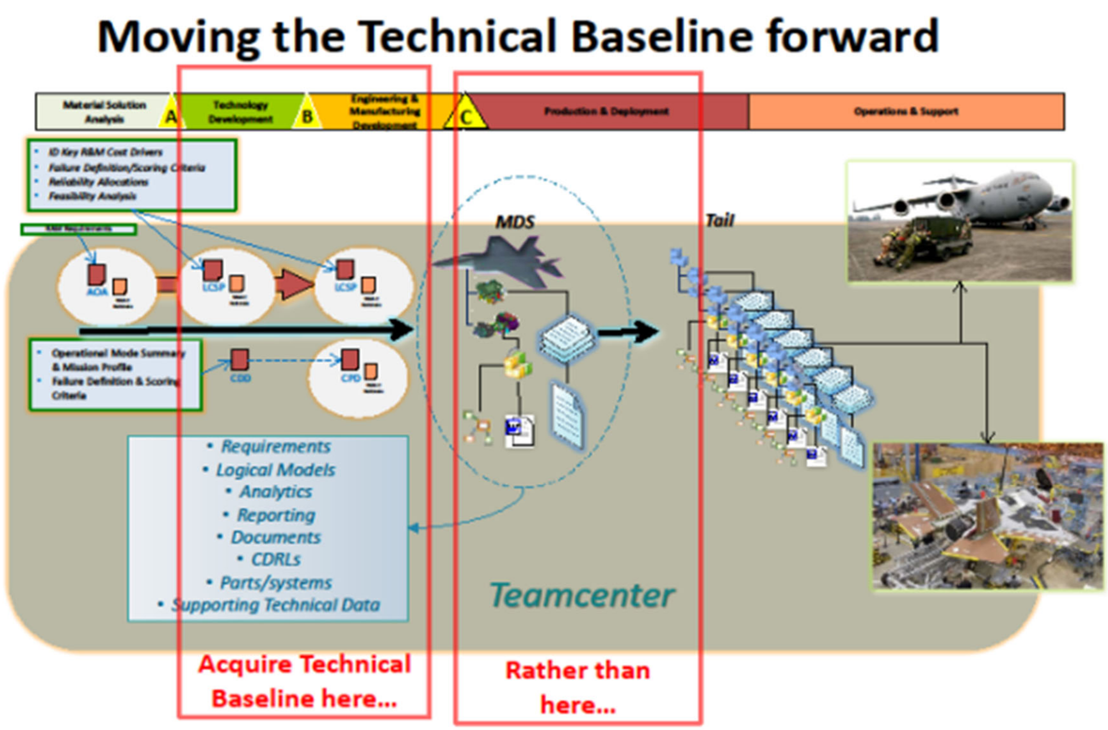


**Figure 1. PLM Overlay on DoD-5000.3 Milestones**

## PLM

### *Product Life-Cycle Management Capability Initiative*

Product Life-Cycle Management Capability Initiative (PLM-CI) is part of the Air Force (AF) Logistics Information Technology (Log IT) modernization effort. Specifically, PLM-CI is an effort to deliver an Enterprise Defense Business System (DBS) chartered to improve AF logistics and engineering through the life cycle of a product. Specifically, improvement must address common access by logistics and engineering communities to Product Life-Cycle Information (PLI). It must also provide accurate storage and quick retrieval of unclassified PLI to support efficient configuration management, integrated engineering processes across and between program offices, timely responses to customer requests for engineering and related technical assistance, and effective engineering analysis activities. These improvements should be focused on upstream acquisition activities and downstream sustainment engineering processes that impact supply and maintenance customer support (Lilu & Uchmanowicz, 2015).

### *PLI*

PLI[2] encompasses two areas. First, PLI is defined as engineering specific stock listed and non–stock listed master product data information that includes engineering managed items, drawings and geometry, Sustainment Bills of Material (BOM), Technical Orders, maintenance specific data (e.g., master configurations, maintenance requirements, process orders), supply data (Part Master and planning BOM), Military Specification/Standard and other product specific documents requiring configuration control, and data for other functional activities including engineering assistance requests, purchasing or acquisition of parts. Second, logisticians and system/sustainment engineers produce specific product support data (i.e., PLI) as part of life-cycle planning and execution processes during acquisition of weapon systems, end items, support equipment and/or modifications (Lilu & Uchmanowicz, 2015).

The DoD logistics and engineering communities lack a standardized and integrated method of accessing PLI, managing configuration control of PLI, synchronizing changes among PLI, and sharing the PLI with downstream consumers (e.g., maintenance, planning). This results in unplanned, manual intervention of limited manpower resources on activities to create, maintain, and update product information before use (Lewis & Dwyer, 2018). Key downstream impacts include degraded planning and maintenance functions, excess inventory costs, delayed weapon system availability, lengthy repair cycles, and increased customer wait times. The absence of a single, authoritative source for engineering data also leads to inefficiencies in gathering technical information, developing and employing analytical tools, conducting analyses, and reporting/storing outcomes. The process then becomes one of time-consuming research and frequent work-arounds required to support Operational Safety, Suitability, and Effectiveness (OSS&E) assurance.

### *Requirements*

The scope of this project was to describe and configure a PLM prototype for United States Air Force (USAF) early acquisition program activities from DoD 5000.02 pre-Milestone A up to Milestone B process (NMCS, 2017). This includes all contract deliverables in the Technical Maturity Readiness Review (TMRR).[3]

In today's Department of Defense (DoD), there is a growing need for the services to own the technical baseline. In the past, much of the technical data required to keep a weapon system or support system operational was maintained and updated by the Original Equipment Manufacturer (OEM). This was considered a best practice, and in many cases, still is. But with the advent of new technologies, and the considerably longer predicted life cycles of existing and future platforms, the DoD realizes that information gathered early in the acquisition process will be the foundation of a robust digital thread that will grow throughout the system's life cycle. Lewis and Dwyer state that to drive achievement of these objectives as rapidly and economically as possible, we organizations (i.e., Army Futures

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[2] PLI is defined as "life-cycle logistics planning data, part items, bills of material, geometry (models and drawings), product structure and technical order data" (Lilu & Uchmanowicz, 2015).
[3] TMRR usually involves two vendors; the design used in this development can support *n* vendors (for example, an engine fly off involving three or more teams).

Command, etc.) must become a “digital data driven organization leveraging a modern PLM platform to reap the benefits of rapid, accurate collaboration across the … Department of Defense” (Lewis & Dwyer, 2018).

In the Air Force, this is referred to as “Owning the Technical Baseline,” and leadership within the Air Force Materiel Command (AFMC) realizes that in order to capture this data at any level, requires tools and processes to capture, store, and analyze data received early in the process (AFLCMC, 2016). Specific requirements for this initiative include:

- Baseline of all Request for Proposal (RFP) data including requirements and program documents
- Receipt and review of CDRLs/data
- Configuration data management change processes
- Population of weapon system data
- Enablement of DOORS integration
- CAD Models and other MBSE Model integration

***New Approach to Acquisition***

The scope of this project was to describe and configure a PLM prototype for USAF early acquisition program activities from DoD 5000.02 pre-Milestone A up to Milestone B process (NMCS, 2017). As Chang and Modigliani (2017) pointed out, tailoring of acquisition models helps to focus programs on their particular core elements. Acquisition professionals can navigate the acquisition life cycle faster, by leveraging the best practices and exemplar strategies of many previous programs. Siemens and the Air Force (AF) exercised their commercial expertise and practices, such as the AdvantEdge Delivery methodology (Siemens PL Software, 2016), to deliver a Commercial off the Shelf (COTS) solution, “PLM-in-a-Box—Early Acquisition Edition” (Lilu & Uchmanowicz, 2015). The team partnered with NMCS using an available Other Transaction Authority (OTA), specifically the Commercial Technologies for Maintenance Activities (CTMA). This is a public/private partnership that uses Agile approaches to solve government problems. The result would be a template solution containing the virtual machine application copy and supporting documentation to enable deployment to a host environment for PLM on-boarding and program management office.

The team designed and deployed the solution to the Ground Based Strategic Deterrent Program (GBSD) program office in October 2017, in support of their ongoing TMRR activities in DoD 5000.02 Milestone B. The scope of this effort included planned and documented collaboration between the GBSD program office, the U.S. Air Force Product Life Cycle Management Capability Initiative (PLM CI) effort, NMCS, and Siemens Government Technologies. The solution definition included program management needs in the areas of Requirements Management processes, Documents Management Processes, CDRL deliverables and Acceptance Processes, Engineering Change Processes, Asset Configurations and Analytics (NMCS, 2016).

The Air Force required models that produce performance results used to validate weapon system specifications to be part of technical baselines for TMRR (U.S. Air Force, 2016). Table 2 lists the model types that needed to perform TMRR. This data is used during analysis to execute the models/tools (i.e., inputs) defined in its analytical architecture, as well as the outputs generated during model/tool execution such that the government can regenerate the data (U.S. Air Force, 2016).

## Execution

### *Phased Approach*

The joint Siemens/U.S. Air Force team executed the project using Siemens' Advantedge™ Agile Methodology. This consisted of 10 "sprints" over the course of a year to get capability to the user for testing and acceptance. Each of these Phases lasted approximately three weeks, with one of those weeks a workshop to make sure both the configurators and functional users were agreeing to the solution that would meet requirements.[4] Each of these sprints generally corresponded to a capability in the PLN suite (Requirements Management, Contract Data Management, CDRL Management, Document Management, etc.). The GBSD program office provided detailed requirements documentation of what data elements were required and sample workflows for the configurators to use.

### *Results*

At the end of each sprint, the configuration would consist of updates to the data model by extension or renaming, a workflow where necessary, and an updated Business Modeler Integrated Data Environment (BMIDE) image. This would then be handed over to the functional team for user testing. Any issues or changes would be agreed upon before the next sprint would start. In practice, each sprint took much less time than planned, and the only delays were the availability of functional subject matter experts. At the end of the last sprint, a fully operational PLM system was built, tested, and working.

### *Deliverables*

The final deliverables for this project consisted of a portable BMIDE image template for reuse by any program, and an Advantedge™ template for other programs to follow if any changes to the base template were made.[5]

### *Follow-On Programs*

As of today, this template is in use in part on the U.S. Navy Stingray PLM instance and the Long-Range Standoff (LRSO) program who is also undergoing TMRR. Standing up a fully configured PLM suite is not an easy undertaking, and the ability to save resources and time down to two to four weeks instead of six to 10 months is noteworthy.

### *Availability of Template and BMIDE Image*

As the NMS Charter requires any work performed under the CTMA OTA, this template is available for use across any DoD program. Currently the templates and images are under the control for USAF AFLCMC/HI organization located at Wright-Patterson AFB, OH.

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[4] Note that this was a configuration exercise, not software development, Teamcenter© was already installed and serviceable, meeting all U.S. Air Force Approved Product List (APL) requirements. The installation process lasted three days.

[5] The GBSD BMIDE Image did have specific naming conventions applied to it at the program's request. Subsequent programs will no doubt want to do the same. This is fairly straightforward and expected.

## Conclusion

The U.S. Air Force intends to adopt the "PLM-in-a-Box, Early Acquisition" Template across all new programs. The project came in ahead of schedule and under budget. As a set template is built and configured, it will save programs time and money to get acquisition data under configuration control and promises quicker reviews. There are, however, hurdles to overcome. First, bringing engineering rigor to the TMRR process is a big organizational change management issue, which also comes with a large training requirement. Second, latency and bandwidth issues in the DoD networks need to be considered.[6] In the end, the AF realizes that the transformation of the acquisition process is not only possible but that it can be achieved at the program level and at an affordable cost.

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[6] These are being addressed inside the U.S. Air Force by means of a Common Computing Environment based on Commercial GovCloud offerings.

## Appendix

**Table 1. Teamcenter© Product List**

| Product # | Product Name |
|---|---|
| TC030109 | Teamcenter Requirements Integrator User |
| TC10101 | Teamcenter Author |
| TC010231 | Change Management User |
| TC030301 | Schedule Manager User |
| TC030233 | Contract Data Management User |
| TC030101 | Requirements Manager User |
| NX13100 | NX Mach 3 Product Design |
| NX30120 | NX Viewer |
| TC20615 | Visualization Professional |
| TC1DOTC | Teamcenter Deployment |
| TC20505 | Reporting and Business Analytics |
| TC030107 | Teamcenter Requirements Integrator/RIF/ReqIF Interface |

**Table 2. GBSD MBSE Model Types**

| Model | Description |
|---|---|
| Coordinate Systems (Frames) | A partial list of coordinate systems is provided here for reference use with the models described below. The coordinate systems (frames) listed are only partially defined and the ultimate coordinate systems required for the WS is not limited to this list.<br><br>Vehicle Reference Frame – A Cartesian coordinate frame defined with the x axis pointing aft ward along the missile center line. The origin is on the missile center line and relative to a consistent and non-changing location (i.e., located at 1000" forward of the missile aft skirt edge.<br><br>Vehicle Flight Control Frame – A Cartesian coordinate frame defined with the x axis pointing forward parallel to the missile center line and the origin located at the center of gravity (CG) location. This frame moves with the missile CG location during operation.<br><br>Vehicle Aerodynamic Frame – A Cartesian coordinate frame defined with the x axis pointing forward along the missile center line. The origin is located at the aerodynamic moment reference point. |

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| Propulsion Model | The propulsion system model contains all necessary elements to fully describe the boost and post-boost systems.<br><br>This includes the axial thrust, action time, mass expulsion rates, including time scaling relationships of these parameters for the solid propellant rocket motors. Must also include all reaction control systems and engines used in the post-boost stage. |
| Mass Properties Model | The mass properties model describes the mass properties of individual components and assemblies with corresponding CG location, moments-of-inertia, and products-of-inertia (Mass Moments of Inertia [MOI], MOI, tensor). It describes how those mass properties change as a function of time via table lookup or equivalent. The Center of Gravity (CG) locations in x, y, and z is defined in Vehicle Reference Frame. The MOI tensor defined about Vehicle Flight Control Frame. The mass property data includes the GBSD operational configuration as well as GBSD test flight configurations (includes mass due to test instrumentation, etc.)<br><br>This model will include weapon system growth allowance as well as baseline mass properties. |
| Aerodynamics Model | The aerodynamics model provides the data necessary to define inflight aerodynamic forces and moments. The aerodynamic forces define using axial force coefficients in the Vehicle Aerodynamic Frame. The aero moment coefficients follow the right-hand rule for each axis in the Vehicle Aerodynamic Frame. |
| GN&C Model | The GN&C model:<br><br>· Provides a detailed description and derivations of all navigation, steering, guidance, and control law logic necessary to calibrate, align, and fly the missile<br><br>· Models the plant (physics) and control loops of the platform mechanization (including actuators and sensors)<br><br>· Models the plant and control loops of the inertial sensors |
| Flight Mission Model | For trajectory optimization, the Flight Mission Model includes the trajectory assumptions and constraints governing the mission control logic for the timing of events such as such as staging initiation, jettisons, and other events. This model also includes analysis parameters related to all trajectory shaping assumptions, constraints, and rules, which may include, but are not limited to, staging dynamic pressure constraints, shroud jettison dynamic pressure constraints, attitude rate constraints during trajectory events, azimuth direction, altitude at launch, V-gamma reentry constraints, and other data that affects range/payload performance. |

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| Thrust Control System Model | The thrust control system model provides the control dynamics for all thrust control elements (such as gimbals and jets) which, in conjunction with the GN&C model, are sufficient to reproduce in-flight dynamics. |
| Separation/Staging Model | The staging/separation model describes the effect of staging separation between each of the boost and post-boost stages and the shroud. The model also includes interstage skirt jettison timing as applicable. |
| Dynamics Model | The dynamics model contains all necessary data to perform and simulate structural dynamics analyses including loads and control bending modes. Includes the files associated with the software used such as ANSYS, NASTRAN, solid model files, etc. |
| RS/RV Models | RS/RV models, which include separation, reentry, spin-up, aerodynamics, and all sub-models relevant to reentry and reentry accuracy performance. |
| Post-Boost Prototype Model | This model represents the system that will be demonstrated by the post-boost prototype. This model identifies and predicts the performance of the prototype and will be used to assess performance following testing. |
| Propellant Residual Model | The propellant residual model defines the equations and data necessary to predict residual fuel at the end of the final boost stage (boost and post-boost phase) allocated for perturbation reserves and performance margins. |
| Parameter Perturbation Model | The parameter perturbation describes all missile system parameters that are necessary for a Monte Carlo evaluation including statistical distributions, means, and variation parameters. |
| WS Solid Model | The AVE solid model includes the geometry and mass properties for all major system components. This includes locations and orientations of sensors and separation planes.<br><br>The Ground Segment solid model includes a representation of the preliminary design with focus on the most impactful design elements (i.e., major changes from existing LFs and LCs). |
| AVE Structural Models | Models (including the files associated with the software used such as ANSYS, NASTRAN, etc.) used for structural and/or thermal analysis of AVE structure elements during, but not limited to, AVE on-alert status in the LF, AVE fly-out, and AVE in flight. |
| Launch Systems Structural Models | Models (including the files associated with the software used such as ANSYS, NASTRAN, etc.) used for structural analysis for the reuse of the existing facility including any modifications/additions to it. These models also include those for analysis of new LS structures and the MSS interface to the LF infrastructure. |

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| Launch Systems Power Budget Models and HVAC Models | Models that enable calculation and simulation of LS power budget analyses to ensure that power demands can be accommodated by backup and emergency power systems. Include HVAC models that show LS mechanical systems meet thermal needs of the weapon system. |
| RAM Model | RAM model as described in 3.2.8.3 |
| WS Cost Model | Model includes all estimated life-cycle costs (i.e., Acquisition, deployment and O&S) for the entire WS. The math model includes uncertainty bounds, cost estimating methodologies and relationships. |
| WS Deployment Model | Model supporting the results of the analysis conducted in 3.2.19.1 |
| WS Survivability Model | Model includes survivability estimates for pre-, trans- and post-attack for the Command and Launch Systems and all phases of flight for the AVE (i.e., boost, mid-course, terminal). |
| WSC2 Communication Models | All math models required to assess WSC2 communications effectiveness against the *WSS* (may include but not limited to responsiveness analysis, link budget analysis, System-generated Electromagnetic Pulse analysis, etc.) These models include simulations of communications between ALSC-R and NC3 with other WSC2 elements. |


**Figure 2. Sample Business Use Case**

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