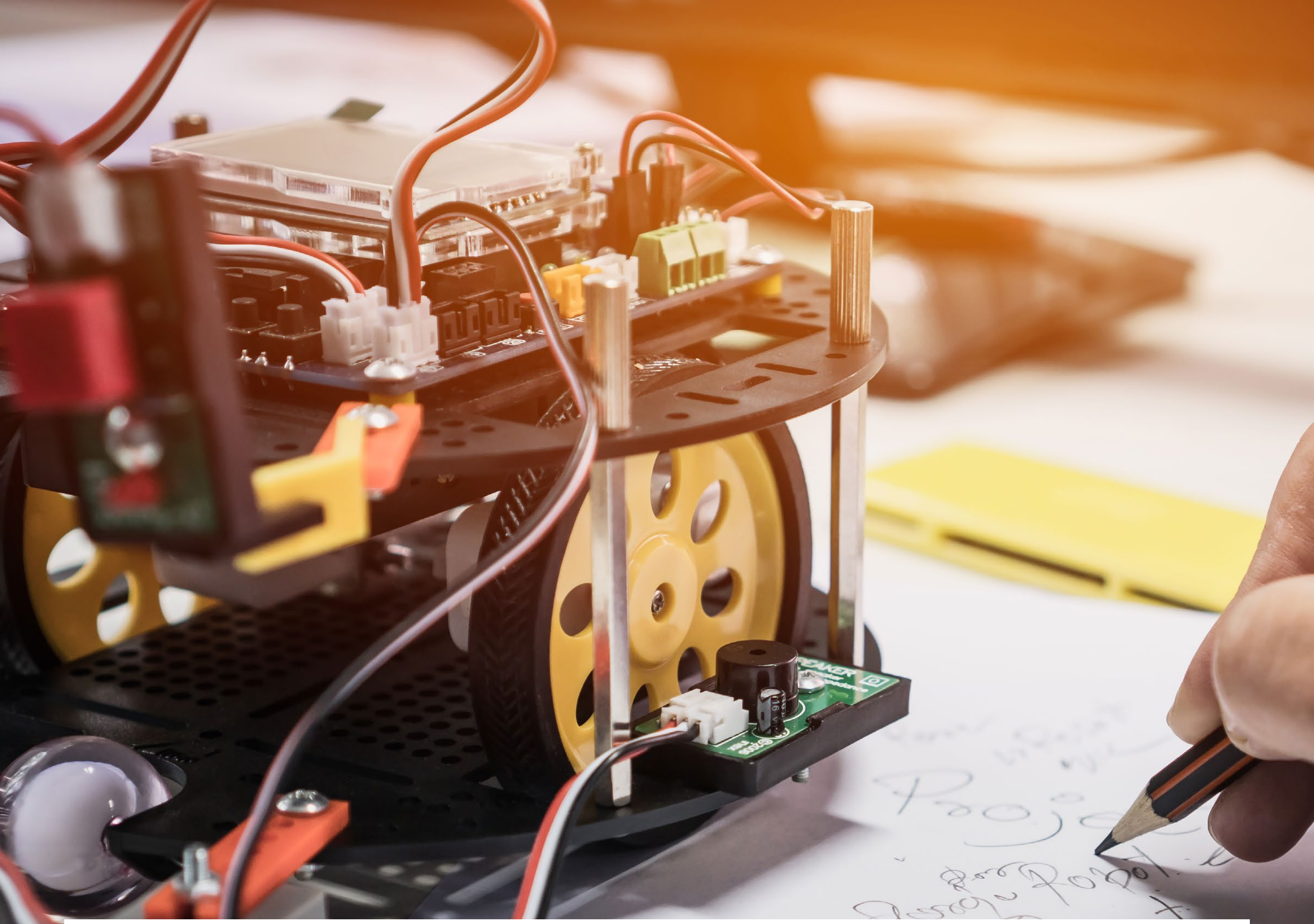

# MODEL-BASED ENGINEERING FOR PRODUCT SUPPORT

by **SHAWN D. HARRISON, PMP**

Use of predictive analysis and modeling to improve system availability and reliability is a statutory responsibility of a product support manager (PSM). With today's weapon systems largely designed (or modified) using Model-Based Engineering (MBE), three-dimensional (3D) models should figure prominently in carrying out this responsibility.

While current MBE focus in the Department of Defense (DoD) and military Services' "digital campaigns" largely aims at the front end of acquisition (i.e., requirements development, design, production, and test), PSMs must consider many product support applications. PSMs and their teams must become conversant about MBE concepts and leverage models to preserve or improve system availability and reliability across the life cycle.

This article's purpose is to (1) summarize recent research on MBE and product support; (2) review several weapon system examples; and (3) describe a proposed future state of product support activities underpinned by MBE.

## RESEARCH ON MBE USES

Three DoD industry partner articles/briefings and the DoD "Digital Engineering Strategy" exemplify current research on the application of MBE for product support available in open source, DAU, Defense Technical Information Center, and professional engineering association publications.

Denise Duncan's October 2015 article, "DoD as a Model-Based Enterprise," in the *DSP Journal* was among the first published articles to go beyond design and development of systems and address the use of models for product support. Duncan emphasized using MBE for virtual prototyping, updating interactive electronic technical manuals, and enabling faster and more efficient part sourcing and organic manufacturing. Duncan stated that MBE could provide greater collaboration throughout the supply chain, improve configuration management, and enable immersive training. Though the article provided few implementation details, simply introducing these possibilities likely spurred others in the defense world to consider the implications for product support.

As thinking about Digital Thread and Digital Twin concepts accelerated within DoD, Siemens published its "Driving the Digital Enterprise" briefing, circa March 2018. The authors identified no fewer than 30 product support processes across the system life cycle from "ideation to realization to utilization" and proposed a Digital Thread/Twin approach to drive improvements in maintenance planning and simulation, technical publications, supply, failure reporting and correction, and configuration management. With digital tools, the authors proposed that customers could improve maintainability as well as condition- and reliability-based maintenance, while resolving in-service difficulties.

Later in 2018, a Booz Allen Hamilton team published an INCOSE (International Council on Systems Engineering) paper titled "Integrating a Model-Based Systems Engineering and Model-Based Product Support Approach for Affordable System Sustainment." The authors appear to have been the first to coin the term "model-based product support" (MBPS), which they defined as a way to "determine logistics support requirements, design the system for supportability, [and] acquire … and provide cost-effective [support]." They emphasized the need for MBE-MBPS from early in requirements definition through design, transitioning to sustaining engineering and leveraging a "central data repository [Authoritative Source of Truth (ASoT)] that provides structured, authoritative product information … from concept to end of life." Furthermore, they emphasized the use of Digital Twin and Digital Thread concepts as the model-based foundation for trade studies, life-cycle cost prediction and validation, and service life extension programs (SLEPs).

Finally in 2018, DoD published its "Digital Engineering Strategy" to champion a vision for modernizing how DoD designs, develops, delivers, operates, and sustains systems. The strategy identified "Product Support Models" among the seven types of models connected by an MBE-enabled ASoT. Among other benefits, the strategy envisioned "highly useful physics-based models … that evolve alongside the end item[s]" (i.e., Digital Twins), 3D printing and digital manufacturing, augmented reality and virtual reality (AR/VR), and advanced human-machine interactions to enable smarter, faster decisions.

## WEAPON SYSTEM EXAMPLES

Several new and legacy weapon systems have been leveraging or plan to leverage MBE for product support. The following is not an all-inclusive list by any means, but it demonstrates Service investments in models that can deliver affordable and effective long-term sustainment. Notably, commercial industry and academia (as well as government research labs) play a large role in getting these efforts off the ground (in some cases, literally, in terms of 3D optical scanning and model creation).

**U.S. Army.** Hampered by obsolescence challenges, the Army's Aviation and Missile Command (AMCOM) has partnered with Wichita State University (WSU) to disassemble and create a 3D model of a UH-60L Black Hawk, the Army's primary utility helicopter. According to a July 2020 govdesignhub.com article, the Army hopes to create conditions to repair or replace parts using additive and other advanced manufacturing techniques In addition, Black Hawk Digital Twins will enable accident or battle damage assessment, design of nonstandard repairs, and testing of new technologies. Finally, a goal of the project is to create a VR capability to enable maintainers to practice maintenance prior to performing work on the aircraft.

**U.S. Navy.** As part of the Navy's Logistics Digital Transformation, Naval Sea Systems Command (NAVSEA) initiated an MBPS prototype in Fiscal Year (FY) 2020 via Other Transaction Authority (OTA), with a goal of delivering a prototype in FY 2021. Aimed at improving ship and weapon system logistics, reducing sustainment costs, enabling predictive analysis, and creating Digital Twins to increase operational availability, MBPS represents, according to a June 2020 NAVSEA briefing, a "seismic shift" in the sustainment of ships and submarines. MBPS will replace "analog with digital, 2D [two-dimensional] with 3D, reactive with predictive, manual with automated, stovepiped with integrated, flat files and spreadsheets with machine learning and artificial intelligence (AI), and limited in-service feedback with dynamic updates." Product support activities benefiting from MBPS include Condition-Based Maintenance (CBM+), configuration management, technical publication updates, on-demand AR/VR training, maintenance and supply optimization, additive manufacturing, and logistics support analysis.

**U.S. Air Force.** Among several new and legacy programs, the DoD Digital Engineering Strategy acknowledged the Air Force's most prolific example of legacy system MBE, the A-10 Thunderbolt close-air support aircraft developed by the former Fairchild Aircraft. With no active original equipment manufacturer technical data support, the program office created an estimated 10,000 models to reconstruct the ASoT for its Wing Replacement Program, a service-life extension modification.

Another legacy system, the B-52 long-range strategic bomber, is digitizing portions of the aircraft and interfaces (e.g., engine mount assemblies). Its Commercial Engine Replacement Program focuses only on what is needed for the modification and not digitizing the entire aircraft. Its virtual system prototype also will include the ability to simulate faults such as fuel pump malfunctions. In addition, the B-1 bomber (like the UH-60L), is being digitally scanned by WSU with a focus on predicting failures (e.g., fatigue, cracking, etc.) as the completed Digital Twin incorporates real-world data and, as Jared Morgan stated in his October 2020 *Air Force Times* article "flies ahead of the fleet in the digital environment." Finally, in addition to the eT-7A Red Hawk

Advanced Pilot Trainer e-designation announced by the Secretary of the Air Force in September 2020, the Air Force in May 2021 issued new guidance clarifying criteria for "e-Series" and "e-Programs" and named the Next Generation Air Dominance (NGAD) sixth-generation demonstrator, the Ground Based Strategic Deterrent (GBSD) program, A-10, and B-52 CERP, as examples.

The table summarizes the types of product support and life cycle management activity applications addressed in the literature review and Services' weapon system projects.

## MBE AND PRODUCT SUPPORT—PROPOSED FUTURE STATE

Several of the above processes, including many Sustainment (aka, Sustaining) Engineering processes, can be examined in more concrete terms of what future state operations could look like. This article does not provide a detailed discussion of the infrastructure (e.g., Product Life-cycle Management (PLM) system, engineering tools, and networks), training, or change management associated with MBE; these are the subject of the digital campaigns. In this article, these processes are assumed to be in place in the near or mid-term future. And, in fact, they already exist in several programs

**Design interface.** MBE enables a new level of government design review (e.g., Preliminary or Critical Design Review) for new systems and equipment. "Fly-through" demonstrations of integrated native computer-aided design (CAD) models and color-coded time-lapse "movies" depict system components and physical flows (electrical, hydraulic, fuel, etc.), with progressive visual "peelback" from nose to tail (or stem to stern). Physical system modeling results (e.g., finite element analysis, computational fluid dynamics, etc.) demonstrate compliance with requirements and specifications. Finally, model-based Human Engineering Design Analysis Document (HEDAD) deliverables enable a next-generation capability to build confidence in system designs, maintainability, and multiple anthropometric case maintainers' system access previously impossible with 2D drawings.

**Technical manuals.** MBE enables efficient development of and updates to Technical Manuals (TMs), particularly Interactive Electronic Technical Manuals (IETMs,) which include Model-Based Instructions

### Table 1. Summary of Product Support Applications

| Product Support or Life-Cycle Management Application | Literature Review or Service Legacy System Example | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Duncan | Siemens | Booz Allen Hamilton | DoD Strategy | UH-60L Black Hawk | NAVSEA MBPS | A-10 WRP | B-52 CERP | B-1 |
| Virtual Prototyping | ✓ | ✓ | | | | | ✓ | ✓ | |
| Technical Manual Updates | ✓ | ✓ | | | | ✓ | ✓ | | |
| Supply Management, including Part Sourcing and DMSMS | ✓ | ✓ | | | ✓ | ✓ | ✓ | | |
| Advanced Manufacturing | ✓ | ✓ | | ✓ | ✓ | ✓ | | | |
| Configuration Management | ✓ | ✓ | | | | ✓ | | | |
| Immersive Training/Rehearsal | ✓ | ✓ | | ✓ | ✓ | ✓ | | | |
| Decision making (including CBM+ and Predictive Analysis) | | ✓ | | ✓ | | ✓ | | ✓ | ✓ |
| Trade Studies | | ✓ | ✓ | | | | | | |
| Cost Prediction and Reduction | | ✓ | ✓ | | | ✓ | | | |
| Modification (including SLEP) | | ✓ | ✓ | | | | ✓ | ✓ | |
| Battle Damage Assessment | | | | | ✓ | | | | |
| Non-Standard Repairs and Technical Assistance | | | | | ✓ | | ✓ | | |

Key: CBM+= Condition-Based Maintenance-plus; CERP=Commercial Engine Replacement Program; DMSMS= Diminishing Manufacturing Sources and Material Shortages; MBPS=model-based product support; SLEP=service life extensions; WRP=WRP Aviation.

*Source:* The author.

(MBIs). These offer a superior capability to static PDF-based TMs. MBIs include maintenance procedures tied directly to rotatable, embedded 3D models and other dynamic tools such as flow diagrams, wire trace illuminators, etc. TM updates resulting from field recommendations or modifications flow seamlessly from sustainment engineers reducing or eliminating the need to (re)create static artwork, translating model updates directly into downstream IETM updates. Facilitated by an in-situ VR environment, MBE provides the basis for verifying certain TM actions, including some performance tasks (e.g., removal of doors and panels and other simple tasks). In fact, the eT-7A program is exploring the feasibility of verifying about 10 percent of its performance tasks using a VR laboratory.

**Supply management.** For provisioning and cataloging, MBE enables the efficient generation of Engineering Data for Provisioning (EDFP). Currently the Defense Logistics Agency Logistics Information Service supports 3D PDF (with embedded models), which does not require sophisticated CAD software or proprietary lightweight viewers. And 3D PDFs provide a level of fidelity above 2D drawings, which makes possible the more efficient assignment of National Stock Numbers. In the future, if DoD expands its native CAD viewing capabilities, this could eliminate the need to create 3D PDFs and reduce the risk of disconnects between product-definition data ASoT and logistics product data. In terms of parts repurchases or Diminishing Manufacturing Sources and Material Shortages (DMSMS) (i.e., obsolescence) management, model-based technical data packages can be passed directly to prospective suppliers/manufacturers. On the other hand, they can facilitate rapid creation of a 3D PDF "technical part report" for lower-tier suppliers to facilitate redesign or remanufacture of replacement parts.

**Configuration management.** A PLM-hosted indentured MBE ASoT product tree (that's a mouthful!) brings unparalleled levels of configuration management and control. Digital Thread and Digital Twin capabilities provide intimate tail- (or ship-, tank-, etc.) number level detail undergirding all other Product Support processes.

**Training.** Model-based AR/VR training has been used for decades up to and including high-fidelity mission rehearsal. At present, likely few if any systems dynamically update training systems directly from ASoT product definition data updates. However, creating the conditions for seamless continuity between the two (with training system "downstream" from actual system) would reach a new level of concurrency. Because weapon systems and training systems are frequently developed and supported by different organizations (including government and contractors), sharing of a government-owned "tech stack" could be one means of achieving continuity. This was suggested by former Air Force Assistant Secretary Dr. Will Roper in his September 2020 "There is No Spoon" address to the Air Force Association's 2020 Virtual Air, Space and Cyber conference.

**Condition-based maintenance.** Model-based solutions can improve the effectiveness of CBM+ implementation by enabling high-fidelity simulations and analyses to predict parts failure. When combined with health monitoring data (e.g., recorded aircraft information sensor-based data) and maintenance records, Digital Twins provide tremendous insight into individual fielded systems. Dr. Eric Tuegel and coauthors noted in their paper delivered in January 2017 to the American Institute of Aeronautics and Astronautics that "prognosis forecasts will increasingly rely on hybrid data/physics models instead of data-driven models alone." MBE also enables enhanced Reliability Centered Maintenance (eRCM) scheduled maintenance updates to improve system reliability and maintainability.

**Product improvement.** Deficiency Reports, Materiel Improvement Review Boards, and Product Improvement Working Groups typically identify too many product improvement initiatives for the existing resources or bandwidth to accommodate. MBE has the potential to streamline work in this area. For example, if the program possesses a robust "tech stack," organic engineers could conduct feasibility studies and "what-if" simulations to determine the impacts of proposed improvements to component or sub-system reliability. This could assist in prioritizing product improvement and establishing the technical foundation (e.g., models, parameters, etc.) for upgrades and improvements. In another real-world example, Air Force engineers, using digital tools converted legacy turbofan engine inlet fan drawings into 3D models to facilitate interference and stress analyses to assist redesign for increased sustainability.

**Cost prediction and analysis.** Another of the PSM's statutory requirements is use of predictive analysis and modeling to reduce sustainment costs. MBE-supported analysis of the other processes described in this article (e.g., Trade Studies, Product Improvement, Modification Management, etc.) can inform cost estimates necessary to defend program initiatives and resources in support of planning, programming, and budgeting.

**Modification management.** Post-production modification programs often deal with the challenge of determining the fleet as-is configuration baseline ASoT down to specific tail numbers. In this respect, Digital Twins can prevent costly mistakes and rework based on faulty data or assumptions about onboard "real-estate" (e.g., physical space on an equipment rack) that may vary greatly across individual systems. Similarly, models of onboard power generation, fuel capacity, cooling air, etc., can be virtually updated with the proposed modification, allowing informed decisions about changes to physical properties. Mass and aerodynamic models similarly increase knowledge regarding structural and aero-loading properties. Providing models to modification contractors also can lead to more timely and efficient prototyping and reduce the physical system testing needed, mitigating potential performance problems that might require redesign (i.e., Dr. Roper's "eCreate before you aviate" concept).

**Technical assistance requests.** Engineering responses to requests from field or depot maintainers for assistance with troubleshooting or nonstandard repairs (e.g., oversized holes, cracks, corrosion, etc.) are another process improved by MBE. Models support troubleshooting or repair design through simulations or dynamic engineering analyses (e.g., finite element, fluid dynamic, or other metaphysical models) to validate procedural steps and long-term consequences such as development of cracks in material. In the case of a non-standard repair such as an outer mold line (skin) patch, MBE could facilitate field-level additive manufacturing (3D printing) of an inexpensive non-metallic (e.g., plastic) "trial fit" repair assembly/ patch prior to manufacture and assembly of the permanent metal repair. At least one Air Force program has done so already!

**Mishap investigation support.** Finally, MBE more efficiently supports mishap investigations. Digital Twins, like technical assistance requests and product improvement initiatives, can be analyzed and subjected to physical or performance-based analyses and simulations to identify possible impending failures. Pinpointing causal factors through Digital Twin analysis can also facilitate fleet-wide corrective actions and prevent future mishaps.

## CONCLUDING THOUGHTS

Product support managers (PSMs) must embrace the digital campaigns of the DoD, their Department, Agency or Service, and their Life Cycle Management Command. MBE adoption is accelerating, and PSMs must become conversant advocates—particularly in new system development. PSMs should:

- Educate themselves and their logistics teams on MBE's potential to improve product support processes.
- Partner with program engineers to plan and implement life-cycle MBE solutions.
- Advocate for resources for subject-matter experts, tools, and training.
- Support leadership efforts to establish policy, guidance, and standards.
- Be part of the change management activity and normalize MBE to become an intuitive, everyday consideration for product support.

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