「モデルベースシステムズエンジニアリング」特集号 解　説

Incorporating MBSE Across a PLM Managed Digital Thread —Three Real Life Use Cases

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1. Abstract

A system-centric design approach, also referred to as Systems Thinking, is essential to effectively managing exploding product complexities. The combination of pervasive connectivity, rapidly increasing software content, and massive customization significantly increases the potential for costly functional product failures arising at the boundaries of system and subsystem interactions. These failures can no longer be identified or predicted by focusing on Bill of Materials (BOM)-centric structures within the individual implementation domains. Forward looking companies are embracing digital engineering initiatives as a means of managing complexity at the system level.

One key initiative is Model-based Systems Engineering (MBSE) combined with simulation methodologies. MBSE captures design intent in a system-centric model before allocating its implementation to specific disciplines such as mechanical, software, electronics, etc. The simulation uses models derived from these system definitions to explore design space, predict system behaviors, and optimize system parameters.

Another key initiative is a digital thread that spans the entire product lifecycle. A digital thread creates configuration-managed traceability, connecting requirements, detailed design data, collaboration threads, workflows, processes, documentation, and other artifacts critical to preserving the history of the design process.

Unfortunately, traditional product lifecycle management (PLM) software was architected and hard-coded to manage design data on the bottom and the right of the engineering V model, while MBSE data models and simulations occur on the left side of the V model. The challenge therefore is how to integrate MBSE and digital thread using a modern Product Lifecycle Management (PLM) platform capable of embracing the entirety of the engineering V model.

This paper discusses three examples showing that the process of integrating MBSE with a PLM platform can be initiated in vastly different ways.

2. Toyota Motor Europe

Toyota Motor Europe's (TME) initial goal was digital reorganization of existing engineering data to enable automated and reusable system-level MBSE engineering data models with full integration to a PLM platform.

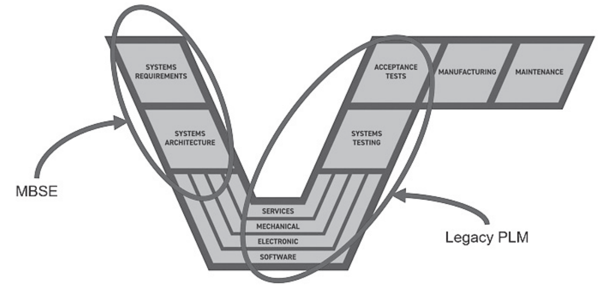

Fig. 1 Engineering V model, PLM and MBSE

When TME started incorporating MBSE into their digital engineering practices, it had already defined the related teams and processes for designing and manufacturing vehicles. This included a system-centric approach to capturing 150% of the architectural structures of mechanical car platforms, including related variants, without the use of formal MBSE modeling tools. The 150% refers to all elements of the platform even if not all of them are used in a specific product variant while 100% refers to the elements from the 150% set (a subset) that are used in a specific product variant derived from that 150% platform. What they were lacking was a resilient and scalable engineering data management platform for rapidly capturing, tracking, and managing the accuracy of the evolving engineering representations with increasing numbers of variants derived from these models.

TME relied on complex spreadsheets and the manual exchange of them among the engineering teams to share this data, a process that was unsustainable due to the number of architectural variants and related simulations. Furthermore, these spreadsheets were devoid of any connection to the rest of the product data and not managed under configuration control. The pedigree, maturity and connectivity of the data were often unclear. TME engineering leadership recognized that without a new data management platform the existing process was not sustainable. What they were looking for was the ability to define and maintain a "single source of truth" — a digital thread — accessible to everyone in the organization and with a clear context of the pedigree and accuracy of the data.

TME's Ernesto Mottola, PhD., Vehicle Performance Engineering, was convinced that a PLM platform

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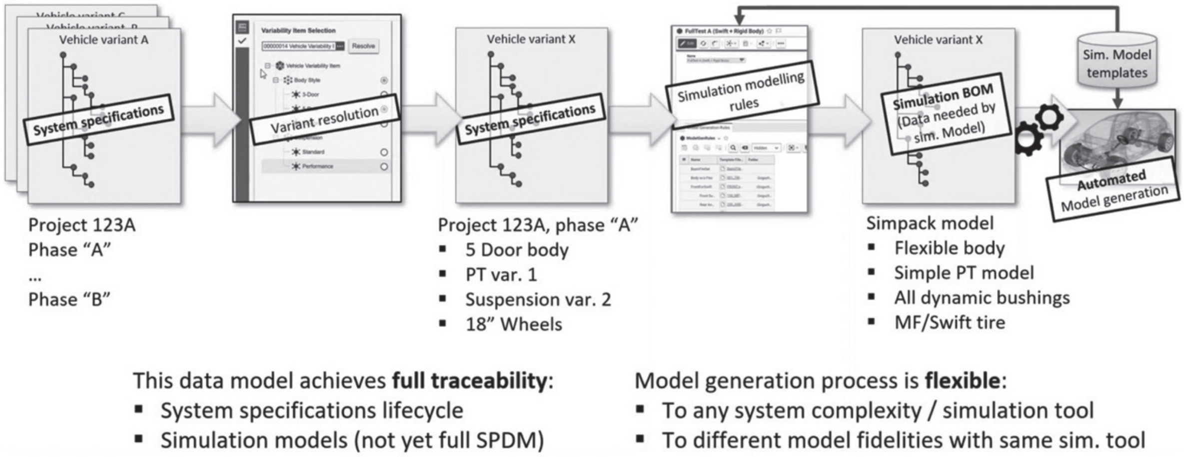

Source: Ernesto Mottola, TME

Fig. 2 TME’s target process for generation of simulation models

should be central to managing that single source of truth. And that upon establishing a digital thread for data, it is possible to design digital processes that enable efficient collaborative work among the parties that produce and consume this data. Ernesto’s mantra is: “connecting data=connecting processes = connecting people”.

Ernesto also had a healthy level of skepticism regarding the ability of PLM vendors to deliver. This skepticism was due to TME’s prior attempts to use legacy PLM solutions for this purpose only to find after various trials and significant costs that hard-coded limitations and file-based approaches of these older solutions could not handle the challenge. What intrigued Ernesto about Aras’ low-code platform was the ease and flexibility of extending the data model and digital thread scope starting with out-of-the-box (OOTB) functionality baselines. Plus, the guarantee that the ability to integrate with the existing in-house Toyota Production System through local Aras Platform adaptations will remain compatible with future releases of the platform without requiring additional costs. That was very important since TME knew that the initial target was only a starting point for what their future digital thread had to encompass (e.g., usage of MBSE modeling languages like SysML, more advanced 3-D simulations, and others), and that therefore selection of a resilient, flexible, and scalable PLM platform was essential.

A detailed plan was developed by the teams from TME, Aras, and an integrator (Inensia) working together for the technology validation phase of the project:

- Focus on the key process needs:
    - Gathering and approval of engineering data
    - Automatic generation of simulation models—but not yet on simulation process data management (SPDM)
    - Ability to rapidly make changes to the design to perform what-if trade studies
- Apply the OOTB Aras Platform services for managing revisions, lifecycles, workflows, and access control
- Extend the OOTB Aras Platform integrated data model to encompass structures and relationships for TME’s Engineering Data Management (EDM):
    - Efficient engineering management of all the parametric data (value, type, units)
    - Support of existing car platform sub-system models
    - Variability rules for resolving the 150% system models into 100% variants
    - All data needed by simulation models (initially low-fidelity simulations in mechanical domain)
- Provide specific convenience features:
    - Separation of data from its presentation
    - Excel-like ease of viewing and editing of the data structure
    - Comparing different versions of data structures
    - Libraries for reusable data models and their items down to specific data types
    - Graphical search for anything in any direction across any structure or relationship

Using the Agile software development methodology, the teams were able to arrive at an optimum solution. The rapid implementation was made possible with the modeling flexibility of the Aras Platform and the hands-on collaboration between Aras, Inensia and TME experts throughout the process. The original spreadsheets are now replaced by the “single source of truth,” the digital thread in the Aras Platform that covers the engineering data for dynamics vehicle performance. The MBSE-variant-design-simulation relationships are managed within this system-centric digital thread regardless of where the system and design details are authored. The engineering community can now rapidly and efficiently create, review, and edit the data, increasing confidence in the data quality and the consistent simulation models generated by a repeatable automated process. With clear evidence of the benefits, the EDM solution for management of engineering data was deployed into production with the engineers readily warming up to the value of PLM. The key to success was TME's understanding of how they wanted to support MBSE and engineering data management in in the digital thread managed by a flexible PLM platform.

3. MIT Lincoln Laboratory

MIT Lincoln Laboratory's (MITLL) initial goal was integration of SysML based system models with their PLM Platform to make standardized MBSE structures part of the overall product data configuration management.

MITLL is part of the Massachusetts Institute of Technology. Its focus is on applied research for the US Government, primarily the Department of Defense. Part of the lab's mission is to develop new technology-based solutions starting with a system definition and early concept development, all the way through to prototype demonstration, production, deployment, and technology transfer. This includes software, electronics, and mechanical products. Production volumes are extremely low, typically one or two units, but could be as high as ten.

MITLL has embarked on a digital engineering transformation initiative with the goal of creating a digital thread that enables traceability across MBSE, simulation, and digital models (multiplicity of design abstractions and engineering domains). According to Denise Fitzgerald, MITLL group leader of mechanical engineering, who is leading the Digital Engineer Transformation initiative:

> *"The goal is to be able to define a system before designing... hardware by shifting from domain-centric models (Computer Aided Design (CAD) and BOM) to system-centric models as central to all design activities in all engineering domains. It's about connecting intent with data in a way that benefits consumers of MBSE."*

MITLL was already very familiar with a commercial PLM Platform that the company has been using for several years for managing mechanical designs including BOMs, documents, releases, changes, workflows, and others. Selecting that PLM Platform as the digital engineering transformation backbone was an easy decision.

MITLL engaged with the PLM Platform vendor to discuss at length the goals and objectives, and to define the implementation roadmap:

- Model a digital thread that integrates MBSE models and simulations used by systems engineers making it a single source of truth for system behavior for all domain-specific models and implementations
- Enable validation and verification across all lifecycle states and all implementation domains against the original system behaviors captured in the MBSE model (combination of virtual simulation and physical testing)
- Create a parameter backbone that connects all models—a common parameter language—to enable a high-fidelity cross-domain model connection requiring a common parameter backbone that connects all models and is key to automating validation of requirements, performing trade space exploration, and inclusion of new technologies like generative designs, artificial intelligence, and others.
- Tie engineering and business tools together (Manufacturing Resource Planning (MRP), Enterprise Resource Planning (ERP), and others)
- Use the PLM Platform as the integration platform for all data models to eliminate the inability of the authoring tools to connect directly between themselves
- Use OOTB PLM Platform services for revision control, workflows, lifecycle, visualization, and others

MITLL recognized early on that integration of their SysML-based system modeling tool of choice into a common digital thread managed by the PLM Platform posed several challenges that had to be addressed before anything else could be achieved:

- The system modeling tool does not enforce any modeling methodology. If every team at MITLL used that modeling tool differently to represent the same system concepts (e.g.: variability) that would make integration with the PLM Platform-managed digital thread unnecessarily complicated. It would also make interpretation of that digital thread by non-systems engineers more difficult.
- Not every detail of the system model needs to be expressed and managed in a digital thread, but it was not that clear how to determine which ones should be. This is because many SysML elements are needed while developing and analyzing a model—but not when referencing a system's functional and hierarchical structures once the model is finalized.
- System model parameters needed to be expressed in a unform way in the PLM Platform-managed digital thread to achieve the common parameter language. It was also not clear how to impose that on the SysML modeling tool.

MITLL and the PLM vendor teams worked together to find a solution to all three challenges. The teams were able to define a common system modeling process acceptable to MITLL systems engineers

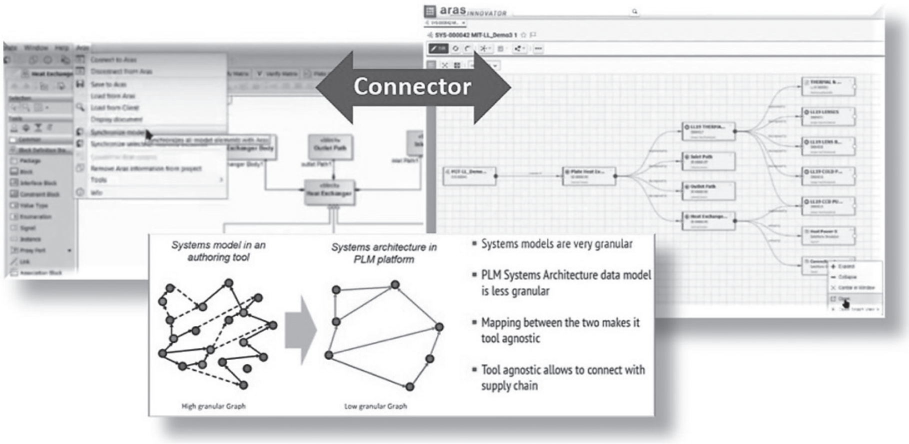

Fig. 3 Synchronization between the system modeling tool and the PLM Platform

and capable of uniformly modeling common parameters critical to simulations. They were also able to arrive at the correct level of system model granularity during synchronization between the system modeling tool and the PLM Platform.

Once these details were well understood, the PLM vendor was able to create a commercially viable connector between the authoring tool and the PLM Platform. The connector was created with a rich set of configuration options that not only address specific needs of MITLL but also allows it to be an OOTB product that can be configured to specific needs of any manufacturer. All system model elements reflected in the PLM Platform are now subject to the platform's revision control and change management as part of the product design, including traceability of all subsequent design details in all implementation domains.

It is interesting to note that all capabilities previously discussed in the Toyota Motor Europe use case were directly applicable to the MITLL process once the system modeling tool integration was achieved. Now MITLL is in the process of rolling out the entire solution throughout its organization with an explicit understanding that all new projects will utilize it.

4. Major Aerospace manufacturer

The project's initial goal was creating a requirements management process that is fully integrated with the MBSE's requirements, functional, logical, physical (RFLP) data model in the context of a PLM managed product lifecycle.

The company relies on a family of controllers with a predefined product line architecture and standardized functional configurations realized in electronics and software. The ability to maximize the reuse of previously defined and implemented functions in various pre-approved configurations while identifying what functionality is missing is key to their business strategy. With the ever-increasing complexity of functions demanded by their internal and external customers, the manufacturer realized that managing requirements with standalone tools and a discrete requirements document was quickly becoming unsustainable.

What they envisioned was a PLM platform capable of defining existing RFLP structures and using the underlying relationships to quickly identify what's available, what's missing, and what's affected by proposed changes. But it all had to be requirement-centric with detailed requirement flow-downs from the stakeholder needs (the R in RFLP) through the functional and architectural breakdown (the FL in RFLP) to printed circuit boards (PCB), field-programmable gate arrays (FPGA), and software modules (the P in RFLP). Safety regulations required that all reuse decisions be backed up with the results of simulations on the modeled structures, test results on the physical assemblies (the T in the extended RFLP+T), and traceability of the reuse decision process.

The additional requirement had to do with how the top-level requirements flow-down resulted in the allocation of the target functionality and optimization of the resulting overall performance across specific implementation domains: PCBs, FPGA, and software. Before a domain specific requirement can specify the target value, engineers must collaborate to achieve an optimum result across domains. A good example is the target control signal latency that is simultaneously affected by the software algorithm, PCB signal integrity, and the FPGA pin input/output (I/O) buffering. Domain specific requirements and parameters (e.g.: percentage of latency allocated to the PCB interconnects) can be committed to only after this type of analysis and optimization is performed and recorded.

Fundamentally the manufacturer was looking for a requirements management capability that:

- Is based on the concept of requirements flow-down and percentage allocation across linked and traceable MBSE data model (the RFLP)
- Is part of the PLM platform's overall product lifecycle management

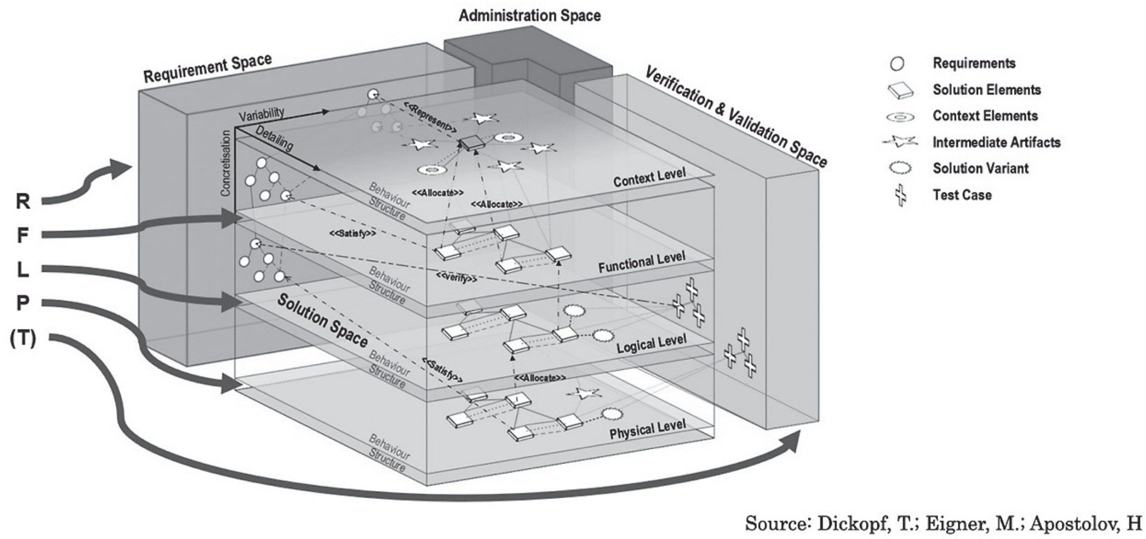

Fig. 4 Layers of the MBSE RFLP Representation

- Enables a cross-domain parametrically driven optimization
- Includes traceability and configuration management in the context of all ancillary artifacts such as decision-making, collaboration, simulation, testing, supporting documentation, and others

The manufacturer was highly skeptical of being able to reach the goal because of prior history with legacy PLM solutions and the inability to extend their hard-coded data models and business logic in a way that is compatible with MBSE's RFLP data representation. It was the limitation of the underlying legacy PLM architectures. The manufacturer engaged with Aras on an educational process of what the key issues were, the key elements of a possible solution, and a set of incremental PoC demonstrations of what's possible to configure on their existing Aras Platform. While the project is still in early stages, it is clear that a modern PLM platform can support a requirements driven MBSE process as an alternative to standalone tools that are fundamentally disconnected from the overall RFLP layers.

5. Conclusions

The use of a PLM platform with an inherent digital thread capability is critical to any successful digital transformation. Planning involves considering the needs of, and impact on, people, processes, and tools. It is more of a journey than a project although individual steps of that journey should be managed as specific projects to measure the progress and effectiveness of the related activities, and to make a course correction if needed.

That journey aspect is important because no organization is ready to implement a complete digital thread all at once, tool vendors do not have all the functionality required to do it OOTB, and the ongoing changes in design, manufacturing, and interconnecting technologies keep redefining the ultimate digital thread target. MBSE and the ever-increasing reliance on simulation are a perfect case in point with new data models and requirements for traceability. As a result, different manufacturers and different teams within their organization are focusing on different aspects of the digital thread by creating local (team specific) partial digital threads. To ensure future traceability between these partial threads it is critical to make sure that they all can trace back to the same overall system model—a common context. The three use cases discussed in this paper are perfect examples of that.

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Paweł Z. Chądzyński, born in Poland in 1954, is currently driving strategy and direction for the advanced solutions on the Aras PLM Platform including requirements, MBSE, simulation, ALM and the related inter-disciplinary design methodologies. Before Aras Paweł specialized in CAD technologies for design of complex printed circuit boards and held several management and technology leadership positions at Cadence, PTC and a small software startup OHIO-DA that was acquired by PTC. Paweł graduated from POLY/NYU with a MS degree in Technology Management in 1982. He also holds BS in EE/CS from the same institution.