Kepstrum

Feb 10th, 2023

CUTTING COSTS THROUGH DIGITALIZATION

ENHANCING THE POWER OF MBSE WITH THE DSP

The business landscape has undergone a dramatic change due to the impact of technology on internal processes, production methods, and customer connections. In today's highly competitive market, digitalization is crucial for success, especially in the manufacturing and product development industries where new technologies are being rapidly developed to meet evolving and previously non-existent or non-ubiquitous market demands such as electrification. To truly keep pace with rapidly changing market demands and regulations, engineering companies must not only adapt their business platforms but also their engineering methodologies.

To achieve reliable results in technology developments with limited historical data and to eliminate the risk and high financial and reputational costs of unforeseen product failures, a shift to physics-based deterministic development processes must accompany the necessary shift to using digital platforms. This is where Kepstrum's DNA Structured Platform (**DSP**) comes in, an enterprise-level database software that combines the best aspects of Model-based Systems Engineering (**MBSE**) with physics-based modeling and Kepstrum's patented risk reduction methodology, named Intelligent Reliability Methodology (**IRM**) US 9,612,933, allowing organizations to take advantage of the benefits offered by digital platforms while ensuring the quality and reliability of their products.

Engaging a Comprehensive Digital Transformation With MBSE

A digital transformation can be said to be successful if it manages to increase an organization's collaborative capability (connectivity), their processes' transparency and traceability, product reliability, manufacturing consistency, market adaptability, and reduce procedural and material waste. Any one of these facets of a business's operation can be improved with various enterprise resource planning (ERP) systems, methods, and platforms, but for engineering companies to make a robust and enduring digital ecosystem, these benefits should be pursued simultaneously within a Model-based Systems Engineering platform; "MBSE is a formalized methodology that uses models as the center of system design, as opposed to document-centric engineering. It supports the requirements, design, analysis, verification, and validation associated with the development of complex systems."[1] MBSE enables an organization to create and manage a single digital thread, "a data-driven architecture that links together information generated from across the product lifecycle and is envisioned to be the primary or authoritative data and communication platform for a company's products at any instance of time"[2]. A digital thread "connects traditionally siloed elements in manufacturing processes and provides an integrated view of an asset throughout the manufacturing and product lifecycle."[3]

Adopting a Model-based Systems Engineering (MBSE) platform and creating a Digital Thread can provide a number of business benefits, including:

- **Improved Collaboration:** MBSE platforms enable stakeholders to access and collaborate on a single, consistent digital representation of the system, which can lead to improved communication and coordination among team members.
- **Increased Efficiency:** MBSE's centralized structure can streamline the systems engineering process by minimizing errors and inconsistencies that arise from "broken telephones" in the design process.
- **Enhanced Traceability:** A Digital Thread provides a complete, end-to-end record of a system's development, including design decisions, requirements, testing results, and changes made over time. This can help ensure accountability and facilitate complex problem-solving.
- **Better Decisions:** MBSE platforms provide decision-makers with access to a wealth of data for informed decision-making
- **Improved Reusability:** By capturing and storing information in a digital format, it becomes easier to reuse and repurpose the information for other systems and projects, saving time and resources.

Quantifying the savings that can be achieved by switching to MBSE development and production processes can be hard

1. Shevchenko, Nataliya. "An Introduction to Model-Based Systems Engineering (MBSE)." Carnegie Mellon University, Software Engineering Institute's Insights (blog). Carnegie Mellon's Software Engineering Institute, December 21, 2020. http://insights.sei.cmu.edu/blog/introduction-model-based-systems-engineering-mbse/. Accessed 29 Jan 2023
2. Singh, Victor, and K. E. Willcox. "Engineering Design with Digital Thread." AIAA Journal, vol. Volume 56, no. Number 11, 2018, pp. 4515-4528. Aerospace Research Central, https://arc.aiaa.org/doi/10.2514/1.J057255. Accessed 31 Jan 2023.
3. Diann, Daniel "Definition: Digital Thread" https://www.techtarget.com/searcherp/definition/digital-thread. Accessed 29 Jan 2023.

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given the variation between and within different industries, but in 2015, Embedded Market Forecasters (EMF) published the results of 6 years of survey data[4] wherein they established that the "addition of model-based systems engineering delivers a 55% reduction in total development cost", and that "MBSE developments have not only proved to be less costly but have continued to cost less as experience with MBSE has increased." The ROI of MBSE only compounds as organizations fully adopt the system and move from modeling individual products to entire product lines. The increasing ability to re-use assets and knowledge in a mature MBSE environment only enhances the benefits.

EMF also acknowledged that MBSE enables faster development times with fewer development delays, using smaller, more effective and more connected engineering teams. The inherent benefits of such a system mean that projects aren't just completed 2-3x faster than similar endeavors pursued within the context of traditional development cycles, they are also delivered at a higher quality that is closer to the pre-design expectations that were outlined in the product and system requirements.[5]

Organizations that employ MBSE systems in their production methods are not just more cost effective, they are more competitive; they can more easily respond to time-sensitive market opportunities, old assets can be easily upgraded, and disconnected knowledge and experience can be leveraged to meet those opportunities. The increase in productivity and savings may be variable but are nonetheless undeniable; scaled to an organization's individual circumstances, with factors such as product complexity, production volume, and other project-specific elements influencing the potential savings a MBSE infrastructure can deliver.

Enhancing MBSE with a Focus on Reliability

The benefits of engaging a digital transformation with MBSE are clear, but the increases to product reliability are a by-product of improved collaboration and traceability. Kepstrum's DSP enables an organization to capture all the benefits of creating a digital thread in a robust MBSE platform while also embedding an explicit focus on reliability into the organization's engineering design and manufacturing processes. The DSP facilitates the computer-aided implementation of Kepstrum's U.S. Patented Intelligent Reliability Methodology (IRM). The guided implementation of this risk reduction methodology within the DSP is focused on protecting new products and platforms against recalls and undefined field failures by facilitating the creation of deterministic designs and placing physics-based models at the core of the digital threads and system models that are used to represent products.

IRM further compounds the savings that can be achieved with MBSE platforms by revealing design weaknesses before physical prototyping, and quantifying design uncertainties. The time and economic costs of re-work, re-designing, producing and re-testing components, can almost be entirely eliminated. Furthermore, using algorithms derived from Kepstrum's deterministic analysis, traditional test-to-pass testing can be replaced with design limit testing that enables organizations to reduce development testing significantly, while simultaneously empowering end-of-line tests to identify material variation in half the time of conventional testing.

The Importance Of Physics-Based Modelling in Engineering & Manufacturing Industries

The DSP was designed to help organizations improve their product development processes and reliability by serving as a platform for documenting, managing, and fully integrating physics-based analytical models into their development processes, all in the context of a modernized MBSE platform. In addition to the extensive library of physics models that are accessible to all DSP users, the DSP facilitates the gathering and application of an organization's knowledge and expertise to convert them into physics-based models to help tackle any challenges that the organization's R&D departments may face as they continue to push technological boundaries. The benefits of this physics-based foundation of a digital thread are clear when taking a closer look at another important tool in the modern technological development arsenal: Digital Twins.

4. Krasner, Jerry "How Product Development Organizations Can Achieve Long-Term Cost Savings Using Model-Based Systems Engineering (MBSE) ---How financial managers can achieve lower costs of development, faster deployment of new products, and lower ongoing maintenance costs". October 2015. Docplayer.net https://docplayer.net/18566603-How-product-development-organizations-can-achieve-long-term-costsavings-using-model-based-systems-engineering-mbse.html , Accessed 31 Jan 2023.
5. Carroll, Edward Ralph, and Malins, Robert Joseph. 2016. "Systematic Literature Review: How is Model-Based Systems Engineering Justified?.". United States. https://doi.org/10.2172/1561164. https://www.osti.gov/servlets/purl/1561164. Accessed 2 Feb 2023

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Digital twins are virtual representations of physical systems or products and are created by integrating real-time data from sensors and other sources with models of the physical asset. The models created in MBSE platforms can be used to create a digital twin, which can then be used to simulate the behavior of the physical asset in real-time, allowing for real-time monitoring, prediction, and optimization of the asset.

Digital twin technologies have a number of values, including:

- **Improved design and testing:** By creating a virtual representation of a physical system, digital twin technology allows for improved design, testing, and optimization of that system before it is built or implemented.
- **Predictive maintenance:** Digital twin technology can be used to monitor and predict the behavior of physical systems, enabling more proactive maintenance and reducing the risk of unexpected failures.
- **Increased operational efficiency:** By providing real-time insights into the performance of physical systems, digital twins can be used to optimize operations and improve efficiency.
- **Better decision-making:** By providing a complete picture of a physical system and its interactions, digital twin technology can support better decision-making by providing a deeper understanding of system behavior.

Digital Twin solutions can increase revenues by "10 percent, accelerate time to market by as much as 50 percent, and improve product quality by up to 25 percent" [6], and are projected to grow 10x in the next five years. Engaging a digital transformation with a digital twin capable foundation is important, but not all digital twins are created equal.

Organizations pursuing digital twin technologies have the option of either using numerical or analytical methods as a foundation for modelling the real world operation of their products. The main difference between these two types of modelling lies in the underlying mathematical models used to represent the system being studied. In the context of traditional engineering development, digital twins are built only using numerical simulations that use mathematical models and algorithms to simulate the system's behavior and solve complex problems. The goal of numerical simulation is to find approximate solutions to these problems by breaking them down into smaller, simpler parts that can be solved computationally. The models are based on assumptions about the system and its behavior, and thus cannot provide exact solutions.

While this method can provide valuable insights and predictions, there are some limitations to consider:

- **Modeling limitations:** Numerical simulations can only provide an approximation of the real-world system. The accuracy of the simulation depends on the accuracy of the mathematical models used, which may not fully capture all of the physical processes involved.
- **Computational cost:** Depending on the complexity of the system being modeled, numerical simulations can be computationally expensive, requiring significant amounts of time and computer resources.
- **Lack of transparency:** Numerical simulations can be complex and difficult to interpret, especially for non-experts. This can make it challenging to understand the underlying physics of the system being modeled, update the underlying models, and validate the results.

On the other hand, in the context of the deterministic development process that the DSP facilitates, digital twins are built by first using predictive models that rely on physical laws and principles to describe the behavior of systems. The predictive models are based on first principles and analytical closed-form equations, to provide a precise representation of the physical behavior of a deterministic system. Engineering teams are able to generate the appropriate models that can explain the behavior of the physical system under a wide range of conditions (flex analytics), without the boundaries of fixed analytics offered by typical simulation packages. The deterministic boundaries and predictive life models generated by the DSP can be fed to simulation teams who can then focus on performance optimization and use their simulations as virtual test benches, allowing these two scientific computing methods to converge to minimize necessary physical testing while increasing reliability.

6. Brossard, Mickael, et al. "Digital Twins: The Art of the Possible in Product Development and Beyond." McKinsey & Company, 30 Nov. 2022 https://www.mckinsey.com/capabilities/operations/our-insights/digital-twins-the-art-of-the-possible-in-product-development-and-beyond , Accessed 29 Jan 23

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The Foundation of our Digital Thread: Digital Spec.

The DSP's Model-Based Systems Engineering (MBSE) architecture and digital twin capabilities start with Digital Spec. (Patent pending: US 18/107,075), our tool for converting traditional product specifications and requirements into digitized functional profiles made of signals. A Digital Spec. profile is the comprehensive and integrated representation of a product as it evolves from the concept stage to a physical product and can represent information about the product's functional requirements before being expanded upon to model and visualize the product's complex functions, interactions, and stresses as the design process advances. In true MBSE fashion, Digital Spec. profiles eliminate the ambiguity and complexity of analyzing complex product requirements in wordy, uncorrelated specification documents and emails. The Digital Spec. is the main engine of the DSP, and can be used as direct inputs to other functions within the DSP.

Enhancing MBSE with IRM and Product DNA

Once the product requirements are captured in the Digital Spec., the engineering teams are enabled to make use of Kepstrum's Intelligent Reliability Methodology. As previously mentioned, IRM is broadly used to protect new products and platforms against recalls and undefined field failures. It uses Multi-Stress/Failure Mechanism interaction analysis techniques to reveal product weaknesses and suggests design solutions in the early stages of development and prototyping. IRM is a systematic and knowledge-based process to generate model-based prognostics for any product. Once the Digital Spec. profiles are expanded upon to model a product's internal functions and external interactions, the product's capabilities are determined by using the profiles, and their constituent signals, as direct inputs to the DSP's analytical mathematical computing functions to generate the product's DNA (Design Limit, Nature of Failure, Actual Life).

Product DNA is an index encompassing a comprehensive multi-variable stress-life model that determines the product's true life expectancy and provides a repeatable and traceable reliability measure that correlates stress-drivers with how and when a product will fail. The DNA Map integrates all the elaborated knowledge represented in the product's digital thread and creates a synergy among qualification tests, calculations, stress limit tests and the analysis of field returns and digital twin data, which are all accessible through one database. With this index and understanding of a product's real world capabilities and limits, manufacturers can eliminate recalls and gain a clear understanding of their safety margin, enabling the highest degree of confidence amongst all stakeholders of the organization. For existing field issues, IRM uses the same tools to replicate problems and generate multiple design options to resolve them. By providing the ability to map failure modes to failure mechanisms and related stresses, IRM enables organizations to generate "lessons learned" quickly, enabling them to resolve complex issues in a fraction of time and cost of conventional methods.

Enhance Productivity, Optimize Costs, & Seize Market Opportunities with the DSP

The DSP optimizes product cost and reliability for engineering teams by consistently digitizing product requirements into the integrated Digital Spec. format in order to understand their capabilities in real world operating conditions. By overlaying customer requirements on the product's capability, engineers can quickly respond to customer RfQs (Request for Quotation), thus empowering the engineering teams to continuously seek new market opportunities for their products. The MBSE architecture of the DSP enables cross-talk amongst engineering teams to solve complex problems and enables them to develop better and more informed product market strategies. By envisioning new and innovative systems and applications for the engineering team's existing products, it empowers the engineers to conceptualize, design and manufacture more efficient and powerful variations of their products. Advanced Engineering teams are enabled to design new products and generate new revenue streams, while simultaneously eliminating costly trial and error methods to accelerate product development and save time. The DSP connects products, systems, and applications in a physics-based modeling environment to understand the risk and reward of committing to new product developments.

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The Future of Manufacturing and Engineering with MBSE

MBSE is the future of industry planning and manufacturing, and encapsulates a revolution in communication capabilities and processes that carry with them a variety of procedural benefits that any organization would find value in. But MBSE on its own serves only to stream-line and improve existing development processes in a new and superior digital environment. MBSE platforms, as the environments in which digital threads and digital twins are created, run the risk of establishing dated engineering methodologies in superior digital environments.

Traditional design processes reliant on experiential knowledge, historical data, numerical simulation, and probabilistic models of product capabilities, can be better implemented than they are at present, but without truly eliminating the risks and shortcomings of such methodologies. With the rapid changes we are experiencing in various engineering industries, and the exponential increase of new technological developments with limited historical data, it is increasingly dangerous to rely on prior field data, numerical simulation, and test-to-pass testing. For companies to succeed, they must undergo a comprehensive digital transformation that goes beyond simply moving their operations to digital platforms, and escape the confines of traditional, probabilistic, and experience-based product development processes.

The DSP empowers an organization to capture all the benefits of adopting the MBSE methodology, providing engineers with a collaborative platform to design and qualify complex products against different applications, and to create a single digital thread that connects all the aspects of their product development, from design, to testing, to manufacturing, and finally to field monitoring in order to give all stakeholders an integrated view of a product throughout its life cycle. The DSP goes further than typical MBSE platforms in that it facilitates the computer aided-implementation of our patented IRM engineering methodology and uses physics-based analytical models as the basis of these digital threads and the system models that represent the product in development or production, enabling the necessary transition to deterministic development processes.

"We must boil it down to first principles, to generate physics-based life models, which will increase reliability for new components without historical data, in order to eliminate recalls."

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