

# SIMPLIFYING COMPLEXITY THROUGH MODEL-BASED SYSTEMS ENGINEERING

Case studies from thyssenkrupp Marine Systems and Lockheed Martin



Complex systems have always existed, and manufacturing has always tested even the brightest engineers. But in recent decades there has been a profound increase in the *level* of complexity with which most companies must cope and also a rapid increase in the *rate* at which complexity is accelerating. Examples include driverless cars; autonomous Urban Air Vehicles (UAVs); quantum computing; and 5G, the next generation of mobile connectivity technologies. Never before have manufacturers been so challenged to design, build and deliver new products on time, on cost and that meet customers' performance expectations.

Innovating and manufacturing in such an environment demands a different way of thinking—namely, modeling to support system requirements, design, analysis, verification and validation. All these essential steps must begin in the conceptual design phase and continue throughout a product’s lifecycle. Model-Based Systems Engineering (MBSE) alone, however, isn’t enough to manage the complexity of systems of systems. Specialized tools that enable all project stakeholders to share a common language and methodology to collaborate across functional disciplines in the early product phases help avoid costly technical changes made late in a product’s development cycle.

No Magic Inc.—the leader in MBSE and modeling solutions for software architecture and business processes—joined Dassault Systèmes following an acquisition in 2018 and is currently being integrated into the **3DEXPERIENCE®** platform. No Magic users— including users of core product MagicDraw— span industries and include leading companies such as BMW, GE, Pfizer, Lockheed Martin, thyssenkrupp Marine Systems among many others.

In the profiles that follow, engineers share their first-hand experience implementing MBSE. Both describe how No Magic—used in combination with MBSE—has helped their organizations address the challenge of managing complexity.

### **thyssenkrupp Marine Systems**

When thyssenkrupp Marine Systems decided five years ago to make MBSE its standard approach to product development, the company sought to address two types of persistent challenges:

1. How to simplify the management of interfaces between the vast number of subsystems that comprise diesel-electric submarines. The company builds the submarines for more than 20 nations and its Howaldtswerke-Deutsche Werft (HDW) Class 209 vessels operate in every ocean.
2. How to help suppliers better understand thyssenkrupp’s exacting requirements to ensure flawless integration of subsystems during assembly at thyssenkrupp shipyard in Kiel, Germany.

“You would need to understand what we produce to appreciate why resolving these challenges was vital,” said Piotr Malecki, an electrical engineer by training and now a systems engineer who has worked at the company for 20 years.

Submarines notoriously demand precision engineering and construction. All interfaces and systems integration must be perfect to ensure the vessels remain undetectable while submerged. To achieve maximum stealth, the submarine’s air-independent propulsion (AIP) system has no moving parts. Each class of submarines is custom-built for specific customers and they are manufactured in small series without the benefit of a prototype prior to the start of production.

No Magic helps simplify the systems engineering complexities between interfaces—the shared boundaries between mechanical, electrical, electronic, computer and other kinds of components. Using No Magic provides a standards-based means of communications that all parties can understand when describing problems and agreeing on solutions, according to Malecki. “This [No Magic] unified methodology increases the efficiency of developing complex systems of systems,” he said.

Engineering disciplines typically work in silos and have their own means of expressing technical information, Malecki noted. “Unfortunately, discipline-specific engineering-speak is not well-suited to conveying ideas in a way that’s universally understood, and this is why a common language that’s clear to all project-team members and potentially to stakeholders is key,” he said. “To overcome these communications gaps, a modeling language unifying multiple [software] languages is essential.”

The common language employed by No Magic users is Systems Modeling Language (SysML), which allows all project members to share information gathered. By offering a more complete representation of systems, SysML helps reduce errors and ambiguities during systems development processes. Based on Unified Modeling Language (UML), SysML ensures that the precision of the information between engineers in early development phases is more accurate. Being an open standard, SysML allows information interchange to other systems engineering tools such as Computer-Aided Design (CAD), electrical and engineering analysis tools.

The fact that No Magic is a strongly standards-compliant application of modeling to support systems requirements, design, analysis, simulation and verification is “extremely important,” Malecki said. The purpose of a simulation is to gain system understanding without manipulating the real system, either because it is not yet defined or available, or because it cannot be accessed directly due to cost, time, resources or risk constraints.

Application of the analytical features of No Magic tools provides assurances that all of the technical information that goes into thyssenkrupp's models—such as the definition of interfaces and engineering diagrams—will be comprehensible to everyone. Further, as those models are updated throughout a product's development, they continue to provide an unambiguous and precise model of the system that can be evaluated for consistency, correctness and completeness. Martin Neff, a Dassault Systèmes systems engineer learning-experience expert, calls this process "a democratization of MBSE."

"No Magic cuts through the complexity of sharing information among engineering teams from the start," Malecki said. "As a result, the end product we want to build is likely to be better designed, with better outcomes and fewer surprises at later stages of the project. That saves time and money."

Systems complexity is very difficult to manage, according to Malecki. "You must first overcome the challenge of how to recognize it. Only then can you begin to take the steps necessary to simplify complexity to what's most essential." In an oversimplistic illustration to make his point, he asks rhetorically what else is a human heart but a pump, two valves and two pipes? "But is this level of understanding sufficient for a surgeon to perform a transplant?"

It's only natural for engineers to want to see everything in its simplest form, but that isn't always as easy as technologists would like, he said. "There are different levels of complexity. MBSE and No Magic provide the capability to help us understand complexity and simplify it to what we need to know so we can better manage it." Malecki shared a wise quote by English novelist and essayist G.K. Chesterton that sums up the essence of the difficulty of managing complexity. "It isn't that [technologists] can't see the solution. It is that they can't see the problem."

Besides "cutting through complexity" to identify a problem, Malecki said an added benefit of MBSE and SysML is that they provide a virtually unlimited repository of information among adopters, all due to standards. "It gives you access—complete openness—to the full knowledge of the industry," he said. "This is a value you can't express monetarily."

Integrating No Magic into MBSE processes isn't exactly a turnkey "plug and play" exercise. He cited the prerequisites for success. First, there needs to be a core team dedicated to MBSE, unwavering in their belief that MBSE brings value to the enterprise. Second, visionary managers open to solving problems and improving the product development process in an unconventional way should be leading the organization. "One doesn't work without the other," Malecki said. Establish realistic expectations, exercise patience, trust that you are doing everything you can to succeed and provide a safe environment for learning. As we apply MBSE, we are very careful to observe what helps us the most and to learn from our failures.

Pressed to reveal his company's Return on Investment (ROI) from the implementation of MBSE using the No Magic toolset, Malecki believes measuring ROI would be very difficult, because that

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**Piotr Malecki, Systems Engineer, thyssenkrupp Marine Systems**

### **thyssenkrupp Marine Systems**

**thyssenkrupp Corporate 2019 Sales: ~USD46 billion (~€41.2)**

**thyssenkrupp Corporate Headquarters: Essen, Germany**

**thyssenkrupp Marine Systems Headquarters: Kiel, Germany**

**Scope of MBSE Implementation: thyssenkrupp Marine Systems**

**Date of MBSE Implementation: 2015**

**Number of No Magic users: 30**

**Projects Where No Magic Is Used: Selected surface vessel and submarine programs**

**Year MBSE First Implemented: 2008**

**Challenges No Magic Intended to Address: Simplify interface management, better express the requirements on system integration**

would require comparing one set of Key Performance Indicators (KPIs) against another. “Given where we apply No Magic—first-time product development that’s new— and our long product cycles to complete a large, complex project, measuring ROI may be impractical,” he said.

“However, we’ve learned over the years that if you want a [software] partner who shares your commitment to MBSE and helps you solve your problems, you’re in the best possible hands with No Magic,” Malecki said. “That doesn’t mean there is a solution to every kind of problem, but No Magic does not make that claim. That’s part of the trust they bring to a working relationship.”

Dassault Systèmes wants to help customers measure No Magic’s value by developing a methodology. “Instead of winning the hearts of just the systems engineering community, we’ll also start winning the hearts of the accounting department,” said Moy Speckman, senior director of Cyber Systems for Dassault Systèmes.

Most No Magic customers already believe they are getting good value for their investment compared to No Magic alternatives, according to Speckman. thyssenkrupp Marine Systems is one such customer. “You get a lot for your money,” Malecki said. “No Magic strikes a good balance between the prices charged and the value delivered in terms of their tools and customer service.”



#### Submarine and surface ship on the open water

The HDW Class 209 diesel-electric submarines and the MEKO family of surface warships built by thyssenkrupp Marine Systems have a reputation for technological excellence and adaptability.

Photo courtesy of thyssenkrupp Marine Systems

## LOCKHEED MARTIN

No Magic was established in 1995 based on the founders’ belief that “no magic” should be required to develop better software. They posited that the real secret to an organization’s success was investing in disciplined software development and rigorous staff training. Ten years later, No Magic maintained small player status in a field dominated by giant computer, software and information-services companies. Soon afterward, the company “really took off,” recalls Lockheed Martin’s Laura Hart, senior manager of the Model-Based Solutions Group supporting Lockheed Martin’s corporate-wide digital transformation. Lockheed Martin is a No Magic customer.

“No Magic made impressive strides in the systems engineering community in a relatively short period because of their dedication to understanding the customer’s needs,” she said. “They demonstrated this time and time again by actively participating in leadership roles in both professional and standards organizations, such as International Council on Systems Engineering (INCOSE) and Object Management Group (OMG) where they collaborate with their customers in industry and government. The results are better standards such as SysML and United Architecture Framework (UAF), as well as compliant software with richer features.”

When Lockheed Martin first started working with No Magic, there was no contest when comparing them with a large [systems engineering solutions] provider, according to Hart.

“Yes, No Magic’s tools are better, but they also jumped in to help us retrain our workforce and manage another set of [software] licenses,” she said. “All of it had to be not just a little better, but a lot better—and it was. They’ve been a lifeline to their customers.”

Companies engaging Dassault Systèmes to leverage everything that No Magic, now called CATIA® Magic, offers is far more than just a business transaction, according to Neff. “Dassault Systèmes partners with companies to make sure they extract the full value,” he said. “The speed with which an organization can integrate the tools into its product development processes depends on the maturity of the organization’s systems thinking.”

Perhaps the most compelling reason Lockheed Martin adopted No Magic was its open standards, according to Hart. Lockheed Martin was heavily vested in other systems engineering tools and “many [software] licenses” by the time No Magic appeared on its radar. Around the same time, Lockheed Martin was attempting to perform what Hart described as “some pretty advanced integration” using software tools by a No Magic rival. Its interfaces to other integration tools proved to be unworkable. “We couldn’t keep using something that kept changing out from underneath us,” she said.

Lockheed Martin found itself in a tough position. Even though the No Magic tools offered the best features and standards compliance, the expense to procure all of the systems engineering software tools from a single vendor was prohibitive. The decision to operate in a heterogeneous environment was possible since the No Magic Cyber MagicGrid adapts to any given system. (Before its acquisition by Dassault Systèmes, No Magic developed Modeling Methodology for Systems© (MMS) and MagicGrid©. Each method addresses a slightly different scope of system engineering processes.)

Standards-compliant best practices based on sound systems engineering methodology is a key success factor of MBSE, according to Hart. “We have to be able to support more than one tool, and with No Magic’s high level of compliance, we’re able to use a standard language and standard methods—clear and unambiguous representation of concepts—without having to also teach cumbersome workarounds for exceptions. Teaching systems engineering fundamentals is now much more efficient,” she said.

Hart has been an advocate for using MBSE since 2003. She worked for Lockheed Martin for 15 years when she accepted an offer in the mid-2000s to join one of the premier federally funded research & development (R&D) laboratories in the United States. Lockheed Martin lured her back to the company when then President, Chairman, and CEO Marilyn Hewson supported a top-down transformation of all of Lockheed Martin’s manufacturing processes—including the implementation of MBSE—across the corporation. Hart estimates the massive undertaking is about 40 percent complete, as of mid-2020.

Lockheed Martin and the industry at large have long advocated for tools that comply with standards, with the end goal of tool interoperability across engineering domains, as well as to avoid “vendor lock” (getting stuck with a particular tool vendor) because then the company would be locked up in a proprietary format, according to Hart. “The end goal is a total digital transformation across a product’s lifecycle, including sustainment,” she said. “Because of No Magic’s hands-on role within the standards working groups, [No Magic] usually releases a new version of their tool six months to a year earlier than their competitor, and it’s usually more compliant.”

**“A key output of MBSE using MagicDraw is a system model that can be used as an integrating construct to realize a larger collaborative digital tapestry spanning design, manufacturing, production, test and sustainment through the use of advanced models and technologies.”**

**Laura Hart, Senior Manager, Model-Based Solutions Group**

## **Lockheed Martin**

**2019 Sales: ~USD 60 billion**

**Headquarters: Bethesda, Maryland**

**Scope of MBSE Implementation: enterprise-wide**

**Challenges No Magic Intended to Address: Accelerate the efficiency of complex systems development, and help support advanced integration of complex systems.**

Hart's team matures technologies that it inserts into Lockheed Martin's digital transformation program, she said. The team identifies gaps and needs, and develops integrated solutions to fill them. I like No Magic, but I'm more interested in knowing we have a tool that is accelerating the efficiency of the development of complex systems through the application of Model-Based Systems Engineering."

Beyond helping Lockheed Martin be more innovative in building advanced aerospace platforms, Hart sees an equally important role for MBSE and No Magic in capturing the institutional knowledge in large high-end, long-lived programs that might be in production for 20 year or more. Lockheed Martin has many such programs in which maintenance, repair and upgrades are big issues, and sustainment is critical. "Some of that knowledge gets lost when team members leave the company and can result in over-constrained systems over time," she said.

"No Magic is a perfectly good tool for tracking program decisions," Hart said. "It's really about the longevity of all of the aircraft programs—not just 'here's the design,' but 'here are the design decisions.'" Without knowing those decisions, manufacturers might be hesitant to upgrade a legacy aircraft without understanding why a certain decision was made, she explained. MBSE creates a digital data trail—a knowledge repository—allowing engineers to make whatever changes are necessary to upgrade those aircraft or create variants more efficiently and more cost-effectively.

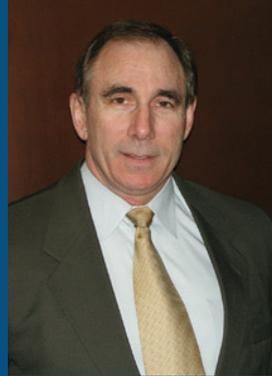
## **SOLVING REAL-WORLD CHALLENGES**

What engineering-oriented manufacturer cannot relate to the challenge of managing growing complexity in the Digital Age? Engineering-driven manufacturers must figure out how to solve difficult problems across domains to successfully design and build systems of systems using Model-Based Systems Engineering. Lockheed Martin, thyssenkrupp Marine Systems and many other can attest as much.

### **CATIA MAGIC AND THE 3DEXPERIENCE PLATFORM FOR MBSE**

With CATIA Magic, MBSE enables engineers to access data ubiquitously and transparently without having to rely on peer-to-peer integrations. With the acquisition of No Magic, Dassault Systèmes reinforces its systems engineering capabilities and Industry Solution Experiences based on the **3DEXPERIENCE®** platform. Industry can now develop the "Internet of Experiences"—smart and autonomous experiences that digitally connect products, nature and life in the physical world. The No Magic solutions are integrated on the **3DEXPERIENCE®** platform to develop a best-in-class Model-Based System Engineering and System of Systems Engineering solution and offering renamed CATIA Magic. CATIA Magic solutions, the most robust and standards-compliant in the market.

## ABOUT TONY VELOCCI



Tony Velocci is former Editor-in-Chief of Aviation Week & Space Technology (AW&ST) magazine and Editorial Director, Aviation Week Group. At the end of 2012, he retired from The McGraw-Hill Companies, Aviation Week's parent company. He remains deeply interested in technology and engaged in the aerospace industry. He is on the board of directors for the National Aeronautic Association and the Industry Advisory Board for Embry-Riddle Aeronautical University.



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