Model-Based Systems Engineering

Business Opportunities and Overcoming Implementation Challenges

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Introduction

CIMdata has recently executed a survey on model-based systems engineering (MBSE). The survey was targeted at expanding knowledge about where and how companies that design a wide variety of products have deployed MBSE to support and enhance their product development processes and to discover associated business value. This report provides both background information on MBSE as a strategy, its benefits, and application of technologies as well as some key results from the survey.

The respondents to the survey came from a spectrum of company sizes with the majority falling into revenue bands at the high and low extremes—a 46% of companies had revenues greater than $5 billion, while 25% had revenues of less than $100 million. These results are consistent with other surveys we have executed related to systems engineering, and CIMdata believes that ~25% of responses being from very small companies is indicative of the ability of small company executives and their corporate cultures to achieve a systems engineering strategy more easily than for larger more complex organizations. All of the survey responses were from either North America (73%) or Europe (27%). Figure 1 shows the industries represented.

![Figure 1—Industry Distribution of Responses](image-url)
The Changing Nature of Product Development

Manufacturing companies, particularly those who develop complex electromechanical systems with significant electronics and software content are facing increasing challenges and risks in developing innovative new products with ever shorter lifecycles. Sophisticated global consumers are increasingly demanding customization of products that have the latest technological features but must be efficiently mass produced using common product architectures, software, components, and sub-systems. Moreover, the “Internet of Things” points to a future where electronics and software content will be pervasive in almost every product that has any tangible or perceived value to consumers.

As industry has evolved, so too have the tools for designing and building increasingly complex products. Product complexity takes many forms, with 3D product geometries being more complex due to functional and styling concerns, but also through the more frequent combinations of new technologies such as electronics, embedded software, control systems, as well as products that rely on multiple physics domains (e.g., structural, thermal, fluids, chemicals, electromagnetics, acoustics, optics). The interactions among the combined domains increase the risks inherent in developing new products—delays in getting to market, reduced quality, catastrophic failures, more product recalls, personal liability claims, and many others. In addition to the product complexity issue, regulatory demands by governments and other organizations have become more strict, requiring detailed, traceable reporting for safety regulatory authorities as well as compliance of recycling or disposal of scarce or harmful materials and re-purposing of existing products and components. Globalization of markets, product development, and manufacturing has also resulted in a more complex product development situation.

These factors have led directly to increasing investments in upfront engineering to verify that a product design meets performance and compliance requirements well before it is manufactured or even prototyped. The time when multiple prototype iterations can be built and tested has passed; the process of prototype-test-prototype is simply too slow and too expensive for today’s complex products. Companies have used many techniques such as 6 Sigma and failure mode and effects analysis (FMEA) to help understand and mitigate risk. However, a more comprehensive approach that begins to minimize risk and control costs from the very beginning of product concept, and continues to decrease the potential for risk as the design matures is more productive. The survey results verify the problem. Over 66% of companies stated that number of parts, number of variants per product platform, and level of product customization all impacted their products’ complexity. More than 86% of respondents stated that they have had to implement formal engineering initiatives to allow them to deal with complexity and risk.
In response to these pressures engineering organizations are investing in systems engineering and model-based systems engineering in particular to gain deeper insights into their product designs to support better engineering decisions earlier in the product development cycle. The MBSE concept is described in detail below, but its essence is the application of visual and executable modeling principles to define a product virtually using systems engineering activities across all contributing domains—a set of models that support requirements management, product design and optimization, as well as testing and verification activities. The use of increasingly powerful modeling and simulation capabilities is key to assuring the product design is adhering to the requirements throughout the lifecycle, including those that represent capabilities in multiple domains such as relationships between software and electronics, and mechanical components and control systems.

**Introduction to MBSE**

Systems Engineering (SE) is an interdisciplinary approach to product and process development that focuses on defining customer needs and required functionality to satisfy those needs early in the engineering development cycle, documenting engineering requirements, then proceeding with design synthesis and system validation while considering the complete product definition and life cycle, including:

- Cost & Schedule
- Performance
- Test, Verification, & Validation
- Manufacturing
- Operations
- Training & Support
- Disposal & Recycling

Model-Based Systems Engineering is defined by INCOSE\(^1\) as the formalized application of modeling and continuous design validation to support systems engineering—requirements, design, analysis, verification and validation activities—beginning in the conceptual design phase and continuing throughout the products development and later life cycle phases. The fundamental difference between MBSE and traditional SE processes is that the authoritative system definition no longer resides in a set of static, text-based design documents, but rather in a living model. A model that provides a thorough understanding of the dependencies, data, and interfaces among the various sub-systems.

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\(^1\) The International Council on Systems Engineering (INCOSE) is a not-for-profit membership organization founded to develop and disseminate the interdisciplinary principles and practices that enable the realization of successful systems. See www.incose.org.
The stated goals and expectations of the INCOSE systems engineering community is that over the next decade (Figure 2) model-based and digital-based engineering processes will become the standard way that products (systems) will be designed, built, maintained, re-cycled, or re-purposed. In other words, MBSE is the natural evolution of systems engineering as it will be applied to the digitally based product development processes of the future. In order to remain competitive and deal with the complexity of modern systems and the global, collaborative nature of product development, companies must transition from dominantly “ad hoc,” disconnected and paper-based systems engineering approaches towards model-based processes and tools that are integrated with other enterprise software platforms (e.g., PDM, MCAD, ECAD, ERP, SRM, etc.) that have become accepted facilitators to bring new products to market.

Just as senior managers have embraced new enterprise-level design and PDM technologies and processes that have rapidly matured over the past several decades, they now need to actively endorse, nurture, and invest in the transition to a strategically driven MBSE culture and process. This transition is already taking place. The survey results indicate that 80% of companies have active management support for MBSE. As is the case with any new initiative, significant people, cultural, and organizational challenges exist in adapting today’s systems engineering best practices into a next generation MBSE framework. There will be cultural resistance due to existing organizational processes and information silos that run counter to the collaborative nature of an MBSE-centric process.
Ultimately, MBSE will not be successful unless it helps break down those communication barriers among all the stakeholders in the product development process. Realizing the benefits from having a common and unambiguous systems description for today’s complex systems requires a next generation digital-based approach. This includes activities such as finding requirements, design gaps, and inconsistencies so as to minimize engineering change orders; re-using modeling and design information within and across domains; increasing trade space exploration at the conceptual stage; improving systems-level testing and validation, in-service maintainability, and flexible design upgrades.

**Business Imperatives of MBSE**

The value of MBSE to any enterprise that builds complex electro-mechanical and software intensive systems stems from the ability of the MBSE platform to integrate the current silos of product development domains of embedded software, controls, electronics, and mechanical into a complete systems definition. This has a dramatic impact on key business metrics. Survey respondents were asked to rank the importance of key performance indicators for MBSE to determine their impacts on the software, electrical, and mechanical domains. Figure 3 shows the weighted value for all respondents. Clearly, traceability of decision making is important, but many other factors also benefit from the application of MBSE.

It is also clear from the survey results that software groups consistently ranked the business value of MBSE in all areas to be higher than electrical and hardware groups. This is attributed to the greater adoption of MBSE by software development organizations. CIMdata believes that software developers have understood the value of systems thinking because many possible solutions exist to any software problem—thus they need well-defined requirements that drive convergence of software developments to a correct and valid solution.

Each of these factors can be used as MBSE key performance indicators (KPIs) to monitor the business success and health of MBSE initiatives. In each case sub-metrics that roll up to a KPI need to be implemented and measured. Improved risk management for example could measure metrics for number of
risks (issues) identified, number of issues resolved in a time period, number of issues that are older than a certain number of weeks, and number of issues that cross domains. This would lead to a strong measure of current and outstanding risk.

The survey also asked about barriers to deployment. Figure 4 shows responses by percent of respondents. It is very interesting that all of the top-ranked issues have to do with culture and organization, which reinforces the fact that technology has to support people. Cultural issues are also a major impediment to other initiatives such as PLM adoption.

The use of modern, standard tools and languages is an important enabler to making technologies more accessible to users. Figure 5 shows the most used languages as reported in the survey. SysML is a clear favorite. This is influenced by the fact that it is a more modern language than UML and is often cited as being easier to use. The high level of DoDAF usage reported is influenced by the large number of A&D industry responses to the survey. The Other category was dominated by various structured methods as opposed to languages.

CIMdata considers MBSE solution platforms to be critical to successful deployments and use. To validate this assumption the important attributes of
MBSE solution platforms were ranked. Figure 6 shows the weighted ranking of all of the elements. Again, a people-related factor, ease of use, is most important. Just as with the introduction of any new strategy and technologies, adequate education and training are seen as critical to successful implementations of MBSE. The second most important enabling factor has to do with managing system requirements and linking them to design elements to support traceability.

The ANSYS MBSE Platform

For more than 40 years, ANSYS has been committed to enabling innovation by improving the way manufacturing companies design and develop products through Simulation-Driven Product Development.

The ANSYS vision for simulation-driven product development has been realized over the past two decades—via research and development as well as a number of strategic acquisitions. Starting with a focus primarily on component level structural analysis in the 1980s, the ANSYS portfolio now enables MBSE through 3D multiphysics modeling and simulation within the domains of mechanical, thermal, fluid dynamics, and electronics, as well as embedded software, controls and chemical reactions.

ANSYS’ technologies are not limited to detailed design and analysis within the individual engineering domains. In 2012 they extended their MBSE portfolio with the acquisition of Esterel Technologies to deliver a broad set of capabilities for model-based system design and verification activities. ANSYS SCADE System® is a SysML-based platform featuring functional and architectural system modeling with full traceability to requirements. Unlike other SysML tools, SCADE System is purpose built for system engineers and hides many SysML details making it easier-to-use. The MBSE platform from ANSYS is also tightly integrated with SCADE Suite®, an environment for embedded software design and automatic code production. This integration allows engineers to link system requirements to design elements and eventually the final implementation. These attributes of the ANSYS MBSE platform—
requirement traceability, ease-of-use, and linking requirements to detailed designs—have all been identified in the CIMdata survey as key attributes of an MBSE platform, see Figure 6.

It is also important to note, that ANSYS has made recent investments in Modelica, a broadly accepted and open standard for the behavioral modeling of mechanical, thermal, and fluidic systems. According to a recent press release, ANSYS will incorporate Modelica with its existing VHDL-AMS modeling technology for electrical systems and its SCADE™ technology for embedded software systems to support mechatronic system simulation. Add in the 3D multiphysics capabilities mentioned above, and engineers can explore product designs from the standpoint of complete systems all the way down through detailed designs.

**Recommendations for Deployment**

Preparing the organization to use MBSE so that it makes a positive impact can be a major challenge. From the survey responses shown in Figure 4, it is clear that, like many other strategies for product development (particularly those related to PLM) the main issue is how the organization can be encouraged to embrace the technologies put in place. People have to be convinced of the value of MBSE to the overall organization, as well as to their personal work processes. On the personal level, ease of use can be critical to acceptance. Education and training via both formal classes is critical to address the process changes and cultural issues that will ultimately dictate the success of implementing MBSE.

Because MBSE is not usually supported by a single solution, the concept of an MBSE platform that facilitates the flow of information among the various capabilities (from requirements definition to model definition to analysis and validation) is critical. Another important factor is how connected data is in the platform—requirements must be related to the models used to implement them, from the earliest concept to the final product definition.

At the organization level, to be most effective, MBSE must support the full product development process and all functional areas of the development team. Systems engineering is best when it is holistically deployed throughout the product development organization, not only in silos such as software development. CIMdata recommends a broad approach that considers all parts of the system modeling platform from requirements definition through low-level modeling that provides early validation continuing stepwise refinement until full product definition is achieved.

**Conclusions**

The survey results identified many business challenges associated with product complexity and the opportunity for addressing them with model-based systems engineering. Companies both large and small are implementing MBSE strategies and solution platforms that are providing benefits that accrue across multiple
domains (software, hardware, and electronics)—with software being the most advanced area today. The ability to create products in an MBSE environment that assures compliance to customer and other requirements is becoming more easily attainable and is providing a competitive edge to the early adopters of MBSE technologies.

The depth and breadth of ANSYS’ MBSE platform is impressive and continues to expand. Companies facing engineering challenges and who are planning to implement MBSE as part of their PLM initiatives should evaluate the special attributes of the ANSYS platform outlined above.

About ANSYS

ANSYS brings clarity and insight to customers’ most complex design challenges through fast, accurate and reliable engineering simulation. Our technology enables organizations—no matter their industry—to predict with confidence that their products will thrive in the real world. Customers trust our software to help ensure product integrity and drive business success through innovation. Founded in 1970, ANSYS employs over 2,700 professionals, many of them expert in engineering fields such as finite element analysis, computational fluid dynamics, electronics and electromagnetics, embedded software, system simulation and design optimization. Headquartered south of Pittsburgh, U.S.A., ANSYS has more than 75 strategic sales locations throughout the world with a network of channel partners in 40+ countries. Visit http://www.ansys.com for more information.

About CIMdata

CIMdata, a leading independent worldwide firm, provides strategic management consulting to maximize an enterprise’s ability to design and deliver innovative products and services through the application of Product Lifecycle Management (PLM) solutions. Since its founding over thirty years ago, CIMdata has delivered world-class knowledge, expertise, and best-practice methods on PLM solutions. These solutions incorporate both business processes and a wide-ranging set of PLM-enabling technologies.

CIMdata works with both industrial organizations and providers of technologies and services seeking competitive advantage in the global economy. CIMdata helps industrial organizations establish effective PLM strategies, assists in the identification of requirements and selection of PLM technologies, helps organizations optimize their operational structure and processes to implement solutions, and assists in the deployment of these solutions. For PLM solution providers, CIMdata helps define business and market strategies, delivers worldwide market information and analyses, provides education and support for internal sales and marketing teams, as well as overall support at all stages of business and product programs to make them optimally effective in their markets.
In addition to consulting, CIMdata conducts research, provides PLM-focused subscription services, and produces several commercial publications. The company also provides industry education through PLM certification programs, seminars, and conferences worldwide. CIMdata serves clients around the world from offices in North America, Europe, and Asia-Pacific.

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