

Is Model-Based Systems Engineering for You?



The discipline of systems engineering (SE) is widely accepted as the best way to manage the difficult product development process for today's complex, interconnected products and systems. Model-Based Systems Engineering (MBSE) has often been touted as the next best thing, with a 6-year research project showing a 55% reduction in total development costs compared to projects not using MBSE. But what makes MBSE different from SE, and can it really help improve your organization's product development process? This paper will describe MBSE and the benefits it is intended to provide, whether it is practical for your organization to adopt and, if so, how to get started.

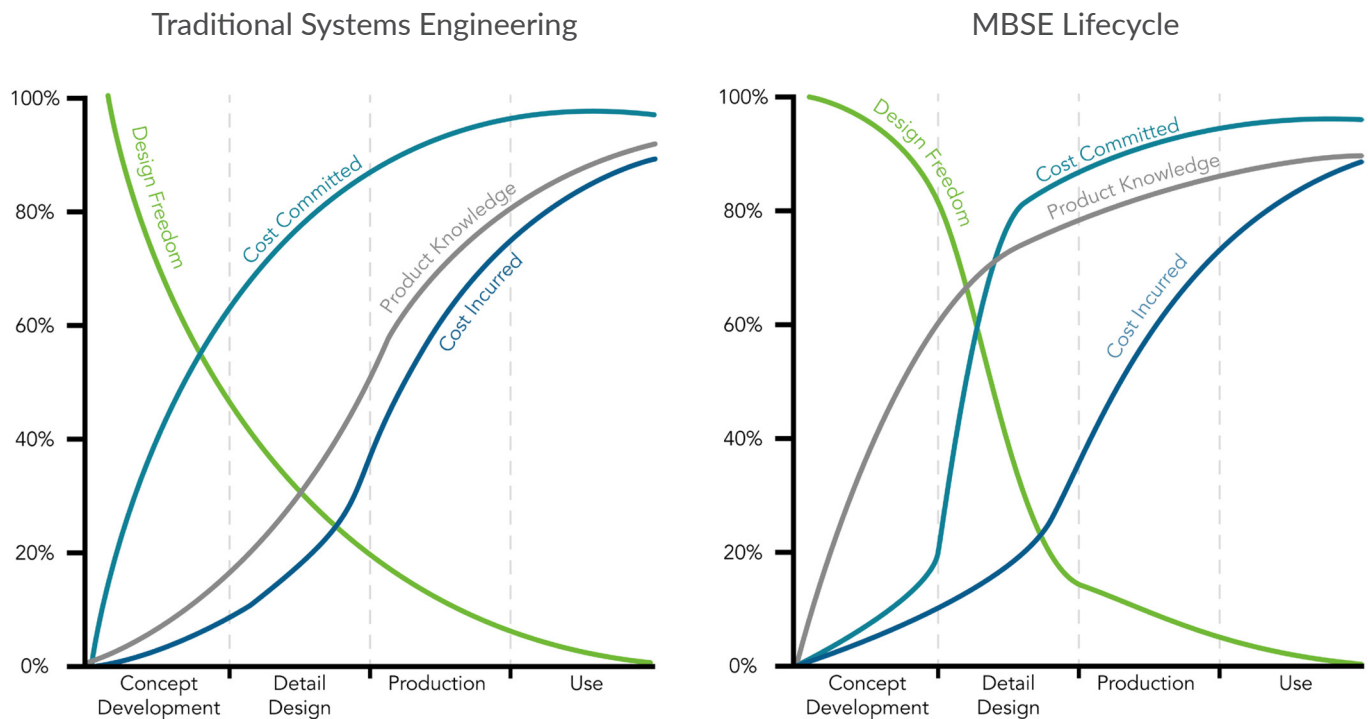
Accelerating Product Development

Systems engineering is undergoing a transformation from a discipline born and practiced largely within aerospace and defense to one being used more widely for the development of complex smart, connected products. Historically, SE is a proven way to overcome and manage complex development projects. Now, companies recognize that SE is important to manage risk and complexity, improve development processes, and gain a competitive edge. It is also a vital foundation for the adoption of Digital Innovation, which is the tools, techniques, processes, and cultural changes that are used to accelerate and improve an organization's product development and delivery.

Model-Based Systems Engineering is an evolution of SE methods that uses models in place of document-centric design artifacts to help improve outcomes for development projects that are too complex and difficult for traditional approaches. A recent economic analysis performed by Azad Madni and Shatad Purohit of the University of Southern California shows that projects with high levels of system and environmental complexity (where the system operates and how it is regulated) paired with long product life present the greatest opportunity for cost savings with MBSE. These types of projects still tend to reside in highly regulated industries such as aerospace, defense, medical devices, and transportation. The progression of SE to MBSE can be compared to the transition from hand-drawn and 2D designs to today's powerful CAD/CAE systems.

MBSE vs. SE

The International Council on Systems Engineering (INCOSE) defines MBSE as “the formalized application of modeling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing through development and later life cycle phases.”



MBSE represents a shift away from document-centered design artifacts, which can become an unwieldy collection of text by the end of a complex development project, and toward the use of models and diagrams of system functions, system logic, and physical aspects.

It uses standardized models and methodologies combined with a common language so that all team members are able to communicate more effectively and understand all aspects of the system design.

More importantly, MBSE is a foundational reorganization of engineering methods and the underlying technology stack. It requires re-thinking the entire development process and being able to institute the cultural and organizational changes necessary to adopt new ways of working. The shift away from document-centric development is also a key enabler of Digital Innovation, which allows companies to innovate more easily for competitive advantage.

From an investment standpoint, the initial costs associated with SE are lower, but the vast majority of expenses arise post-development: during test, production, maintenance, and end of life, when it is much more difficult and expensive to rectify design issues.

Why Use MBSE?

The move to a model-based approach showed a reduction in total development costs of 55%, according to research conducted by Embedded Market Forecasters. More than 4,000 embedded developer responses were received over the course of six years from 2009-2015, reporting on design results, tools, technologies, and resources used. It should be noted that the EMF research focused primarily on software development and the results may not directly extrapolate to more complex systems that integrate complex hardware and software or that represent systems of systems.

Case studies from a document search conducted by Sandia in 2016 showed that an MBSE approach can significantly improve project performance and engineering efficiency while reducing rework and late discovery of defects.

The use of system modeling offers numerous advantages compared to the complex hierarchy of text-centric requirements documents used in standard systems engineering practices, including:

- **Communication and understanding** improves through the use of standardized models, methodologies, a common architecture modeling language such as SysML, and a central repository for designs from all teams.
- **System complexity** becomes easier to manage as a system model can be viewed from multiple perspectives. The impact of design changes can also be analyzed before they are implemented.
- **The modular approach** supported by MBSE allows the system to be broken down into smaller systems. Smaller systems are less complex, easier to reuse in other systems, easier to validate, and enable better detection of defects early in the SDLC (System Design Life Cycle).
- **Product quality** improves as an unambiguous and precise model of the system can be evaluated for consistency, correctness, and completeness, with greater design traceability. Raytheon engineers cited defect rates that were 10-50% of the same team's rates on previous projects according to Matthew Hause, author of How to Fail at MBSE.

MBSE can significantly improve project performance and engineering efficiency while reducing rework and late discovery of defects.

- **Risk** is reduced as designs can be iterated more quickly early in the development process with broad stakeholder involvement, allowing missing elements and design conflicts to be discovered before prototyping or production.
- **Faster cycle times and lower costs** associated with design changes result from enhanced knowledge capture and reuse of information through the standardization and abstraction inherent in model-driven approaches. The Raytheon engineers noted above found productivity increases from 150-700%.
- **Training** of systems engineering fundamentals can be enhanced using the clear and unambiguous representation of the concepts provided by models.

More detailed analyses of MBSE value prospects are available at the INCOSE Wiki.

A significant finding from Madni and Purohit is that major influences including system complexity, environmental complexity, and product life are important indicators of where MBSE provides the greatest benefit. High levels of complexity combined with long product life yield the greatest opportunity for substantial cost savings when MBSE is applied.

Barriers to Adoption

MBSE can offer demonstrable advantages, as evidenced by several bodies of research. However, organizations looking to adopt MBSE need to take into account challenges that may arise, especially when the project scope is large and the product or system is highly complex – the very scenarios most likely to benefit from MBSE.

According to a recent survey of MBSE practitioners conducted by Mohammad Chami and Jean-Michel Bruel, 88 percent of respondents agreed or strongly agreed that awareness and change resistance, along with purpose and scope definition, were top challenges they faced. The human factor is decidedly one of the hardest to quantify, and can be one of the most pervasive and difficult to overcome.

Accurately defining the project purpose and scope (the “why” and “what”) prior to deployment presents numerous difficulties in practice due to the many ways that modeling can be used across many areas of product development.

It can be very difficult to secure management support and funding for such a significant organizational, process, and technology change, which can impact everything from regulatory compliance and records retention to a wholesale overhaul of the structure of engineering controls. Executive buy-in is also crucial to ensure that all team members undertake the changes required to support the new approach.

MBSE requires a substantial upfront investment in time and money across several areas, according to the research from Madni and Purohit:

- Process definition according to the chosen methodology
- Infrastructure, such as licenses, equipment, development environments, and tools
- Training on tools, modeling languages, and SE and MBSE concepts and best practices
- Model-related costs including model development; model verification throughout the product development process; fine-tuning characteristics, implementation, and policy management; and configuration management

It is crucial to fully understand the time frame and commitment involved in successfully transitioning to MBSE

The team will need to agree upon and select a methodology and tool and train engineering teams on the tool. The tool may need to integrate with all other tools, such as requirements management, drawing release, testing, and simulation. Implementation plans need to consider how engineering data will be shared with contractors and suppliers.

The tools themselves tend to be one of the smaller expenditures. The time investment in organizational changes, training, and coordinated investments in compatible systems is likely to be a much more significant expense. Process changes may instigate the need for spending on processes and systems that are affected by the product development process initially targeted for MBSE. For example, it may become clear that a better requirements management process is needed, which results in investing in a new tool such as DOORS or Jama, along with related organizational and training impacts.

There is likely to be a need for bringing in systems engineering experts to support internal teams in the integration of these new processes and tools to ensure data integrity and the ability to generate required controlled documents and other design artifacts. And while it may not be as difficult to find experienced systems engineers, there is a distinct lack of engineers with MBSE experience, as evidenced by several case studies noted in the Sandia literature review.

Even in an ideal scenario, the investment in fully moving to MBSE typically does not yield immediate payback. Expected improvements in reduced validation costs through early discovery of design issues and requirements cannot be measured until later in the product life cycle.

Top Adoption Challenges

A recent survey of MBSE practitioners identified ten challenges commonly encountered in the course of adopting MBSE:

- **Significant upfront investment**, including investment strategy, accurately estimating costs, and quantifying return on investment
- **Adoption strategy** and whether to initiate MBSE in a sandbox environment or as part of a product slated for production
- **Purpose and scope definition** before deployment begins, which can be difficult due to the many ways modeling can be used
- **Awareness and change resistance** among key players due to varying levels of expertise and training
- **Executive-level sponsorship** for the long-term effort required for adoption quality
- **Method definition and extension** according to the defined purpose and scope, from initial setup through the addition of new method extensions
- **Modularity and reusability** that isn't corrupted by the copy-and-paste method of data sharing
- **Complexity management** of high numbers of model elements and dependencies
- **Tool dependency and integration** with other engineering tools such as simulation and requirements management
- **Large models visualization**, including painstaking customization to satisfy large numbers of tool users and difficulty in navigating and understanding large models

Source: A Survey on MBSE Adoption Challenges, Mohammad Chami and Jean-Michel Briel

Is MBSE Right for You?

Given the challenges outlined above, how can you determine whether it makes sense to adopt MBSE? Three questions can help guide your decision:

Is your product complex?

Is it one of dozens that gets integrated into a far more complex product, such as one element within a commercial aircraft or commercial vehicle? Product complexity can be characterized by a large number of unique components in the system and their interactions, high levels of development knowledge, and an extremely detailed system description.

Does your product operate in a complex environment?

Environmental factors include stringent regulatory requirements, standards adherence, support for numerous or unique interfaces, and a large number of stakeholders.

Will your product have a long lifecycle or be the first in a new product line?

Lengthy development cycles of a year or more or those for products with a lifespan of many years are typically challenging development projects that may benefit from MBSE. A brand-new product that will be followed by subsequent models can also be a good potential candidate.

If your development project aligns with these three considerations, then taking an MBSE approach may deliver substantial benefits.

However, there are circumstances where adopting MBSE is ill-advised.

If you are producing highly engineered and customized products that require a considerable volume of recurring engineering tasks, such as incremental stress analysis or component compatibility checks, adoption of MBSE when the vast majority of design requirements are stable and well-understood would not be expected to yield a positive benefit.

Likewise, partial implementations of MBSE show minimal benefit beyond traditional methods, according to the Sandia research, and may actually increase overhead if teams make some use of MBSE tools while still producing legacy text documentation.

If key stakeholders expect a quick return on investment, indicate lack of commitment, or fail to understand the gravity of implementation (for example, suggesting that the team should first deploy an MBSE tool and “see how it goes”), then the MBSE initiative is unlikely to succeed. There needs to be a combination of the right project opportunity, timing, and solid organizational commitment to support the transition to MBSE. All stakeholders need to thoroughly understand the scope, level of commitment required, and expected outcomes.

In these situations, an analysis of your product development program may be a successful alternative. Revisiting and rejuvenating your systems engineering processes, improving project engineering or management, or engaging in training to improve fundamentals such as articulating good use cases may be sufficient to improve your development outcomes.

Success Story

Achieving Project and Cultural Success with MBSE

Objective

A leading aerospace manufacturer was preparing to build a completely new product, with goals for features and functionality that had never before been achieved. A team was formed to determine how to realize these goals and turn them into the requirements that would drive development. The company's leadership believed using Model-Based Systems Engineering (MBSE) would have value and determined that this would be the first project to implement it on a large scale.

Challenges

The design team developed a negative impression of MBSE from the outset. Very few people knew what it was or how to extract value from it, and misconceptions abounded. Project leadership rolled out an MBSE tool without understanding the foundational MBSE methodology it was intended to support or the proper techniques for using it. As a result, the team reverted to their old development methods, with the added burden of populating the MBSE tool to appease leadership. Requirements were being developed in silos, which slowed development, complicated decision-making, and introduced risk. The team struggled for months before bringing in consultants experienced in MBSE.

Solution

Since MBSE had a negative connotation with the team, the consultants framed the effort as taking an integrated approach to architecture and requirements definition. Using models, the team was able to move quickly from high-level program objectives to system requirements. The selected methodology integrated disparate tasks and filled gaps that were preventing progress. Once the team understood the methodology and began work, the consultants helped address limitations with the MBSE tool.

Outcomes

Not only was the original objective of developing requirements met, there were many added benefits to the overall program. The team gained clarity about the program goals, a better understanding of their system and relationships, and improved communication among teams. The consultants provided the processes, activities, tools, and techniques that allowed the team to effectively accelerate development. Staff received training and coaching that empowered individuals and set a path for future success.

How to Get Started with MBSE

If, after a thorough analysis of whether MBSE is a good fit for your organization, you are ready to embark on the transformational changes required to successfully adopt it, the following steps can help ensure the success of your efforts.

1. Identify

Identify a project or series of projects with sufficient complexity and scope to make investing in MBSE worthwhile. The best candidates involve product complexity, environmental complexity such as regulatory compliance, and those with long product life spans, starting at the inception of the project. If possible, start with a small pilot effort in a sandbox environment to establish familiarity with the MBSE approach.

2. Evaluate

Evaluate how MBSE tools and methods will integrate with your existing engineering tools and methods, specifically:

- Requirements management and tracing
- Regulatory and contractual compliance considerations, including a single source of engineering data, audit trails, records retention, formats for transmitting engineering data to suppliers and customers, and impacts to approved quality management systems
- Technology stack for software development and test
- Integration with other engineering modeling and analysis tools

3. Ensure Leadership Support

Ensure technical and management leadership have a thorough understanding of what's involved in adopting MBSE and fully support it. There are several aspects that need to be considered:

- Committing to the cultural and organizational changes required to adopt MBSE as the central design method, not just adding an MBSE tool while continuing to produce and maintain a document-centric design documentation method
- Ensuring adequate investment in training and configuration management for models and templates
- Engaging and enlisting the support of all stakeholders who may be impacted, including:

- | | |
|---------------|--------------------------|
| - Finance | - Information Technology |
| - Technology | - Contracts & Legal |
| - Operations | - Quality & Compliance |
| - Engineering | - Supply Chain |

4. Appoint MBSE Leadership Role

Put an experienced SE in a leadership role over engineering processes and seek out engineers with MBSE experience. According to the Sandia research, SE leadership resulted in significant performance improvements. At the same time, a lack of experienced MBSE practitioners stood in the way of successful adoption.

Bringing in Outside Expertise

Ideally, your organization already has a strong systems engineering team in place but perhaps lacks the MBSE expertise needed to undertake such a major transformation. Bringing in MBSE consultants to partner with your SE teams can help provide guidance, training, and an impartial perspective that can help get the project off the ground and ensure long-term success.

Consultants work as embedded team members that lend the right talent as and when needed, and can stay on long-term or just long enough to ensure the project is well underway. They offer new ways of doing things, diplomatically reach across organizational boundaries, and tap into experience and ideas from the rest of their firm. Consultants tend to stay current with the latest industry trends and MBSE methodologies due to their work with multiple clients.

Conclusion

If your organization is preparing to undertake the development of a complex product within a highly regulated industry that will have a long product lifecycle, MBSE can offer substantial, measurable advantages. It is critical to understand the cultural and organizational changes required and the complete re-thinking of your entire development process, along with the timeframe that will elapse before achieving a return on investment. With the support of management and stakeholders, the appropriate investment in time and effort, and rigorous team engagement, benefits can be real and long-lasting.

Even if you are not fully prepared to embrace MBSE at this point, your organization can benefit from committing more heavily to systems engineering through additional training or an analysis of opportunities for improvement. For additional information on improving your systems engineering efforts, read *Managing Complexity with Systems Engineering*.