CHALLENGES IN THE DESIGN OF COMPLEX SYSTEMS 2025

ESSAY

GRADUATE CATEGORY

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Systems Complexity and Workforce Challenges in 2040: enabling MBSE as a solution for a successful Aerospace & Defense global enterprise

1. Introduction

We were hired to position your company as a high-tech global design and manufacturing enterprise in the year 2040. In order to clarify our scope of work, first, we will define what this kind of company is. We are considering that a high-tech global design and manufacturing enterprise is characterized by its innovative design practices, integration of advanced technologies, and with a global operational framework. Those enterprises tend to leverage cutting-edge tools and methodologies to enhance competitiveness in a rapidly evolving market. Additionally, they are defined by their ability to adapt to technological advancements and global trends, ensuring efficiency and sustainability in their operations. Figure 1 presents a summary of the characteristics of a high-tech global design and manufacturing enterprise.

Figure 1. Characteristics of a high-tech global design and manufacturing enterprise

Source: The Consultants

For us to be able to give some orientation for your company to succeed both domestically and globally in the year 2040 we used some generative AI tools to predict the main challenges that your company would face in the future. Table 1 presents the challenges with the respective key challenges and references for a general high-tech global design and manufacturing enterprise.

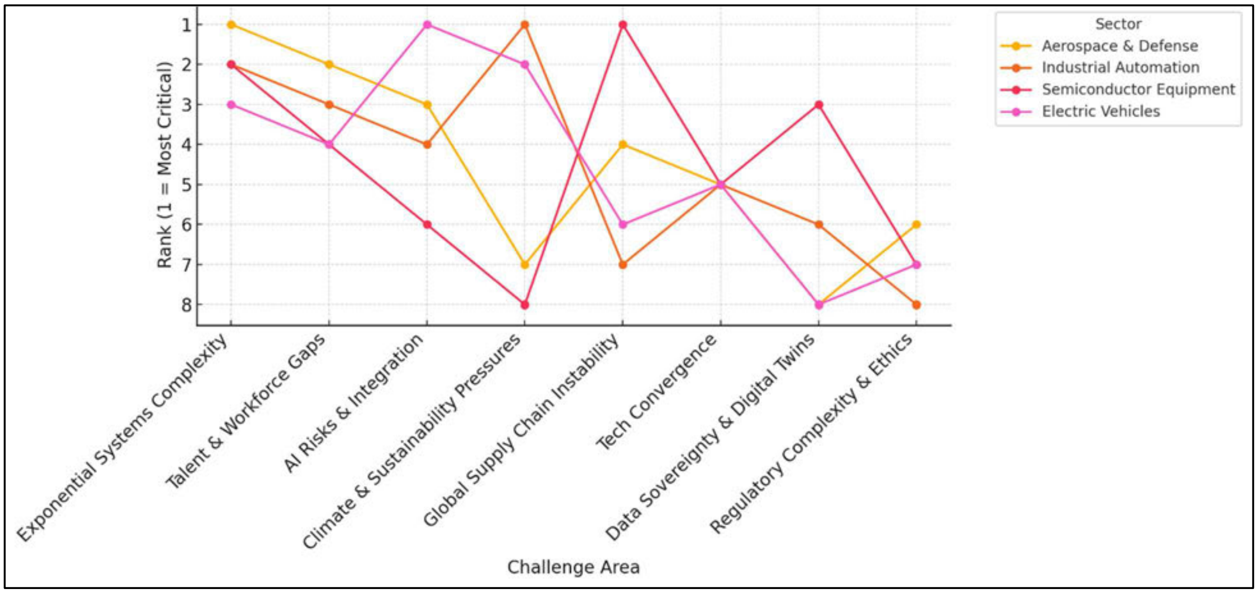
Table 1. Challenges for a general high-tech global design and manufacturing enterprise

Challenge Area	Key Challenges	References
Technological Advancements	Skills gap, cybersecurity risks, data privacy concerns, compatibility with legacy systems	Norman, (2024), Owolabi et al., (2023), Kramer, (2024), Gupta & Jain, (2024), Sinulingga et al., (2024)
Workforce and Talent Retention	Aging workforce, competition for skilled workers, global talent management complexities	Rehman et al., (2024), Taiben, (2024), Adebayo et al., (2024)
Regulatory and Compliance Issues	Sustainability standards, data protection laws, ethical AI adoption, industry standards	Owolabi et al., (2023), Kramer, (2024), Bustamante et al., (2024)
Supply Chain Management	Market volatility, distributed manufacturing, supply chain transparency, resilience	ElMaraghy et al., (2011), Ma, (2024), Gupta & Jain, (2023), Adebayo et al., (2024)

Source: Scispace

According to the sector that your company wants to work in, the challenges rank will be different for each sector as shown in Chart 1. Considering the four sectors that have high-tech global design and manufacturing enterprises - Aerospace & Defense, Industrial Automation, Semiconductor Equipment, and Electric Vehicles - we chose the Aerospace & Defense sector, because it has few competitors (Airbus, Boeing, Lockheed Martin, Northrop Grumman, and RTX). Additionally, companies in this sector are used to have high profitability.

Chart 1. Comparative Ranking of 2040 Challenges by Sector



Source: ChatGPT-4o

Chart 1 shows that the two most critical challenges for Aerospace & Defense companies are Exponential Systems Complexity and Talent & Workforce Gaps. This is aligned with Table 1 in which the first two main challenges are related to Technology and Workforce. Therefore, a successful high-tech global design and manufacturing Aerospace & Defense enterprise in the year 2040 is defined as a company characterized by the ability to deal better than its competitors relating to Exponential Systems Complexity and Talent & Workforce Gaps.

2. The Unique Solution

According to the existing literature and our experience as consultants, both challenges can be addressed through only one solution: the successful implementation of Model-Based Systems Engineering (MBSE). MBSE can be defined as the "formalized application of modeling to support systems design and analysis, throughout all phases of the system lifecycle, through the collection of related processes, methods (languages), and tools used to support the discipline of systems engineering in a “model-based” or “model-driven” context” (Vaneman, 2016).

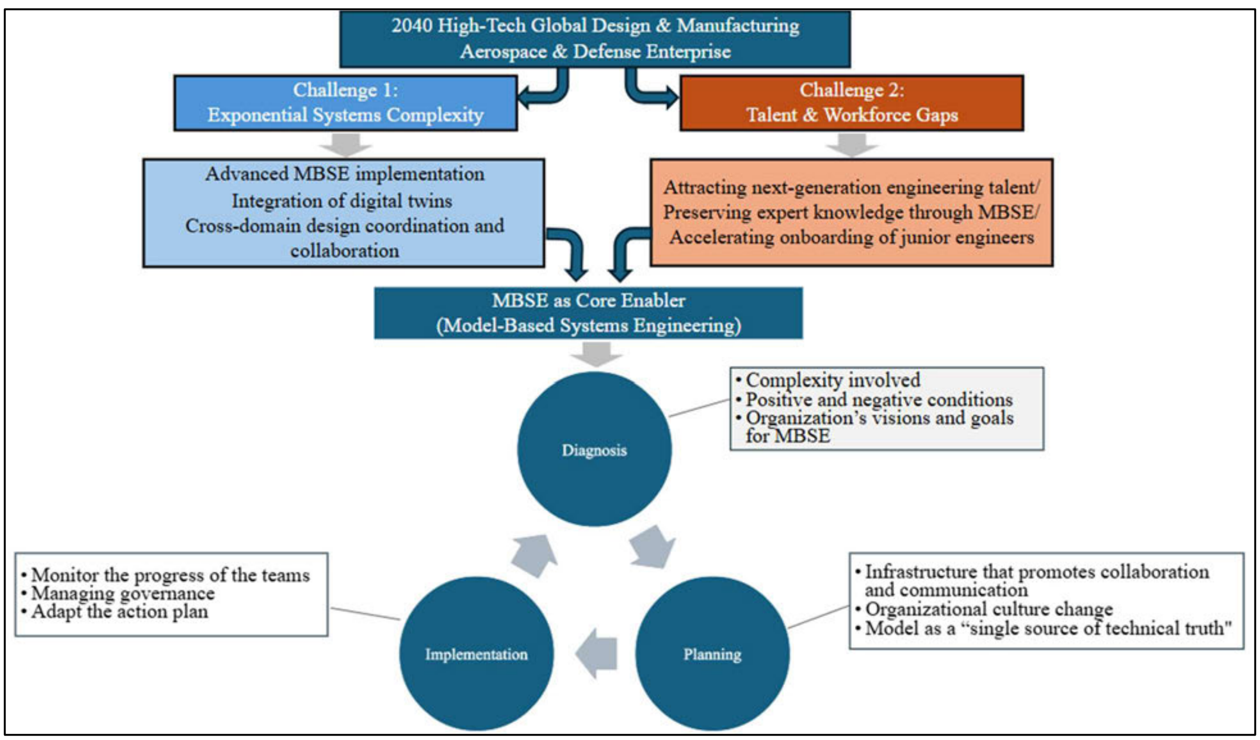
Kozak et al. (2023) defends that the implementation of new technologies, like MBSE, must be followed by a change management mindset which needs a method to facilitate its adoption. In this sense, they highlighted some challenges such as understanding the complexity involved;

identifying positive and negative conditions for emergence; understanding how to adapt the action plan; and being able to monitor the progress of the teams.

Moreover, to scale MBSE, Vaneman & Carlson (2019) identified some challenges, like: understanding of the organization's vision and goals for MBSE; establishing a model as a "single source of technical truth;" managing governance; creating an infrastructure that promotes collaboration and communication; and recognizing the need for and planning organizational culture change.

The findings of Kozak et al. (2023) and Vaneman & Carlson (2019) can be organized into three main stages: diagnosis, planning and implementation. As this is a solution to be achieved within 15 years, we are suggesting that these three stages of our method should interact with themselves as a cycle e not as sequential stages. The idea is that we use Scrum Methodology (Sachdeva, 2016) and define some Sprints which could be implemented in parallel. Figure 2 shows how these three stages are related to the challenges and the solution. The next section details the proposal and the strategies to implement the unique solution for both challenges. The fourth section shows the stages and what needs to be done from today until 2040.

Figure 2. Relationship of the three stages with the challenges and the solution



Source: The Consultants

3. Proposal for both Challenges

To address each challenge in a feasible way, it is necessary to breakdown them into sub-challenges and establish key-strategies, aligned with MBSE, to overcome each sub-challenge.

Table 2 presents the sub-challenges, key strategies and their sources, and expected outcome to each challenge. In general, for the Exponential Systems Complexity challenge, we expect that MBSE could manage the system lifecycle, give real-time feedback, and allow team integration. The implementation of MBSE-based strategies addressing Talent & Workforce gaps is expected to foster stronger recruitment from STEM talent pools, ensure the preservation and reuse of critical engineering knowledge, and accelerate the productivity and contribution of new engineering hires.

Table 2. Key strategy for each key sub-challenge

Challenge	Sub-Challenge	Key MBSE-Based Strategy	Source to Choose the Strategy	Expected Outcome
Exponential Systems Complexity	Requires advanced MBSE	Adopt SysML 2.0 standards and model governance; integrate MBSE with PLM and verification frameworks.	INCOSE MBSE Vision 2035; SysML specifications; DoD Digital Engineering Strategy	System lifecycle complexity is managed consistently; fewer late-stage design errors.
	Requires digital twins	Develop executable MBSE models with co-simulation; integrate sensor data into digital twins.	NASA Digital Twin Framework; INCOSE Systems of Innovation Working Group	Real-time system feedback improves performance monitoring and maintenance predictions.
	Requires multidisciplinary design coordination	Create cross-domain model views and manage interfaces via shared architecture boards and cloud-based MBSE tools.	INCOSE Systems Engineering Handbook; Airbus Model-Based Engineering playbooks	Integrated teams collaborate effectively across mechanical, software, and mission domains.
Talent & Workforce Gaps	Attract new engineering talent	Deploy gamified MBSE learning environments; partner with universities to expose students to real projects.	INCOSE Workforce Development initiatives; industry-university collaboration case studies	Increased interest and recruitment from STEM talent pools; improved employer brand.
	Preserve institutional knowledge	Document engineering knowledge in reusable MBSE libraries; capture rationale in annotated models.	Northrop Grumman MBSE reuse programs; Boeing model traceability practices	Critical engineering expertise is preserved and reused across programs.
	Enable fast onboarding and productivity of junior engineers	Use MBSE-based onboarding portals with guided walkthroughs and modular components for early contributions.	GE Aerospace MBSE onboarding models; Capella training documentation; Lockheed mentorship models	New hires become productive faster and contribute to validated models earlier in their career.

Source: ChatGPT-4o

The following two sub-sections explain each Key MBSE-Based Strategy for each sub-challenge.

3.1. Exponential Systems Complexity

Sub-challenge: Requires advanced MBSE

- Adopt SysML 2.0 standards and model governance: Systems Modeling Language 2.0 (SysML 2.0) enables interoperable models that are more powerful and flexible. Model governance ensures that models are trustworthy and useful across the organization, preventing chaos.
- Integrate MBSE with PLM and verification frameworks: Product Lifecycle Management (PLM) integrated with MBSE allows the management of processes and product data across the product lifecycle. Verification frameworks integrated with MBSE ensure that systems verifiably meet their requirements and are well-designed.

Sub-challenge: Requires digital twins

- Develop executable MBSE models with co-simulation: Executable MBSE Models with co-simulation are models that simulate and combine multiple subsystems to observe behavior throughout the time; help visualize system dynamic, validate system logic, and detect integration issues early.
- Integrate sensor data into digital twins: Digital twins represent a physical system in a live digital way. The sensors integrated to them allow lifecycle optimization, anomaly detection, and predictive maintenance.

Sub-challenge: Requires multidisciplinary design coordination

- Create cross-domain model views and manage interfaces via shared architecture boards and cloud-based MBSE tools: Cross-domain model views allow that different disciplines - systems engineering, mechanical, electrical etc.- work in a common model considering views crafted to their needs. Shared architecture boards can be meetings or tools structured to manage architectural decisions and system interfaces. Additionally, it promotes early conflict resolution and prevents siloed design. Cloud-based MBSE tools make possible real-time collaboration among teams that are globally distributed, certify version control, concurrent engineering, and model accessibility.

3.2. Talent & Workforce Gaps

Sub-challenge: Attract new engineering talent

- Deploy gamified MBSE learning environments: Use game mechanics (e.g., points, levels, challenges) within MBSE platforms to attract younger generations such as Gen Z. These interactive environments make systems engineering engaging and intuitive, increasing early interest and retention.
- Partner with universities to expose students to real projects: Collaborate with academic institutions to introduce MBSE in capstone projects, innovation labs, and internships. This allows students to work on authentic systems engineering problems, aligning education with industry needs and improving recruitment outcomes.

Sub-challenge: Preserve institutional knowledge

- Document engineering knowledge in reusable MBSE libraries: Capture core components, patterns, and best practices into model libraries for reuse. This supports design consistency, reduces redundancy, and preserves engineering heritage.
- Capture rationale in annotated models: Embed decision logic, trade-offs, and stakeholder considerations directly within models. This helps future engineers understand why decisions were made, even after the original designers have left.

Sub-challenge: Enable fast onboarding and productivity of junior engineers

- Use MBSE-based onboarding portals with guided walkthroughs and modular components for early contributions: New hires are introduced to enterprise systems through interactive tutorials, standard practices, and structured MBSE environments, ensuring rapid acclimation. The guided walkthroughs provide scoped model tasks—like parameter updates or subsystem verification—that junior engineers can perform immediately, accelerating productivity while building confidence.

4. Method Stages

4.1. Diagnosis: Assessing Organizational Readiness and Complexity

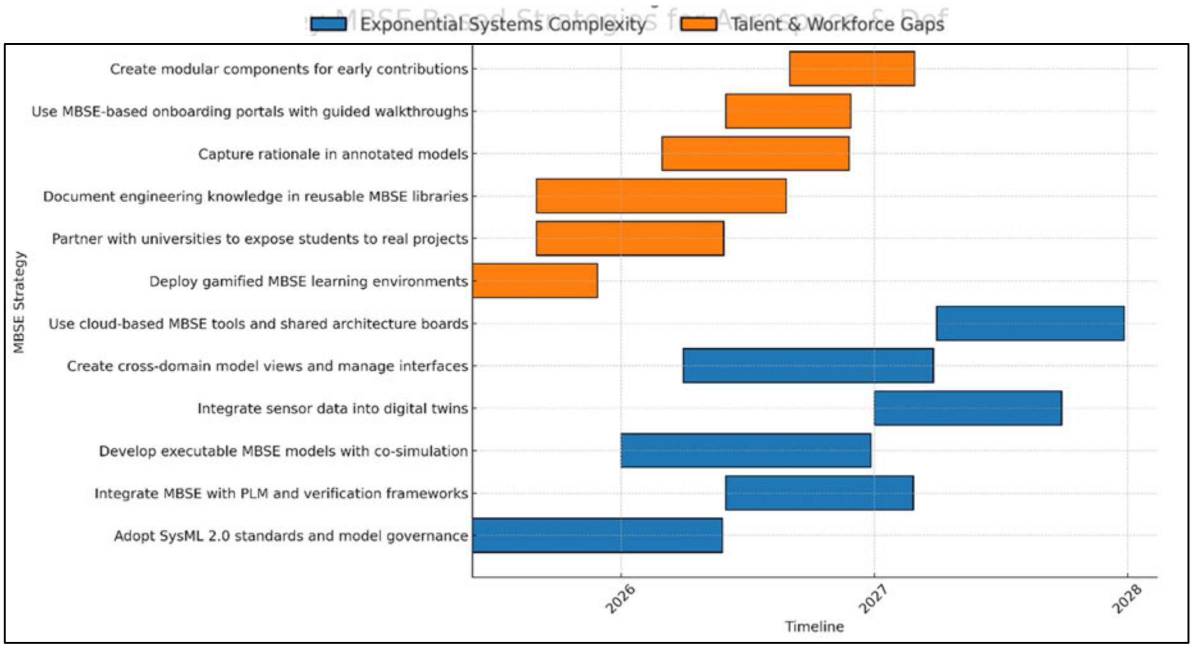
The diagnosis stage serves as the basis for implementing MBSE within an Aerospace & Defense enterprise. As shown in Figure 2, this stage focuses on evaluating the current state of the organization in terms of **complexity involved**, identifying **positive and negative conditions for emergence**, and clarifying the **organization's goals for MBSE.** Rather than initiating change prematurely, diagnosis aims to answer two critical questions: *Where are we now?* And why *is MBSE necessary for our company to be successful in 2040?* Besides, the diagnosis stage should produce a readiness profile that maps current infrastructure and workforce capability against the organization's ambition. This profile serves as a decision-making input for prioritizing actions in the planning stage.

4.2 Planning: Building Governance, Infrastructure, and Cultural Pathways

Following the diagnosis stage, the planning stage focuses on designing a phased, scalable, and sustainable strategy for MBSE adoption. It addresses the key question: *How do we move forward in alignment with the Key MBSE-Based Strategies identified?* This stage transforms diagnostic insights into structured plans encompassing governance, enabled through an **infrastructure that promotes collaboration and communication**; digital platforms that uses a **model as a "single source of technical truth"**; and organizational transformation, regarding **organizational culture change**. Culture change management is not within our scope and your company needs to address this through other consultants.

The result of the planning stage is a multidimensional roadmap that connects technical, human, and strategic layers of MBSE implementation. It ensures that the organization is not only structurally equipped but culturally ready to transition into a model-driven, globally competitive enterprise. For the two challenges and sub-challenges that we identified above, Figure 3 presents a timeline to implement each Key MBSE-Based Strategies.

Figure 3. Timeline to implement each Key MBSE-Based Strategy



Source: ChatGPT-4o

The timeline shown in Figure 3 represents the Foundation phase of the MBSE implementation until 2028. The next phases are Institutionalization and Global Optimization. Table 3 adds the timeline for the latter two phases and the focus of each phase.

Table 3. Key strategy for each key sub-challenge

Phase	Timeline	Focus
Phase 1 Foundation	2025–2028	Pilot MBSE and talent programs, define governance
Phase 2 Institutionalization	2028–2032	Expand MBSE adoption across domains, integrate tools, mature digital twins
Phase 3 Global Optimization	2032–2040	International certification alignment, AI integration, global team scaling

Source: Adapted from ChatGPT-4o

All those deadlines are defined considering that the project is already funded, key management team are available, and leadership supports MBSE adoption. Besides this macro planning, your team should prepare the Sprint Planning (Sachdeva, 2016), which is the micro planning needed to achieve the timeline we suggested.

4.3. Implementation

During the implementation stage, the manager responsible for this stage should **monitor the progress of the teams**. This could be done through the events: Sprint Review, Sprint Retrospective and Daily Scrum Meeting (Sachdeva, 2016). In these ceremonies the implementation team need not only to **manage the governance** of the project but also **adapt the action plans** to ensure that the planned schedule will be accomplished.

6. Conclusion

We are glad to be part of the strategic business plan of your company and help you to succeed in becoming a high-tech global design and manufacturing Aerospace & Defense enterprise in the year 2040. In essence, two challenges intersect to create a multifaceted complexity profile—where technological fragmentation and workforce inadequacy together obstruct innovation, scalability, and global competitiveness. MBSE offers a structured, model-driven approach to overcoming this dual-layered complexity by enabling system-level traceability, fostering collaboration across domains, and supporting workforce capability development through simulation-driven tools.

MBSE successful implementation is a key factor for your company to be positioned where you want in the next 15 years. To ensure this deployment with less conflicts and resistance, we suggested a method consisting of three stages: diagnosis, planning and implementation. In the diagnosis stage your team will need to understand where the company is and why MBSE is necessary. In the planning stage, your team will need to define the Sprints, that is, the micro-planning to establish how to make each Key MBSE-Based Strategy real, following the timeline that we proposed. Finally, in the implementation stage, your manager, along with your team, will need to monitor the progress of the Sprints and adapt them according to the difficulties that arise to avoid any delay on the timeline.

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