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Model-Based Systems Engineering Perspectives: A Survey of Practitioner Experiences and Challenges

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***Abstract*—Model-based systems engineering (MBSE) is an established field, aiming to bring traceability and complexity management to the systems engineering process. However, multiple conceptual, technical, and organizational challenges continue to impede the effective deployment of MBSE in practice. This paper reports the results of a survey completed by 76 MBSE researchers and/or practitioners, on their organization's use of MBSE. Our analysis indicates that many organizations have yet to fully leverage MBSE. Several have not completely transitioned to MBSE in their systems engineering processes, or do not adhere to any specific method, indicating a lack of a comprehensive and organization-wide MBSE approach. We find that challenges such as change management, cross-team collaboration, and tool customization persist. We report on these challenges and provide recommendations as potential solutions.**

***Index Terms*—model-based systems engineering, MBSE adoption, MBSE methodologies, MBSE tools, interoperability, collaboration challenges, survey, model management, empirical research**

I. Introduction

Model-Based Systems Engineering (MBSE) enhances systems engineering by using models as the primary method of domain modeling, information exchange, and improving collaboration across disciplines [1]. MBSE offers comprehensive system views, enabling early issue detection and fostering a deeper understanding of system components and interactions. MBSE ensures consistency and traceability while reducing errors, by maintaining a single source of truth (the *system model*) throughout the system's life-cycle [2]. Purported benefits include increased efficiency through model reuse and automation, effectively managing complex systems, and supporting integration and verification and validation tasks [3].

Despite these stated benefits, MBSE in practice remains under-reported across various organizational contexts, including real-world insights on MBSE adoption and usage of standardized MBSE methods across large enterprises. This gap in knowledge hinders the ability to fully leverage MBSE's potential benefits across various industries. To address this knowledge gap, *this paper presents the findings of a survey study conducted with 76 researchers and/or practitioners to understand MBSE practitioner's experiences and challenges*.

The study involved a comprehensive questionnaire, which is structured into three categories addressing different aspects of MBSE. The first category gathers *information on participants' professional backgrounds*, roles in Systems Engineering, industries supported, and their familiarity with MBSE tools and practices. The second category focuses on *MBSE implementation*, including adoption levels, the tailoring of methodologies to different organizational levels, tool customization, and collaboration challenges between practitioners. The third category explores *how MBSE models are managed*, including visibility, progress reviews, change management, and the modular organization of models. It also addresses the impact of methodology updates, collaboration with external organizations, and broader challenges in MBSE adoption.

Our survey was followed by a full-day hybrid workshop, called onto:Nexus[1], in which the survey results were presented to participants and discussed in detail. The workshop was held at NASA Jet Propulsion Lab (JPL) in Pasadena, USA. This workshop focused on bringing together key researchers and practitioners in the area of MBSE, with a focus on the topic of ontological modeling and analysis. More than 120 participants attended the event (38 in-person, 85 online), from academia, industry, and governmental institutions, and primarily concentrated on the aeronautic and space domains.

This paper's contribution is the reporting and detailed analysis of the survey's results. We provide quantitative data, qualitative analysis, and extract the reported challenges and recommendations for MBSE adoption. This paper thus captures a snapshot of MBSE in practice and serves as a reference point for researchers and practitioners to understand how practitioners are handling (or struggling) with MBSE.

The main findings of the survey are:

- 38% of respondents have initiated practices for adopting MBSE on a small scale, but have not yet fully integrated them into their workflows. 37% have established MBSE practices, 19% are still in the exploratory phase, and only 5% have fully transitioned to using MBSE in their systems engineering processes.
- Nearly 30% of participants reported that their organization does not adhere to any specific method.

[1] https://www.opencaesar.io/blog/2023/11/01/onto-Nexus-Workshop-2024.html

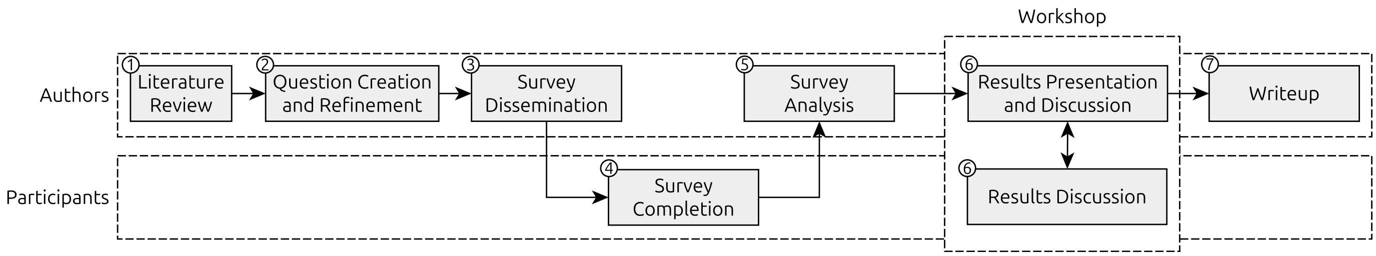

Fig. 1. Seven-step survey methodology

- A significant portion (70%) of MBSE use is either at the product level (24%) or at the project level (46%).
- Nearly 50% of participants reported no customization of existing MBSE tools. Where customization is performed, vendor support and training are mentioned as enablers.
- Over 50% of participants reported their MBSE methodologies did not support effective collaboration across organizational boundaries due to interoperability issues, non-standardized methodologies, and IT-related barriers.
- A large portion (42%) of participant's MBSE methodologies actively provided visibility to stakeholders, including model-based reviews, model reports, and status boards.
- Only 14% of participants answered that their MBSE methodologies have a rigorous change process, often limited by tooling. 44% reported little or no change impact management.
- Over half (51%) of respondents have no collaboration on their MBSE models with external partners or suppliers.

The paper is structured as follows: Section II describes the context and set-up of the survey. Sections III, IV, and V report on and analyze each category of the survey, while Section VI provides insight based on the survey as a whole. Section VII details work related to ours, and Section VIII concludes.

II. Survey Description

This section presents the methodology of our survey and an overview of the categories for questions.

A. Study Methodology

Figure 1 defines the seven-step methodology of our survey.

Step 1) A short literature review was performed to find best practices and related work, as summarized in Section VII. In particular, we aligned our survey's methodology according to best practices [4]–[6], as demonstrated by other surveys in model-based engineering [7].

Step 2) The survey questions were generated by the authors, conducted over three rounds across three meetings. The first meeting resulted in the initial draft creation, where a core team designed questions based on the literature review. In the second meeting, the process incorporated expert reviews and pre-testing, where MBSE researchers and practitioners, including those from NASA JPL, provided feedback on clarity, relevance, and potential bias. Between meetings, authors who were not involved in question generation completed the survey to assess clarity and identify areas for improvement. During the third meeting, revision and refinement took place to ensure questions effectively captured the intended data. This iterative process resulted in 20 questions categorized into three groups.

Step 3) Following question generation, a Google Form questionnaire was created[2]. We recruited participants through multiple channels: social media (LinkedIn, Facebook), direct contacts at industrial partners, invitations to workshop attendees, and professional R&D networks. Participants were invited to share the survey to interested colleagues. This *accidental sampling* [5] approach aimed to ensure a diverse and representative sample by reaching individuals across sectors and professional backgrounds.

Step 4) We gave participants 20 days to complete and return the questionnaires, and sent a reminder after five days. A total of 76 participants completed the survey. Participants are labeled P*X*_*Y* in this paper, where *X* represents their level of experience (0=*none*, 1=*beginner*, 2=*moderate*, 3=*expert*), and *Y* is a participant ID from 1 to 76.

Step 5) The authors then performed a preliminary analysis of the survey, extracting the quantitative results and major challenges reported. The survey methodology combined qualitative and quantitative analysis to assess MBSE adoption, modularization strategies, and collaboration challenges. Thematic analysis was applied to open-ended responses, identifying key themes such as modularization approaches, interoperability, and governance mechanisms.

Step 6) To enhance validity, we cross-validated the findings through discussions at the onto:Nexus workshop, where participants involved in the survey were provided the chance to elaborate their responses and provide additional context. In particular, many of our MBSE recommendations were provided in these discussions.

Step 7) These elaborations were incorporated into this article during its preparation, along with further analyses.

Note that due to the detailed and honest responses of participants, we are unable to release a full response dataset. We are concerned that participant anonymity could be compromised with negative consequences. In particular, we note that some answers mention the participant's management and collaborators in a negative light as challenges to MBSE adoption.

[2]Survey link: https://forms.gle/xcvj8ukLngLN31xYA

TABLE I
CATEGORIES OF SURVEY QUESTIONS

Category	Questions
Participants' Background	1.1 Where is your home institution located?
	1.2 What role(s) do you play in Systems Engineering?
	1.3 Which industry/ies do you support?
	1.4 What is your level of experience with MBSE?
	1.5 What is your level of experience with semantic web technologies?
	1.6 Which modeling and/or analysis tools do you have experience with?
	1.7 What MBSE activities you are currently engaged in?
	1.8 What motivates you to attend onto:Nexus?
MBSE Methodology and Tools	2.1 What is the level of MBSE practice in your organization?
	2.2 Do you follow a well-defined method for MBSE? If yes, which one? if not, why not?
	2.3 Do you define your MBSE method on a project/product level, program level or organization-wide? Elaborate.
	2.4 Do you find it easy to customize your MBSE tool(s) for your method? Elaborate.
	2.5 How do you integrate different domains and disciplines in your MBSE method?
	2.6 Does your MBSE method enable effective collaboration on models between your practitioners? Any challenges?
MBSE Model Management	2.7 How do you give stakeholders visibility to your MBSE work? how do you review progress?
	2.8 Do you have a rigorous change process for your MBSE models? Describe successes and challenges.
	2.9 Do you organize your model into separate but inter-related modules? How do you enable the co-evolution of those modules and deal with change impact? Elaborate.
	2.10 How do you deal with the impact of change to your MBSE method (its vocabularies and/or viewpoints) on your models? Elaborate.
	2.11 Do you collaborate on MBSE models with other organizations (e.g., partners or suppliers) that could be using other methodologies (or tools)? How do you manage this?
	2.12 What other challenges to the adoption of MBSE in your organization do you see? Elaborate.

B. Overview of Survey Question Categories

Table I reports the survey questions, split into the three categories as described here.

1) Category 1 - Participants' Background: This category focuses on the respondent's professional background, experience, and current involvement in Systems Engineering. It asks their home institution, their roles within Systems Engineering, and the industries they support. It also asks about the experience of the MBSE users, including their familiarity with the relevant modeling and analysis tools. The questions also explore the respondent's involvement in MBSE activities, helping to overview their qualifications and ongoing work.

2) Category 2 - MBSE Methods and Tools: The second category focuses on the implementation and practices of MBSE within an organization. It seeks to understand the current level of MBSE adoption, the presence of a defined method, and whether this method is tailored at the project, program, or organizational level. The questions explore the ease of customizing MBSE tools to fit the method, as well as how different domains and disciplines are integrated into the MBSE process. The questions also address the effectiveness of collaboration between practitioners using models.

3) Category 3 - MBSE Model Management and Evolution: The third category of questions asks how MBSE is managed and communicated within an organization. It addresses how stakeholders are given visibility into MBSE work and how progress is reviewed. The questions explore whether there is a structured change management process for MBSE models, asking for insights into successes and challenges faced. Additionally, it inquires about the organization of models into modular, interrelated components and how changes in those modules are managed. The impact of changes in MBSE method—such as updates to vocabularies or viewpoints—on models is also discussed. Collaboration with external organizations using different methodologies or tools is explored, focusing on how this is managed. Finally, the questions seek to identify broader challenges in adopting MBSE within the organization, inviting elaboration on potential obstacles.

III. Category 1 - Participants' Background

This section reports on the background of participants, which provides context for their answers.

A. Q1.1/Q1.2/Q1.3 - Participant Location, Industry, and Roles

About 58% (44 of 76) of participants have their home institution in North America, followed by 23% in Europe, and 18% in Asia (and other geographies).

Participants were asked to identify their roles, with the option to select multiple categories. A majority (51%) identified as researchers, followed by systems engineers (45%). Additional roles included methodologists (24%), managers (21%), and tool experts (11%).

More than two-thirds of the participants are from companies in heavy industries, namely the aerospace (53%), defense (36%), automotive (22%), and aviation (14%). This is explained by the fact that these industries rely heavily on systems engineering for the design of complex and safety critical systems. To complement the industrial perspective, we also reached out to researchers from academia who specialize in systems engineering. Among our participants, 38% identified as being in academia. It should be noted that participants can choose more than one industry.

B. Q1.4/Q1.6/Q1.7 - Participants and MBSE

To better understand the overall expertise of the participants, we asked them to describe their experience with MBSE. The results (presented in Figure 2) show that 41% of our participants have more than 5 years of experience, followed by 33% with moderate experience (2 to 5 years). Beginners account for 20%, while only 7% of the participants have no experience with MBSE at all.

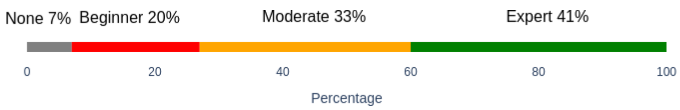

Fig. 2. Respondant MBSE experience

We also asked the participants to list the modeling tools (shown in a blue color in Figure 3) and analysis tools (shown in red) they have used. Figure 3 shows that SysML remains the modeling language that is the most used, followed by UML, and Protégé. We do see also the emergence of ontology-based languages such as OML, and OntoUML. As for the analysis tools, Python, Matlab, and R are most commonly used.

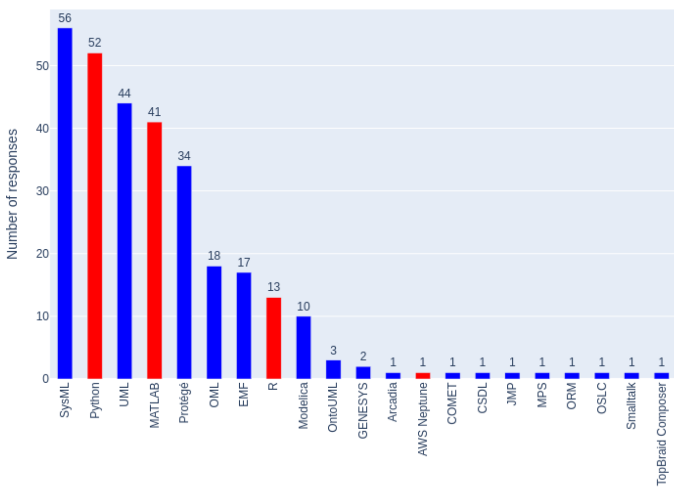

Fig. 3. MBSE modeling and analysis tools used

Finally, we asked the participants to (multi-) select the MBSE activities they are engaged in. We provided a list of four activities: (a) *researching/developing new approaches to make MBSE more effective*, (b) *increasing their knowledge about MBSE*, (c) *developing systems with an MBSE approach*, and (d) *evaluating different MBSE approaches*.

Our analysis indicates that 82% of the responses are researching/developing new approaches to make MBSE more effective, followed by increasing knowledge about MBSE (53%), developing systems with an MBSE approach (41%), and evaluating different MBSE approaches (28%).

In summary, the responses show the population diversity of the participants, ensuring comprehensive coverage for our survey. Notably, 74% of participants have moderate to advanced experience with MBSE, similar to past surveys [8]. As such, we believe the survey reflects the perspectives of experienced practitioners, reinforcing the survey's significance in understanding the current practice of MBSE in the field.

IV. Category 2 - MBSE Methodology and Tools

This section reports on the second category of questions focusing on MBSE use within the participant's organization.

A. Q2.1 - Level of Practice

Figure 4 shows the MBSE level of practice in organizations. Among the 76 participants, 19 either did not respond or found the question not applicable. These non-respondents are mainly consultants and researchers who do not focus on the level of MBSE practice. Of the remaining 57 participants, 22 (38.5%) said they had begun adopting MBSE on a small scale, while 21 participants (36.8%) reported having an established MBSE practice, 11 (19.2%) indicated that they are still in the process of understanding and adopting MBSE, and only 3 participants (5.2%) indicated they have fully transitioned to MBSE, using it exclusively in their work.

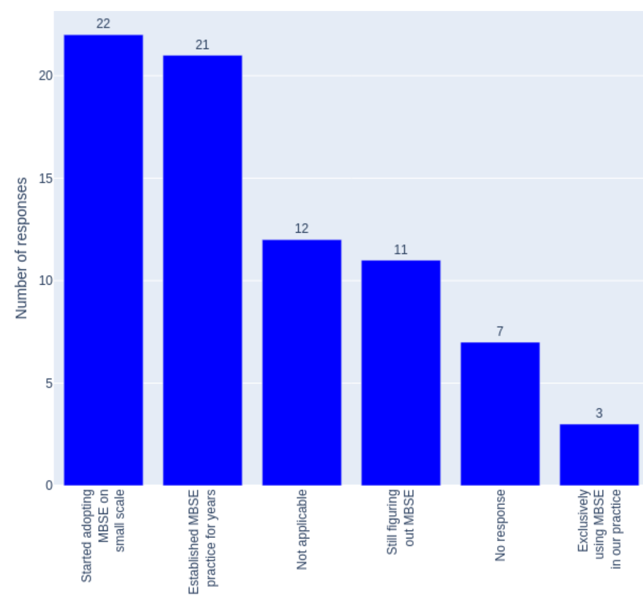

Fig. 4. Organization MBSE level of practice

B. Q2.2 - Well-defined Methodologies

Figure 5 presents question Q2.2 findings, where participants reported the MBSE methodologies used by their organizations. Only 47 out of the 76 participants provided a response (the question was optional). Among these, 14 out of 47 participants (29.78%) reported that their organization does not adhere to any specific methodology. Additionally, we found that nearly one-fifth of the participants (19.14%, or 9 participants) indicated that their organization uses a custom methodology.

Among those who do not use any methodology, participant P2_25 indicated the lack of a standard approach for MBSE, stating that "all MBSE methodologies need to be tailored to the needs of the projects." Another participant (P2_44) indicated that the cause is "lack of training and established best practices". Most of the participants, including the experts, who have adopted an MBSE approach stated that they tend to customize existing methodologies and, in many cases, they need to combine multiple methodologies to meet the needs of their projects. Among those who use MBSE methodologies, MagicGrid [9], OOSEM [10], and a hybrid approach emerged as the most popular options.

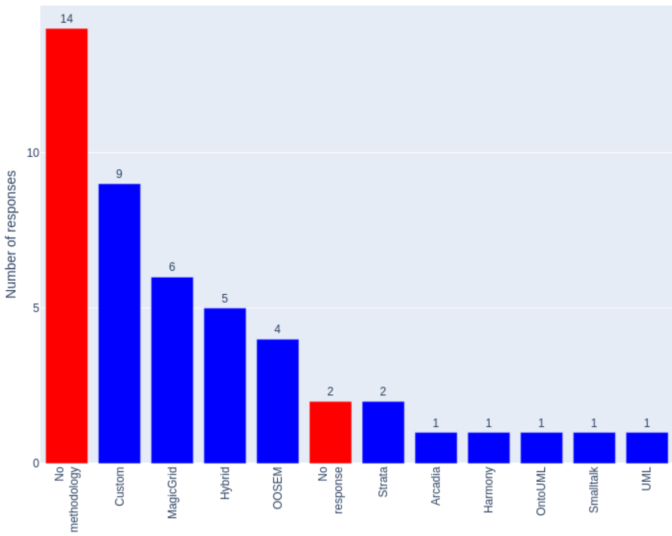

Fig. 5. MBSE methodologies employed

C. Q2.3 - Methodology Scope

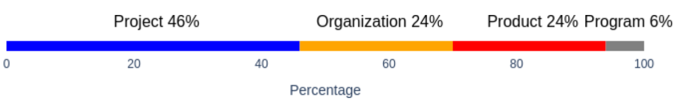

Fig. 6. Scope of the application of MBSE

Figure 6 indicates that a significant portion (70%) of MBSE use is done primarily at the product (24%) or project level (46%). This suggests that many organizations still lack a comprehensive, enterprise-wide MBSE methodology that could be universally applied across the organization. One participant P2_24 stated that the focus on project/product level helps them address domain-specific demands.

The adoption of an organization-wide MBSE strategy represents only 24% of the applications of MBSE. One expert participant P3_55 whose organization adopted an organization-wide strategy stated that this was possible through the development of "guidance and standards". Another participant P3_65 stated that the "aim [of having an organization-level methodology is] to facilitate reuse of digital engineering platforms across programs and projects".

D. Q2.4 - Tool Customization

When asked whether or not it is easy to customize MBSE tools, nearly half the participants found customizing existing tools difficult, around 30% find it manageable, while 21% say

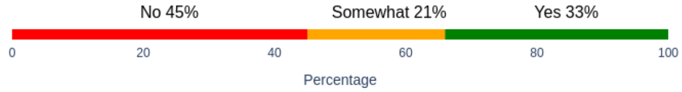

Fig. 7. MBSE tool customization

it depends on various factors (see Figure 7). Interoperability between tools emerged as a challenge for tool customization. Participant P2_25 said that "each tool seems to operate in isolation, within its own silo," while another participant P2_42 mentioned that "interoperability between MBSE tools is difficult and drives novel approaches in research and practice." Another participant P2_44 said that APIs for MBSE tools are often poorly documented, complicating customization further.

Cost is another barrier. One expert participant P3_59 shared that "customizing UML/SysML tools with profiles and custom plugins to create a native, methodology-specific experience is very expensive." Another expert participant P3_66 described customization as "cumbersome and labor-intensive". Additionally, it appears that vendor lock-in limits flexibility, making customization more difficult.

Among those who find tool customization easy, vendor support was mentioned as a helpful factor. Some participants also discussed specific techniques, such as using custom template models, which facilitated the customization process. Two participants indicated that customization became easier with practice, as they refined their techniques. Expert participant P3_56 noted that customization was "only easy because we've made lots of mistakes applying MBSE in the past."

For those who felt that customization was "somewhat" easy, the process often depended on personnel training and availability. One participant P2_30 noted that "additional training and assistance for non-systems engineers is important. We are anticipating more mature software and tools from the MBSE community." Another participant P2_24 added that customization is somewhat manageable now but anticipated that "it will become more difficult as customization needs become more advanced". That said, when focusing on experienced participants, opinions converge towards tool customization being a complex task due to a lack of semantics, its cumbersome and labor-intensive nature, and vendor-lock solutions.

E. Q2.5 - Integration

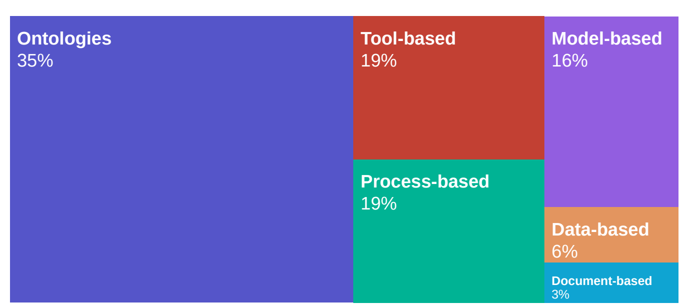

Fig. 8. MBSE integration

Integration of multiple domains and disciplines emerged as a core challenge in the survey, although only 33% of respondents provided a definitive answer (possibly due to the question's complexity or optional nature). Figure 8 shows the categorization of the answers. The most-reported integration strategy was 'ontologies' (11 responses, 35%), possibly due to the ontological focus of the workshop. The next answer was 'tool-based' strategies (6 responses, 19%). Tools mentioned were Ansys ModelCenter[3], Dassault 3DEXPERIENCE[4], CATIA Magic (Cameo)[5], OpenMBEE[6], and Digital Engineering Hub Pathfinder [11]. 'Process-based' also had 6 responses (19%), focusing on the project process to manually integrate. Close behind were the model-based strategies, including adapters (5 responses, 16%). Two responses (6%) mentioned a 'data-based' approach, where integration was performed at the data level. Finally, 1 response (3%) mentioned that integration was performed in a 'document-based' manner.

Experts reported on the use of centralization for integration. For example, participant P3_66 reported on "a generic hub-and-spokes architecture with adapters to all needed tools". Participant P3_72 detailed that they "integrate multiple disciplines around a central data store with well-defined semantics". Other experts (P3_49, P3_53, P3_59, P3_70) explicitly mention ontologies as their strategy, either as a logical foundation or by aligning with higher-order ontologies.

F. Q2.6 - Collaboration

We found that 38% of respondents replied positively to the question of whether their MBSE methodology enabled effective collaboration. Of these, 7% responded that *ontological modelling* was the mechanism to support collaboration across tools. These respondents also listed the challenges they faced. 45% of these respondents listed *semantic and/or technological interoperability* as the main challenge to collaboration (31% technical and 14% semantic). This indicates that the problem of technological and semantic silos is a pressing problem for MBSE methodologies. Other challenges encountered were the lack of a System-of-Systems approach considered in the methodology, unclear MBSE benefits for investment, collaborative model creation and updates across users, and the learning curve of MBSE languages and methodologies.

Experts reported two main themes of challenges in collaboration. The first is infrastructure/organizational issues, such as "access from outside stakeholders" (P3_55), and intellectual property concerns (P3_72). Another theme is on the fundamental difficulty of collaborating when there are many model-specific and domain-specific practices. One participant P3_59 reported that "The effectiveness of collaboration depends on the loose coupling among domains. When domains are tightly coupled, collaboration is difficult because each domain lacks a strong sense of individual ownership on information."

[3]https://www.ansys.com/products/connect/ansys-modelcenter

[4]https://www.3ds.com/3dexperience/

[5]https://www.3ds.com/products/catia

[6]https://www.openmbee.org/

V. Category 3 - MBSE Model Management

This section explores aspects of organizational MBSE use, such as processes for model management and reporting.

A. Q2.7 - Stakeholders Visibility

For whether their MBSE methodology provided stakeholders visibility and reviews, 42% had a positive answer. Participants indicated that this was an active area of development, where their process would or had recently transitioned from document-based visibility to model-based visibility. Practices included: a) model-based reviews, b) model navigation web pages/reports, focusing on progress reports (*work left to be done*) versus status reports (*work already completed*), d) sharing diagrams, screenshots, presentations, status boards, and custom viewpoints through HTML and Excel.

Additionally, continuous integration and continuous development (CI/CD) and design science methodologies were reported, along with a focus on engaging system engineers in the stakeholder reporting, and emphasis on the training, teaching, demonstration required. Participants mentioned several tools including Cameo Collaborator (including Diagram and Teamwork Cloud)[7], OpenMBEE, Excel, Powerpoint, and Jira[8]. Progress metrics reported included a) the model *grow rate* (number of elements over time, b) the concept count, concept relationship count, and pattern count, c) (from expert participant P3_60) "the maturity of the systems model and tools, but also maturity of the people, maturity of the model management/sustainment processes, and maturity of the modified Systems Engineering processes utilizing models".

The MBSE experts surveyed had a strong trend towards Web-based, viewpoint-specific reporting. For example, P3_56 stated "Model navigation pages are created for stakeholders to view model content specific to the technical review data package corresponding to that review in the life-cycle." while P3_64 reports "Although the model content is directly accessible, most stakeholder interaction is through focused web-accessible reports that reveal just a narrow analysis of interest".

B. Q2.8 - Change Process

For the question of whether their MBSE methodology had a rigorous change process, only 14% of respondents answered positively. These participants mentioned tools such as CDO-LM: A Module System for Models[9], CATIA magic integration into Power BI, ESSENCE[10], JIRA (issue management) and GitHub (model documentation), Teamworks from Dassault, and Cameo Collaborator. Participants noted that they were often limited by the tooling. The practices mentioned were: documented release processes, change requests, semantic versioning and modular packaging, audit logging, integrating CI/CD and automated reporting, and using Git commit and branching strategies.

[7]https://www.3ds.com/products/catia/no-magic/cameo-collaborator-teamwork-cloud

[8]https://www.atlassian.com/software/jira

[9]https://projects.eclipse.org/projects/modeling.emf.cdo

[10]https://www.omg.org/hot-topics/essence.htm

A trend in the expert opinions on this topic is that for rigorous change management process "the primary challenges tend to be human rather than with respect to tooling" (P3_48). Some interesting expert MBSE practitioner comments highlighted a preference for creativity over standardization when integrating discipline information into models, with one respondent P3_56 noting that "change processes slow that down." Another comment from participant P3_64 pointed out that there is "still significant impedance mismatch between managing changes at the level of model syntax and what users can effectively review. Users really want to review [model] diffs projected into reports." P3_48 also reports a request for a visual model differencing capability in SysML.

C. Q2.9 - Modularization

Organizing models into self-contained modules that can be independently developed and evolved is a key enabler in MBSE. To evaluate participants' modularization practices, we analyzed their responses, identifying recurring themes and strategies that reflect varying levels of maturity.

Among the 76 participants, 39 provided detailed responses describing nine modularization approaches. These include the *SOLID Approach* for simplicity and separation of concerns, *Hub-and-Spokes* and *Federated Models* for enabling interoperability, and *Vehicle-Level Modeling* for system integration. Others highlighted *Classic Encapsulation* and *Package Partitioning* for ensuring module independence and traceability, while advanced strategies like *Ontology-Based Approaches*, *Alignment Links with Formal Verification*, and *Root Architectures* emphasized consistency, traceability, and scalability in hierarchical systems.

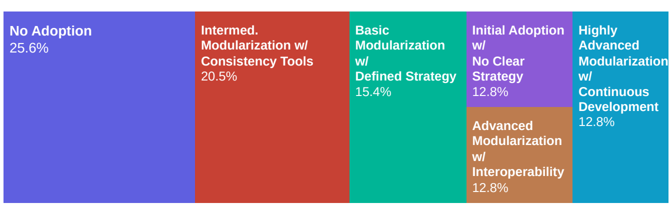

Fig. 9. Modularization Practices in MBSE.

From these responses, six maturity-level categories emerged:

- **No Adoption**: No strategies employed; for example, one participant P0_2 stated, "No, I don't."
- **Initial Adoption**: Limited efforts without clear strategies; participant P2_24 said, "Trying to use Teamwork Cloud."
- **Basic Modularization**: Defined strategies but lacking advanced tools. Participant P2_32 noted "We encourage the use of modular models at different levels of granularity."
- **Intermediate Modularization**: Use of tools like Alignment Links and Impact Analysis; participant P2_42 said, "Yes. Impact analysis across models when changed."
- **Advanced Modularization**: Focused on interoperability using Hub-and-Spokes; participant P2_30 remarked, "We focus a lot on interoperability throughout technical, semantic, and organizational levels."
- **Highly Advanced Modularization**: Integrated into continuous development processes; participant P3_59 explained, "We are working towards providing agile refactoring to improve modularity."

Figure 9 illustrates the distribution of emerged categories. Foundational levels with no or initial adoption compose 38.4% of the responses, highlighting a need for training and awareness to address gaps in adoption. Intermediate levels represent 36% of the responses, showing progress but requiring enhanced tools and collaboration to mature further. Only 25.6% demonstrated advanced or highly advanced levels, emphasizing the resource intensity and expertise needed to scale modularization practices. These findings highlight the need for robust tools, targeted training, and cross-organizational collaboration to achieve widespread adoption.

D. Q2.10 - Change Impact

We asked participants how they manage the impact of changes in MBSE methodologies, such as evolving vocabularies or viewpoints, on their models. Among the 34 responses, we identified recurring themes reflecting varying levels of maturity in handling change impacts.

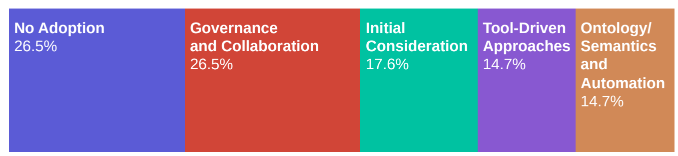

Fig. 10. Change Impact Analysis - Q2.10

Figure 10 illustrates the distribution of themes, highlighting the need for enhanced tools, structured governance, and semantic consistency. These findings highlights the complexity of managing changes in MBSE, with responses ranging from no adoption to advanced ontology-driven approaches. A significant portion (44%) of participants reported *"No adoption"* or only *"Initial"* considerations for managing change.

For instance, P0_2 stated, "No, I don't," highlighting a gap in formal processes, while others described early-stage efforts to avoid frequent changes. *"Governance mechanisms"* were mentioned by 26% of participants, including change boards and stakeholder agreements. For example, P3_51 noted, "We negotiate changes collaboratively across teams," indicating reliance on organizational processes to manage change. *Tool-driven* approaches were highlighted by participants, who described using tools like CDO-LM, version control, and validation techniques for model updates, reflecting an intermediate level of maturity and alignment with model lifecycle practices.

A less common but advanced theme was the use of *ontologies and automation* (e.g., P3_56, P3_72), emphasizing semantic modeling and automated propagation. For example, P3_64 explained, "We use ontologies to distinguish core vocabulary from project-specific extensions and ensure consistent updates". The lack of formal semantics in SysML was reported as a challenge for change impact, with P3_56 detailing that "SysML does not have semantics in the sense of meaning."

and continuing that their ontologically-focused approach has underlying semantics such that "change impact propagation (and detection) is instantaneous". Challenges in managing change included difficulties in multi-enterprise collaboration (e.g., P2_29, P3_59). Participants also cited IT firewalls and the lack of standard methodologies as obstacles to cross-organizational efforts.

E. Q2.11 - Collaboration

We asked participants whether their MBSE methodologies enabled effective collaboration across organizational boundaries. Among the 39 responses, we identified recurring themes reflecting varying levels of maturity in collaboration practices.

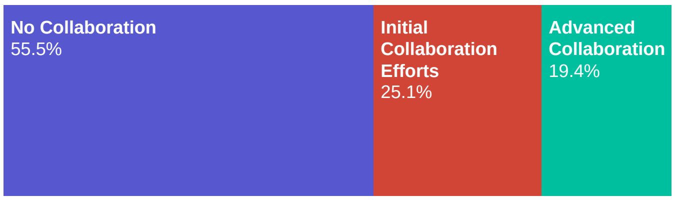

Fig. 11. Collaboration Analysis - Q2.11

Figure 11 illustrates the distribution of collaboration themes, highlighting the challenges and varying practices across participants. Over half of the participants (55.5%) reported *"No collaboration"* on MBSE models with external partners or suppliers. For instance, P0_2 stated, "No, we don't collaborate with partners yet" reflecting a lack of current collaboration efforts. Others expressed intent to collaborate in the future, such as P3_63, who noted, "Not much yet" Approximately 25% of participants described *"Initial collaboration efforts"*, involving research, workshops, or pilot projects. For example, P2_32 explained, "We teach model retrofit methods so that partners may fold models into our workflows. This is done through workshops." Finally, 19.4% reported *"Advanced collaboration"* approaches, employing methods like ontology-based integration and federated models. For instance, P3_48 stated, "For ontologies, yes—I work on industry standards such as FIBO[11] and IDMP-O[12]" highlighting the use of advanced tools and methodologies to facilitate seamless collaboration.

Collaboration challenges identifies included interoperability issues, lack of standards, and IT barriers. P2_44 noted, "IT firewalls make sharing models a challenge," while P2_30 emphasized, "This is a question for interoperability and standards." These findings show a gap in collaboration practices among participants, with a majority reporting limited or no collaborative efforts. Initial strategies like workshops and pilot projects show promise, but persistent challenges such as interoperability barriers and the lack of standards hinder progress. Advanced methods, used by experienced participants, demonstrate the potential for ontologies and federated models to enable effective cross-organizational collaboration.

[11]https://spec.edmcouncil.org/fibo/
[12]https://spec.edmcouncil.org/idmp/

F. Q2.12 - Other Challenges

We investigated the challenges organizations face in adopting MBSE, analyzing 37 participant responses to identify recurring barriers and potential solutions.

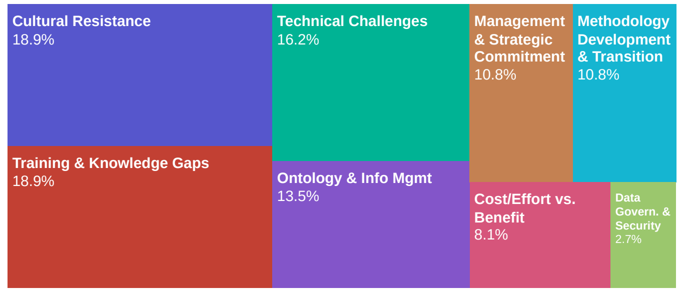

Fig. 12. Challenges for MBSE Adoption - Q2.12

Figure 12 illustrates the distribution of challenges, with the most prevalent issues relating to training, organizational resistance, and technical limitations. Training and knowledge gaps were reported by 18.9% of respondents, highlighting insufficient understanding of MBSE principles and steep learning curves. For example, respondent P3_66 noted the challenge of "training and overcoming the [MBSE] learning curve". Cultural resistance was also cited by 18.9%, emphasizing reluctance to change and the absence of internal MBSE advocates. For example, P2_44 reported "a cultural resistance to using new tools". Technical challenges, including tool integration and data management issues, were identified by 16.2% of respondents. For instance, participants reported difficulties aligning multiple tools within existing workflows.

Concerns about data governance and security, mentioned by 2.7%, included challenges in establishing secure data-sharing protocols and achieving a "single source of truth." Management resistance and skepticism regarding MBSE's return on investment (ROI) were reported by 10.8% of respondents, with one participant highlighting the lack of clear metrics to demonstrate MBSE benefits. For example, participant P2_35 reported "while in theory [MBSE] sounds great and everyone is onboard, the road to ROI is not so clear", while P3_64 detailed "institutional willingness to invest in research and development but no appetite to sustain the results".

Similarly, 10.8% identified challenges in transitioning from conventional to MBSE methodologies, underscoring the need for phased adoption strategies. A smaller portion (8.1%) raised concerns about cost versus benefit, with respondents skeptical about whether the efforts required for MBSE adoption would yield tangible value.

VI. Discussion

In this section, we summarize key findings, discuss their implications, and propose potential solutions.

A. Enterprise-wide MBSE adoption and standardization

While some organizations have adopted MBSE practices, few have transitioned to using MBSE exclusively or systematically at the enterprise level. Most efforts are constrained to individual products or projects, resulting in fragmented implementations. Organizations often lack standardized methodologies, relying instead on bespoke or ad hoc approaches. This fragmentation is compounded by tooling challenges, including limited customization capabilities, inadequate API documentation, interoperability issues, and cost constraints.

Potential solutions: To promote enterprise-wide MBSE adoption, organizations must first align MBSE initiatives with strategic business goals and clearly articulate their value to gain leadership support. Dedicated MBSE roles and governance structures should be established to oversee implementation and ensure consistency. Strategic direction from leadership can guide standardization efforts, facilitate resource allocation, and support the development of training programs. Additionally, organizations should adopt performance metrics and KPIs to monitor the maturity and effectiveness of MBSE adoption. Investing in tool ecosystems with better APIs and cross-platform integration capabilities is also essential to enable scalable, organization-wide usage.

B. Cross-domain integration

Integrating engineering knowledge across domains remains a major hurdle. Organizations report difficulties stemming from semantic inconsistencies, tool heterogeneity, and manual or siloed workflows. In many cases, domain-specific practices persist without a unified framework, creating barriers to effective interdisciplinary modeling and analysis.

Potential solutions: A promising path forward involves using semantic technologies—such as ontologies—to standardize vocabularies and bridge disciplinary gaps. Ontologically-aware tools and modular adapters can facilitate semantic interoperability and cross-domain integration [12]. While some respondents show interest in adopting SysML v2 [13] for its improved semantics and structure, it is recognized that no single language will fully address all integration needs. Therefore, incremental and purpose-driven integration efforts—anchored in semantic consistency and supported by adaptable tool chains—offer a scalable and realistic strategy for multi-domain MBSE adoption.

C. Model management, evolution, and stakeholder visibility

Respondents indicated that their MBSE methodologies did not provide sufficient visibility to stakeholders, do not have rigorous change/impact processes, have no or low modularization, and are not collaborating across organizational boundaries. This implies that further MBSE methodology and tool research and development is required to provide solutions suitable to be integrated into an organization.

Potential solutions: Enhancing model management requires investment in standardized, integrated tooling with clear, stakeholder-specific views and continuous reporting capabilities. Addressing technological, organizational, and cultural barriers through improved infrastructure and collaborative processes is essential. Additionally, there is a need to develop and adopt rigorous modularization frameworks, comprehensive change-management processes, and systematic impact-analysis tools.

D. Threats to Validity

1) Construct Validity: The survey was designed based on a literature review and refined in an iterative expert review process to improve clarity and relevance. However, subjective interpretations of questions by participants may have influenced responses. To mitigate this, open questions were included to capture information beyond predefined categories.

2) Internal Validity: The survey relied on self-reported data, hence there is a risk of response bias. For example, participants may have overestimated or underestimated their MBSE adoption levels. In this study, we used workshop discussions to validate findings and identify inconsistencies to reduce misinterpretations. However, confounding factors, such as differences in organizational size, industry constraints, and access to MBSE tools, may still influence responses.

3) External Validity: The generalizability of our findings may be limited by the sample size. Recruiting industrial practitioners in this specialized field is inherently challenging, as also encountered by other surveys [14]. As a result, our sample size was insufficient to perform a statistical analysis of the responses. Nevertheless, we made every effort to obtain a representative sample of professionals from various industry sectors, including aerospace, defense, automotive, and related industries, which are typically early adopters of MBSE.

4) Conclusion Validity: The use of both qualitative and quantitative methods strengthens the reliability of the results. However, response variability and uneven participation between experience levels can introduce uncertainty in certain findings. The workshop discussions helped validate and refine the interpretations, but more research with longitudinal studies or larger sample sizes is needed to confirm trends over time.

By recognizing these threats, future research can build upon this study's findings to develop more comprehensive and statistically robust analyses of MBSE practices.

VII. Related Work

Huldt and Stenius [14] surveyed the practice of MBSE, and found that although many participants believe that MBSE can enhance various systems engineering activities, there is a significant lack of organizational structures to support enterprise-wide adoption. They also noted improvement areas to make MBSE more effective, including deeper understanding of MBSE value, alignment of MBSE approaches with business processes, and personnel training. These findings align with our own, which indicate that many organizations lack a comprehensive MBSE strategy at the enterprise level, leading to challenges such as lack of standardized MBSE methodology, inconsistent tool adoption, etc. Our survey complements theirs by looking at other MBSE aspects, such as MBSE methodologies, tools, and model management and evolution. In addition, the participants in our survey are considered experts, and many work in industries where MBSE is particularly critical.

Cederbladh *et al.* report on a systematic literature review on the use of verification and validation in MBSE [15]. Their results also indicate the strong dominance of SysML, with UML in second place. Selected adoption barriers include *tool* *interoperability*, *model management*, and *measurable benefits*, similar to our listed challenges. Ma *et al.* present a systematic literature review on MBSE tool-chains to understand their concepts and technologies [16], which also highlight the use of SysML and UML for around 75% of the selected papers. In contrast, our survey elicits answers on MBSE *methodologies* used in practice, and attempts to assess their maturity and capabilities, and directly report practitioner experiences.

Henderson *et al.* performed a literature survey and interviews to collect *lessons learned and best practices* on adopting MBSE [17]. These lessons learned complement our findings, reporting that technical integration challenges, lack of training, and organizational buy-in (among others) continue to be MBSE challenges. White and Mesmer report on discussion topics during three breakout sessions in a workshop on research needs in systems engineering [18]. This includes the feeling that MBSE was not bringing value, and the required cultural changes to better utilize MBSE.

Akundi *et al.* performed an industrial survey to find perceptions of MBSE [19]. They discovered MBSE challenges and divided them as *tools-based*, *knowledge-based*, *cultural/political/cost*, and *customer understanding/acceptance*. Chami and Bruel survey MBSE challenges, when they occur in the system life-cycle, and their dependencies [8]. Knizhnik *et al.* report on interviews conducted at systems engineering organizations, determining that MBSE maturity is low [20]. In contrast to these works, our survey directly captures the maturity and capabilities of participant's MBSE methodologies, and presents selected quotations from practitioner experiences.

VIII. Conclusion

In this paper, we conducted a survey of 76 researchers and/or practitioners from various industry sectors to examine how MBSE is applied in their organizations. Despite the recognized benefits of MBSE practices, we found that many organizations have yet to fully transition to MBSE in their systems engineering practices. We also found that many respondents do not follow a specific methodology, which indicates the absence of a comprehensive, organization-wide MBSE approach.

Our findings highlight many persistent challenges including training and knowledge gaps, organizational resistance, and technical challenges such as change management, collaboration, and tool customization.

We propose three key research directions: 1) establishing an organization-wide MBSE strategy, 2) enhancing modeling languages and semantics, and 3) investing in better methodologies that integrate agile best practices within MBSE to streamline collaboration and model evolution.

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