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A Survey on MBSE Adoption Challenges

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Abstract. Model-Based Systems Engineering (MBSE) has been challenged concerning its successful adoption in real-world applications. Although MBSE remains to be the focal point of any systems engineering activities, its adoption still faces significant hurdles to demonstrate its return on investment. This paper presents the results of a survey on MBSE adoption challenges. Based on our research and industrial work, we first identified a set of MBSE adoption challenges and then asked, through an online survey, participants to collect the opinion concerning these challenges, what phase of MBSE adoption they occur in, and the dependencies between them. With this contribution, we aim to trigger the MBSE and INCOSE community for further discussions and industrial feedback to help in understanding and measuring the challenge space of MBSE adoption. In this way, appropriate solutions could be sought to overcome the existing challenges.

1 Introduction

The domain of systems engineering is practiced in industry to deal with an interdisciplinary process for supporting the system life cycle. According to literature (INCOSE, 2007), (INCOSE, 2014), the systems engineering (SE) process life cycle activities performed by systems engineers are clearly distinguished into two approaches:

- Document-Based Systems Engineering (DBSE) is well known as the traditional one where life cycle activities generate documents as artifacts.
- Model-Based Systems Engineering (MBSE) generates instead a set of model elements with relationships forming a system model.

MBSE introduces new capability into SE practice and is defined by INCOSE as “*the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases*” (INCOSE, 2007). The term MBSE comprises multiple modeling concepts: language, method, and tool to produce one system model or more.

A system model contains model elements (e.g., requirements, functions, components, test cases...) and relationships in between. Indeed, MBSE does not necessary change the “*what to do*” by systems engineers, instead changes the “*how to do it*”. Particularly, MBSE goes beyond the DBSE approach by considering the use of models instead of documents as the primary artifacts produced during the life cycle activities (Delligatti, 2013).

The reasons for adopting MBSE have been emphasized in literature (INCOSE, 2007), (INCOSE, 2014), (Delligatti, 2013), (Friedenthal et al., 2014), (Holt and Perry 2008), and (Estefan, 2008). Delligatti explains a correct MBSE practice as the solution for inconsistency and as a way to performing systems engineering that promises greater Return on Investment (ROI) than DBSE (Delligatti, 2013). Friedenthal et al. assert how MBSE offers significant potential benefits in improving quality, productivity and reducing development risk (Friedenthal et al., 2014). Estefan describes further a survey of MBSE methodologies and its concepts and benefits in details (Estefan, 2008).

However, the adoption of MBSE in real-world applications still struggles with huge challenges (Karban et al., 20011), (Albers and Zingel, 2013), where neither the “MB” nor the “SE” part can fully handle it without issues. An extensive application example is explained in (Parrott et al., 2016) through the implementation status of MBSE at NASA GRC from 2007 till 2016. The authors identified various MBSE adoption challenges such as: the significant investment required to become effective MBSE practitioner, the collaboration in a multi-center modeling effort, and lack of resources.

According to our observations (Chami et al., 2015), (Chami et al., 2018) and nearly ten years ago, the most common question asked during MBSE community events was “*why should I model?*”. Though, this question remains to be asked by those who have not adopted MBSE yet. During the last five years, with the increased MBSE industrial adoption (Cloutier and Bone, 2015), more intention moved towards the question “*how should I model?*”. Those who have been developing valuable models are now asking “*how should I use and manage models efficiently?*”.

These evolving questions reflect that the adoption challenges are still there and are expanding. Solutions might already exist in organizations, as shown in (Hallqvist and Larsson, 2016), but there is still a lack of alignment techniques that support organizations to benefit from experienced MBSE resources' lessons learned. More experienced modelers often do not have the required availability and contracted modeling support can be expensive (Parrott et al., 2016).

One of the first questions that most MBSE community practitioners should ask is how to formulate, measure and understand the existing challenges. Only after that, common solutions could be proposed and shared to eliminate those challenges. A critical step on the path to solving MBSE adoption challenges is to gather and build an understanding of the challenge space experienced by personnel involved with the MBSE adoption.

As part of this path, we have developed an online survey targeting the MBSE adoption challenges, what phase of MBSE adoption they occur in, and the dependencies between them. This survey is based on our research (Chami and Bruel, 2015) and industrial experience (Chami et al., 2015) in the field of MBSE. We asked participants to support us in refining and reviewing the identified MBSE adoption challenges (Chami et al., 2018) to help the MBSE community understand the current state of MBSE challenges.

The term “challenge” in this paper, when mentioned, refers to an MBSE adoption challenge.

1.1 Outline of the Paper

This paper aims to underline the importance of alignment among MBSE community members for effective understanding of the actual status of MBSE adoption challenges. Therefore, the core challenges of MBSE adoption are identified and the results of an online survey questionnaire are presented in detail. The remaining of this paper is organized as follows: In the following section, we describe the survey objectives and design. In section 3 we study the related works and related surveys, showing that literature in this research scope is not very rich. In section 4 we provide a background of MBSE adoption challenges and their phases. Section 5 we precise the survey results and in section 6 we reflect the survey findings and we explain how we intend to evaluate and enforce our vision.

2 Survey Objectives and Design

The MBSE adoption challenges survey was conducted using an online questionnaire. We received 42 complete and faultless responses in total. A few other responses were removed due to incorrect input. The survey content, especially the challenges list (Chami et al., 2018) was the result of several interviews with MBSE experts. Before publishing the survey online, the content was reviewed and discussed among a small group of experts from industry and research. Additionally, several sample survey responses were tested to ensure that the questions have the suitable survey format and the survey has the optimum completion duration. The survey link was later published across multiple MBSE related social networks and emailed to the SysML forum group.

The aim of the survey was to find out the current state of the MBSE adoption challenges, particularly, to target the following three objectives:

- **Objective 1:** Review the collected challenges list and collect new ones
- **Objective 2:** Determine in which phases the challenges are faced
- **Objective 3:** Determine the dependencies between the challenges

The survey was designed as a one-page survey. It contained its purpose description, a representative example of the expected results, a background information section and the questions section. The questions section was composed of 6 required questions grouped into two parts. Part 1 presented 3 fundamental questions to collect the opinion concerning: (1) MBSE adoption challenges, (2) what phase of MBSE adoption they occur in, and (3) dependencies between them. Part 2 presented 3 questions to reveal the demographics and background of the survey participants.

The survey respondents had the opportunity to provide their contact information to take part with the survey price draw. To ensure a greater chance that more respondents complete the survey, the time needed to complete the whole survey was estimated to be less than 15 min. Final results showed that typical time spent was 12 min.

3 Related Surveys

'The State of the Nation' MBSE survey (Towers 2013) covers questions related to modeling in general and MBSE in particular. Most respondents were mainly from aerospace, consulting and defense. The most used words among answers for a question asked to list 3 main challenges of MBSE were: *tools, understanding, people, engineering and software*. A more detailed analysis of this survey results is demonstrated in (Johnson 2015) focusing on the question of MBSE challenges and objectives. The overall outcomes were: *"Lack of evidence for, explanation of, business case. Lack of practical guidance, case studies, examples. Challenges with infrastructure, tools and process"*.

The MBSE survey results shown in (Cloutier and Bone, 2015) cover a wider questions' perspective with more respondents. Furthermore, the authors compare the results of previous MBSE surveys. On the one hand, the first finding clearly indicates that *"there is an increase in the number of companies practicing MBSE and developing internal MBSE methods, tools, and training"*. On the other hand, the other finding lists down the top 5 remaining barriers: *"cultural and general resistance to change, MBSE learning curve, availability of skills, lack of perceived value and lack of management support"*.

The authors in (Parviainen et al., 2009) published the state-of-the-art and results of two surveys about model-driven development (MDD), particularly from the processes viewpoint. In the 2nd survey, the MDD usage and challenges in companies is presented. Results show that most respondents recognized the lack of modeling experts in organizations as a challenge. Other technical challenges were recognized such as comparing and merging different versions of models, visualizing the difference in a usable way, model-level debugging was not sufficiently supported and the use of immature tools caused several problems.

A detailed survey of some of the leading MBSE methodologies used in industry is described in (Estefan, 2008). The MBSE methodology is characterized as the collection of related processes, methods, and tools used to support the discipline of systems engineering in a "model-based" context. It is highlighted, based on NASA best practices, that one of the main challenges organizations face when adopting advance approaches as MBSE, is that *"traditional document-driven approach is likely to continue for the foreseeable future"*.

In comparison to the above existing surveys, our survey work differs in several ways. First, it is targeting one concrete topic and in-depth investigation related only to the adoption challenges rather than general MBSE topics. Second, we provided the survey participants a carefully established list of existing challenges with their definition to avoid any ambiguity. Simultaneously, we allowed the participants to add other challenges which might not have been covered. Third, the survey content was meant to be neutral, relevant to MBSE only and without any specific information related to particular methodologies, modeling languages or modeling tools. Finally, one of the main contributions, which we have not seen in any related works or surveys, is to collect the opinion related to the dependencies between the adoption challenges. Only after having an overview about these dependencies, priorities for overcoming them can be set.

4 Survey Background

4.1 MBSE Adoption Challenges Description

To avoid any ambiguity and ensure that the survey participants understand the collected challenges, they were described before the questions section. It was also highlighted that the order of the challenges does not represent any importance or occurrence. In the following, the collected challenges and their phases (Chami et al., 2018), are described in details:

Upfront Investment: MBSE adoption requires a substantial upfront investment, especially if it has not been considered before. This also includes determination of an effective investment strategy, accurate cost estimation and quantifying its return on investment.

Adoption Strategy: Two approaches dominate MBSE adoption: off-cycle (in a sandbox environment) or on-cycle (directly on productive projects). The first approach is considered ideal, as not all companies have the required budget and time. The second approach is much more challenging and introduces additional costs for running projects. Choosing the wrong strategy can negatively impact the benefits of MBSE.

Purpose and Scope Definition: A crucial basis for MBSE adoption is to define a clear purpose and scope (the *why* and *what*). Ideally, it must be precisely described before beginning the deployment. However, this is a challenge in real world applications, where modeling can be used in so many ways.

Awareness and Change Resistance: The human factor plays a central role, particularly if key players have different levels of MBSE knowledge and adequate time for training is not granted. Consequently, change is not always accepted, compared to existing approaches, it creates strong resistance due to the lack of expertise to deliver the required artefacts.

Executive Level Sponsorship: Although increased MBSE popularity has strengthened executive support, there are still conflicting MBSE adoption goals between short-term driven employees who care about low adoption cost, with others aiming at more adoption quality and long-term solutions.

Method Definition and Extension: It is often necessary to customize an appropriate method according to a defined purpose and scope. It is a challenge to set up the required method, document it and facilitate it with modeling rules, guidelines, tool customizations and training materials. Further challenges arise when new method extensions are needed.

Modularity and Reusability: Many organizations still follow an opportunistic and isolated reuse approach, where a set of data is copied and pasted from one context to another. Unfortunately, this still happens even with system models and results in losing the “*source of truth*” as soon as the copied source or pasted target is changed.

Complexity Management: The evolution of systems through the growing number of components, functions and interactions has dramatically increased their complexity. The issue here is with both the high number of model elements and the dependencies between the whole elements and model(s). Very often this complexity level takes existing methods and tools to the limit.

Tool Dependency and Integration: Companies need to pick a set of tools and train employees accordingly. Such a decision is not an easy task and there is no tool that satisfies all needs. Moreover, integration between systems modeling tools and others, such as simulation or requirements, is still solved with specific solutions.

Large Models Visualization: Different team members are involved in querying the model contents. Unfortunately, existing tools require additional training effort, and customizing the layout of model elements and diagrams is time consuming. Additional challenges appear in large models, where model navigation and understanding become highly complicated.

4.2 Adoption Phases Description

As with the description of the challenges, the adoption phases were also described to avoid any ambiguity. It was highlighted that the collected MBSE challenges will be categorized according to their occurrence during the adoption cycle into three phases:

Early phase: is related to companies with no previous MBSE adoption experience and those questioning how to plan and implement the transition while investing in a high learning curve.

Middle phase: occurs after deploying MBSE on one project and figuring out the first versions of the scope and purpose definition, tool environment and modeling method.

Late phase: occurs after achieving a mature level of MBSE adoption in one application (e.g., functional analysis) and being eager for more optimization and adoption in other applications (e.g., model-based testing, variability management).

5 Survey Results

Based on the challenges discussed above, one can clearly notice that MBSE adoption challenges are based on common factors: human, financial, organizational and technological. Although improvement processes for successful transition to MBSE are already published, e.g., in (Friedenthal et al., 2014), from an industrial perspective it is still very challenging to measure the transition status, particularly when MBSE is oversold. Indeed, it is not MBSE itself but the way it is adopted. Here, there is a need to establish a clear pattern of MBSE challenges among the MBSE community as a precondition for defining a common solution for dealing with them. In this section, we describe the survey questions and report the details of their results.

5.1 Question 1: MBSE Adoption Challenges List

The aim of Question 1 was to target the first objective of the survey by reviewing the set of MBSE adoption challenges and collecting new ones. Respondents were asked to indicate their level of agreement for each challenge whether it is related to MBSE adoption. A 5-point scale was used for this question: strongly disagree, disagree, neither disagree nor agree, agree, and strongly agree. Participants had to select for each challenge one agreement level to complete this question, which was mandatory for a survey submission. An “other” answer option, as text box, was enabled to this question to allow participants to specify other challenges which are not listed in the question with their level of agreement.

Q1 Please indicate your level of agreement or disagreement if the following challenges are related to MBSE adoption:

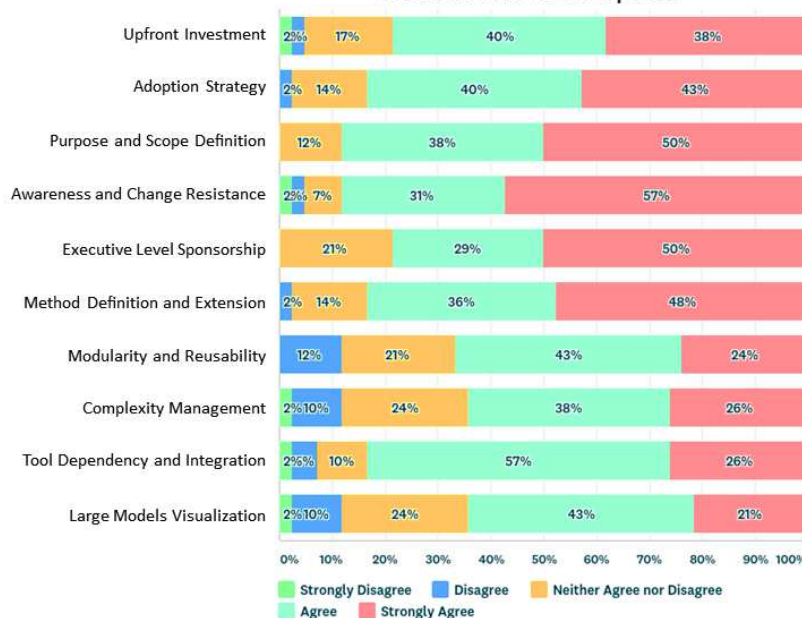


Figure 1. Results for Question 1 - MBSE Adoption Challenges List

Figure 1 shows the results of Question 1. The vertical axis lists the challenges while the horizontal one shows the percentage of agreement levels. According to the summary of responses, between 65% and 85% *agree* and *strongly agree* that all survey challenges are directly related to MBSE adoption. Whereas 7% and 24% decided to *neither agree nor disagree* and between 2% and 12% *disagree* and *strongly disagree* that the challenges are not related to MBSE adoption.

On the one hand, the majority of individual responses (57%) *strongly agree* that *awareness and change resistance* is a principal challenge. Together with those who *agree* (31%) on that, it forms 88% of the total participant’s responses. This confirms that the human factor (or personnel) and the challenges it brings with respect to change resistance is the one that organizations should be solving first. A similar observation has also been reported for the *purpose and scope definition* challenge (88% for *strongly agree* and *agree*). This further asserts the difficulties of defining the goals and boundaries of MBSE adoption.

On the other hand, the technical factors conquered the financial ones. *Upfront investment* seems not be a major challenge as 17% decided to have a neutral opinion and 4% split among *disagree* and *strongly disagree*. Whereas the adoption technical factors (*tool dependency and integration, method definition and extension and adoption strategy*) got more *strongly agree* and *agree* percentage.

For Question 1, an “other” answer option for comments was enabled to collect other challenges not listed in the survey. Below in Table 1 an overview of the comments received are shown:

Participants response of the “other” optional text box:
<i>Mismatch of expectations among stakeholders</i>
<i>Maturity of tool set and methods</i>
<i>Awareness and Change Management is very strong. I face a lot of ignorance and speech that it is not a necessary path to follow. Oversimplification is the main answer.</i>
<i>On demand mentoring of MBSE expert</i>
<i>MBSE tools expert on demand (on line)</i>
<i>Start with proven methodology</i>
<i>SysML diagrams are not easy to read and require training, which becomes a struggle to keep managing team understanding and commitment.</i>
<i>The real value of MBSE which after many years of hype cannot yet be proven</i>
<i>Aversion of engineers to the rigor and detail required - e.g. making sure each requirement has a meaningful short name and number</i>
<i>Convincing system engineers to adopt SysML notations.</i>
<i>Well defined use cases and success metrics for initial pilot implementations</i>
<i>Significant reduce of development cost at the end and development life cycle.</i>
<i>Tension between need to deliver SE products and develop new ways to do so; within the cost constrained environment of the team. (One team, with one budget, cannot both perform duties and learn a new approach.)</i>
<i>Systems Engineering knowledge. Starting with MBSE without knowledge on SE means you will not be able to understand benefits that MBSE can bring to you. Adoption might be harder.</i>
<i>Attracting and / or training engineers and being able to retain them</i>
<i>The already existing capability on Systems Engineering. I see MBSE as an evolution of SE. If the added value for SE (holistic approach, proper requirements engineering based on abstraction layers, functional analysis, proper interface management, proper traceability, etc.) is not appreciated, then MBSE can hardly success.</i>

Table 1. Other Participants’ Responses for Question 1

From Table 1 a view on other challenges is collected. Although these challenges might be organization or application specific, they do not differ too much from the challenges listed in our survey. They can be categorized according to the common factors mentioned before: human, financial, organizational and technological. In this way, the next step for understanding and measuring them can be enabled. In summary, one can clearly highlight the importance of setting the challenges' priorities based on the importance factor of MBSE adoption challenge within an organization.

5.2 Question 2: What Phase(s) of MBSE Adoption Challenges Occur

The aim of Question 2 was to target the second objective of the survey by determining in which phases the MBSE challenges are faced. Respondents were asked to indicate their opinion about the phase(s) where the MBSE challenges occur. A rating scale matrix question was used where rows represented the list of challenges and columns the phases (*early*, *middle* and *late* phase). Multiple responses per row were allowed to enable the section that a challenge occurs in more than one phase. A selection for all challenges was mandatory for a survey submission. Like Question 1, an “other” answer option was enabled to allow participants to add new challenges with the phases they occur.

Q2 Please indicate your opinion about the phase(s) where the following MBSE challenges occur (multiple responses per row are allowed):

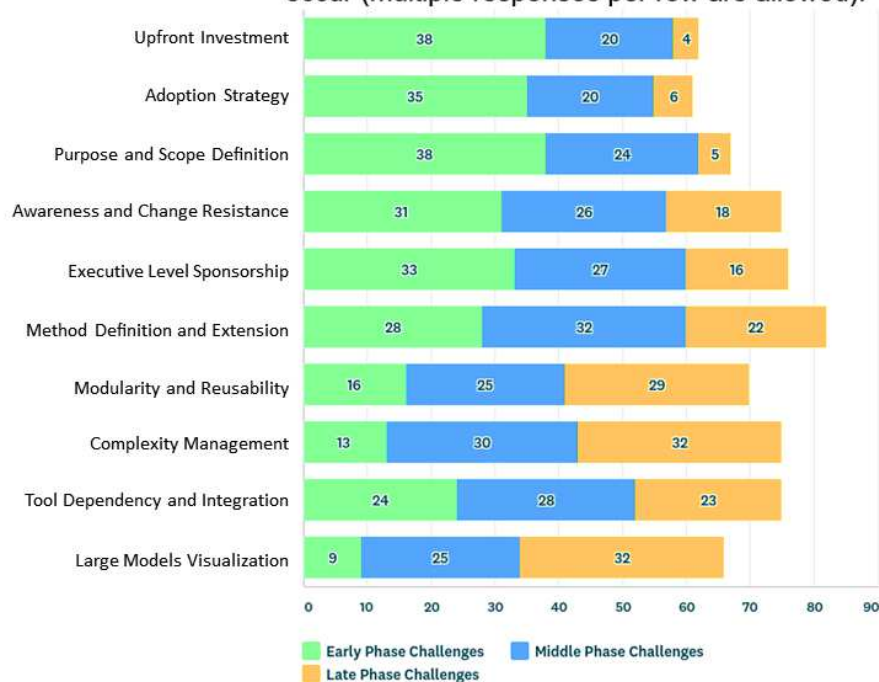


Figure 2. Results for Question 2 – MBSE Adoption Phases

Figure 2 shows the results of Question 2. According to the clear majority of responses received (above 90%) consider that the *upfront investment* and *purpose and scope definition* as *early* phase challenges, 20 and 24 responses respectively as *middle* phase challenges and 4 and 5 responses respectively as *late* phase challenges.

An overwhelming majority of responses (above 70%) recognize that *adoption strategy* (35), *executive level sponsorship* (33), *awareness and change resistance* (31) as *early* phase challenges. Whereas, these challenges continue to play role as *middle* phase challenges with 20, 27 and 26 responses respectively and with respect to late phase challenges they got lower responses (6, 16 and 18 respectively). Responses with respect to the *method definition and extension* challenge tend to spread among the *early*, *middle* and *late* phases. However, all other challenges, i.e., *modularity and reusability*, *complexity management*, *tool dependency and integration*, and *large models visualization* lean more towards *middle* and *late* challenges.

For Question 2, an “other” answer option for comments was enabled to collect the phases of other challenges not listed in the survey. Below in Table 2 an overview of the comments received is shown:

Participants response of the “other” optional text box:
<ul style="list-style-type: none"> • <i>Mismatch of expectations among stakeholders - Early and Middle phase</i> • <i>Maturity of tool set and methods - Early and Middle phase</i>
<ul style="list-style-type: none"> • <i>Most challenges live through all phases of adoption. The 'system of interest', being the organization adopting MBSE requires a full lifecycle analysis of the impact of MBSE; so inherently the SE process must be employed on the SE organization.</i>
<ul style="list-style-type: none"> • <i>Systems Engineering knowledge in all 3 phases.</i>
<ul style="list-style-type: none"> • <i>Training in all 3 phases.</i>
<ul style="list-style-type: none"> • <i>The right MBSE resources (technical and management) in all phases</i>

Table 2. Other Participants’ Responses for Question 2

By observing the results of Question 2, one can clearly highlight the importance of setting the challenges' priorities with respect to the time factor and what phase of MBSE adoption they occur in. It is very important to underline that the late coming challenges have a direct impact on the benefit of MBSE. MBSE success should be measured at the end based on the three phases and not only on the early ones.

5.3 Question 3: MBSE Adoption Challenges Dependencies

The aim of Question 3 was to target the third objective of the survey by determining the dependencies between the MBSE adoption challenges. Respondents were asked to select for each challenge the other challenges it depends on. A rating scale matrix question was used where rows and columns represented the list of the challenges. It was assumed that a row challenge could depend on one or more column challenge(s), so multiple responses per row were allowed. Checked boxes where row and column are same were ignored (no reflexivity).

Figure 3 shows the results of Question 3 in a matrix format with the respective legend. The percentages shown represent the respondents results of dependencies between challenges. The total dependencies per row challenge are also shown. Dependencies are from a row challenge to a column one. For instance, with respect to the *upfront investment*, the majority agrees that it depends on the *purpose and scope definition*, *executive level sponsorship* and *adoption strategy*. The method *definition and extension* depends in average on all other challenges however mainly on the *purpose and scope definition* and *modularity and reusability*. Whereas the *executive level sponsorship* depends on the *upfront investment*, *purpose and scope definition* and *awareness and change resistance*.

Q3 Please indicate your opinion about the dependencies between MBSE adoption challenges

	Upfront Investment	Adoption Strategy	Purpose and Scope Definition	Awareness and Change Resistance	Executive Level Sponsorship	Method Definition and Extension	Modularity and Reusability	Complexity Management	Tool Dependency and Integration	Large Models Visualization	Total Dependency %
Upfront Investment		69%	74%	38%	71%	38%	19%	17%	43%	14%	383%
Adoption Strategy	69%		67%	55%	69%	43%	17%	14%	38%	10%	381%
Purpose and Scope Definition	48%	64%		48%	45%	57%	33%	26%	21%	17%	359%
Awareness and Change Resistance	48%	50%	41%		74%	36%	12%	26%	38%	10%	333%
Executive Level Sponsorship	74%	57%	62%	62%		14%	10%	17%	19%	10%	324%
Method Definition and Extension	41%	41%	67%	29%	21%		64%	55%	60%	31%	407%
Modularity and Reusability	19%	29%	24%	17%	10%	60%		57%	60%	29%	302%
Complexity Management	14%	12%	33%	17%	17%	60%	48%		50%	50%	300%
Tool Dependency and Integration	55%	38%	38%	19%	21%	60%	33%	55%		41%	360%
Large Models Visualization	21%	12%	21%	7%	5%	38%	26%	55%	71%		257%

LEGEND
0 < % ≤ 10
11 < % ≤ 25
22 < % ≤ 35
33 < % ≤ 45
44 < % ≤ 55
55 < % ≤ 65
66 < % ≤ 75
77 < % ≤ 85

Figure 3. Results for Question 3 – Challenges Dependencies

Interestingly the *method definition and extension* gathered the highest dependencies' total percentage value (407%). It was followed by the *upfront investment* (383%) and *adoption strategy* (381%). On the other side, the *large models visualization* gathered the lowest total percentage value (257%). In summary, Figure 3 demonstrates how it supports in tracing the path to solve a particular challenge based on the dependencies. Additionally, having several time-based versions of it would measure the progress of solving, or not solving, a challenge and the prove behind the solution.

5.4 Question 4 to 6: Participants Demographics

The aim of Questions 4 to 6 was to reveal the demographics and background of the survey participants to clearly understand where the results are coming from. The three questions covered the domain of respondents' organization, the products or services they are using MBSE for and the working years with MBSE.

As seen in Figure 4, most of respondents' organizations came from the consulting, training and teaching domains with 31%. It was followed with 19% from aerospace, 14% medical, 10% railway, 7% from defense and computing and IT engineering companies and 5% from automotive. There was no response from space systems. However, for the "other" option, 3 responses each presented companies of SysML/MBSE tool vendor, heavy machinery and engineering services.

In Question 5, we were interested to collect what products or services the participants are using MBSE for. Figure 5 shows the results with most respondents (50%) for the mechatronics systems. Mechatronics systems were characterized by the combination of mechanical, electronics and computer engineering. Software engineering took the third place with 14.29% and then followed with 7.14% for electronics and 4.76% for mechanical engineering. Several other responses were also collected, as seen in Figure 5, including business solutions, logistics, procurement and MBSE tool vendors.

Q4 What type of industry does your company represent?

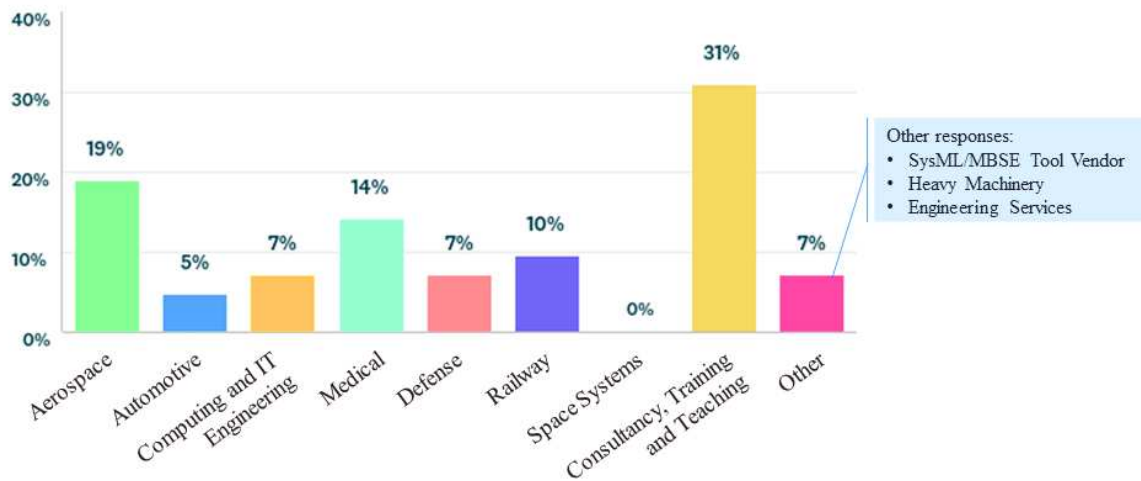


Figure 4. The Domain of Respondents' Organization

Q5 Which of the following engineering disciplines best describes your system-of-interest (i.e., Product) you are using MBSE for?

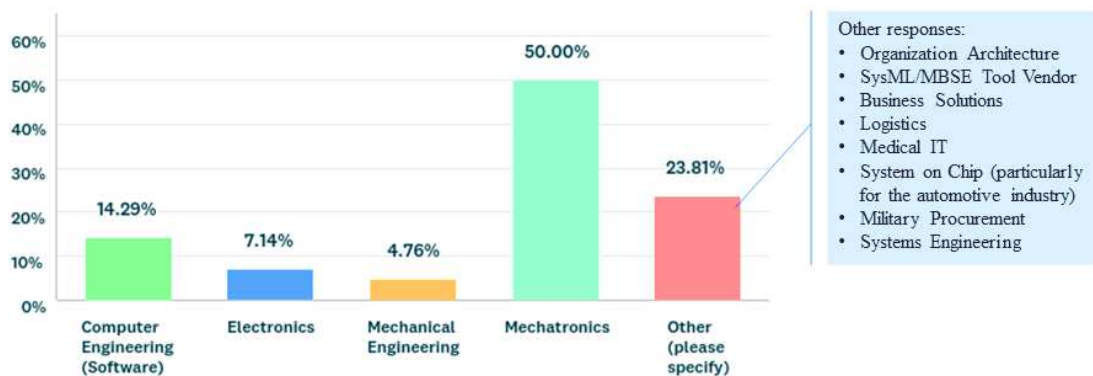


Figure 5. Respondents' Products or Services

The results of the final question are detailed in Figure 6 which shows the respondents' years of experience with MBSE. This question demonstrates the quality of responses based on the experience of participants. The highest number of participants, 47.62%, has more than 5-years experience with MBSE. Other middle responses were for 1 and 3 years (23.81%) and 3 and 5 years (21.43%). Respondent collected with less than 1-year experience were 7.14%.

Although the demographics has no scientific interest in this paper, they provide an overview which industry sectors, domains and group of MBSE experts are facing MBSE adoption challenges. In future work, we aim to analyze the difference across the demographics' results to understand the dependencies between challenges and characteristics of industry, and products' and services' domains.

Q6 How long have you been working with MBSE?

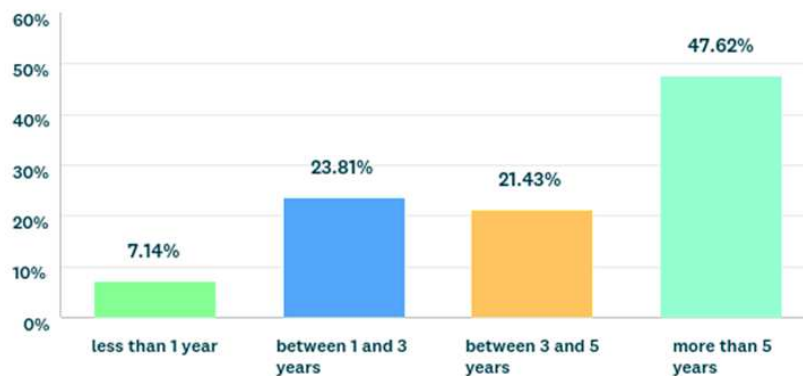


Figure 6. Respondents' Working Years with MBSE

6 Conclusion

6.1 Survey Findings

The work presented in this paper is a first step in the direction of defining, understanding and measuring the challenges associated with the adoption of MBSE. Most responses came from practitioners in consulting, where personnel are involved in different MBSE adoption projects. In this section, we summarize the survey findings. The goal is not to get the perfect answers, but rather understand the actual status of the adoption challenges among the received responses.

Finding 1: The most challenges related to MBSE adoption are noticed to be based on the human and technological factors. It starts with the awareness and change resistance on both executive and engineering levels within an organization. It goes over having the right MBSE resources to define the purpose, scope and method. Additionally, these challenges need to be addressed from the early phases and directly depends on the executive sponsorship and available upfront investment.

Finding 2: Although other challenges were less related to MBSE adoption, results show that respondents know that it will come in later adoption phases. This knowledge is very crucial while looking at the dependencies for overcoming the challenges. For instance, to see how a challenge as complexity management is well known from the beginning as a late phase challenge, the question mainly lies if the adoption strategy, methods definition and modeling tools consider solving it from the beginning. Unfortunately, it is not the case yet in practice, as far as we can testify.

Finding 3: After correlating all the data collected together, an important contribution related to setting the challenges' priorities can be observed. Challenges can be prioritized based on three factors: importance, time and dependency. However, these factors are not unique across organizations. For instance, companies with high available upfront

investment might suffer from having the freedom that each department starts to define its own MBSE adoption solution. This brings later integration and model interchange issues. Like time, organizations with different design and development timeline could face same challenges but in different phases. Moreover, delivering specific customer products (e.g., rolling stock) differ from other delivering generic and more configurable products (e.g., automotive). Therefore, the first step to organize these three prioritization factors based on organizations domains and then look for common aspects if they exist.

6.2 Future Directions

The results of this survey work demonstrate how the survey objectives have been accomplished, they open the opportunity to overcome MBSE adoption challenges and thus to achieve effective MBSE implementation. Since the number of responses was not large enough as planned for particular demographics of Questions 4 to 6 (e.g., automotive, defense), the data collected was not enough to show the analyze of the difference between the results of Questions 1 to 3 according to those from Questions 4 to 6. Therefore, more work to refine the results of this paper is planned.

In a next step, we aim to run dedicated workshops at upcoming MBSE related conferences to report, discuss the obtained results and define the way to overcome these challenges. This should include academic researchers, industrial professionals from different domains. It will be also followed in parallel with a one-to-one personal interview for the same sake. Workshop and interviews results should refine the content of this paper, propose next directions and initiate further collaboration among the MBSE community.

On the other hand, we believe that the challenges faced are not only due to MBSE but the way it is adopted. In order to drive the actions of overcoming MBSE adoption challenges in the right direction, our long-term vision is to target and solve a set of the challenges analyzed in this paper from a methodological, technological and educational perspectives. This is part of our ongoing work related to the D3 MBSE Adoption Toolbox (Chami et al., 2018).

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References

- Albers, A., and Zingel, C., 2013. Challenges of Model-Based Systems Engineering: A Study towards Unified Term Understanding and the State of Usage of SysML. Berlin, Heidelberg: Springer Berlin Heidelberg, 2013, pp. 83–92. Available at: http://dx.doi.org/10.1007/978-3-642-30817-8_9
- Cloutier, R., and Bone, M., 2015. “MBSE Survey,” Presented January 2015 INCOSE IW Los Angeles, CA.
- Chami, M. and Bruel, J.M.: Towards an Integrated Conceptual Design Evaluation of Mechatronic Systems: The SysDICE Approach. In: Proceedings of the International Conference on Computational Science, Reykjavik, Iceland. (2015) 650–659
- Chami, M., Oggier, P., Naas, O., and Heinz, M.: Real World Application of MBSE at Bombardier Transportation. In: The Swiss Systems Engineering Day (SWISSED2015), Kongresshaus Zurich. (8th September 2015)
- Chami, M., Morkevicius, A., Aleksandraviciene, A., and Bruel, J.M.: Towards Solving MBSE Adoption Challenges: The D3 MBSE Adoption Toolbox. In: 28th Annual INCOSE International Symposium. (2018)
- Delligatti, L., 2013. SysML Distilled: A Brief Guide to the Systems Modeling Language, 1st ed. Addison-Wesley Professional, 2013.
- Estefan, J. A., 2008. Survey of Model-Based Systems Engineering (MBSE) Methodologies. INCOSE MBSE Initiative, May 23 2008.
- Friedenthal, S., Moore, A., and Steiner, R., 2014. A Practical Guide to SysML, Third Edition: The Systems Modeling Language, 3rd ed. San Francisco, CA, USA: Morgan Kaufmann Publishers Inc.
- Hallqvist, J. and Larsson, J. (2016). Introducing MBSE By using Systems Engineering Principles. INCOSE International Symposium, 26: 512–525. doi:10.1002/j.2334-5837.2016.00175.x
- Holt, J., and Perry, S., 2008. SysML for Systems Engineering. The Institution of Engineering and Technology, London, United Kingdom, 2008, no. ISBN 978-0-86341-825-9.
- INCOSE, 2007. Systems Engineering Vision 2020, version 2.03 ed. International Council on Systems Engineering (INCOSE), September 2007, INCOSE-TP-2004-004-02.
- INCOSE, 2014. A World in Motion: Systems Engineering Vision 2025. International Council on Systems Engineering (INCOSE), 2014.
- Johnson, J. (2015). Analysis of INCOSE UK MBSE WG 2013 Survey.
- Karban, R., Weilkiens, T., Hauber, R., Zamparelli, M., Diekmann, M., and Hein, A. M., “Cookbook for MBSE with SysML,” Tech. Rep., 2011.
- Parrott, E., Trase, K., Green, R., Varga, D., Powell, J., 2016. NASA GRC MBSE Implementation Status, Feb 17, 2016.
- Towers, J., (2013). Model Based Systems Engineering – The State of the Nation. INCOSE UK Annual Systems Engineering Conference 2013.
- Parviainen, P., Takalo, J., Teppola, S., and Tihinen, M., 2009. Model-Driven Development. Processes and practices. 2009. VTT Working Papers 114.