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Challenges of implementing MBSE in Industry – a tool vendor experience

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ABSTRACT

Model Based Systems Engineering (MBSE) offers a systematic approach to address the challenges faced by industries in developing complex systems. However, the full implementation of MBSE Process, Methods, and Tools (PMT) in industry remains a challenge. This paper focuses on the implementation of the 3DEXPERIENCE MBSE toolchain by Dassault Systèmes Industrial Service (DSIS), introduces the typical challenges observed during the MBSE implementation process and categorizes them into five types. Based on industrial best practices and service experiences, the paper proposes multiple solution elements to overcome these challenges. These elements emphasize stakeholder support, establish an experience-based MBSE capability, enrich MBSE capabilities to solution bricks, create an implementation plan and validate through proof of concepts. The interdependency between solution elements allows efficient implementation and realization of short-term benefits. The paper concludes by discussing the value and applicability of the proposed solution elements, highlighting their potential for the industrial practice. The chapter closes with an outline of future steps to mature and advance the solution elements.

***Index Terms** – Challenges of MBSE Implementation, MBSE Implementation Strategy, Future MBSE Implementation*

1. INTRODUCTION

In today's rapidly evolving technological landscape, the development of complex systems has become increasingly challenging for industries across various sectors. Model-Based Systems Engineering (MBSE) offers a systematic and integrated approach to tackle these challenges by utilizing models as central artefacts throughout the engineering lifecycle [1]. MBSE provides Process, Methods and Tools (PMT) to represent, analyse, simulate, and validate requirements, system functions and system designs as well as parameters of various kind [1, 2]. Doing this, MBSE aims to enable organizations to improve efficiency, reduce costs, and enhance product quality [1]). As of today, MBSE PMT are not fully implemented in industry [3].

Dassault Systèmes Industrial Service (DSIS) aims to enable customers from different industries to gain MBSE PMT benefits by providing the end-to-end 3DEXPERIENCE MBSE toolchain as well as MBSE processes and methods required to use it. The first part of this paper aims to give an insight in the **typical challenges observed by DSIS** when implementing 3DEXPERIENCE based MBSE PMT together with the customer. Based on an analysis of these challenges, the second part of this paper proposes **Solution Elements.** These elements are based on industrial best practices and (service) experiences in 3DEXPERIENCE based MBSE PMT implementation projects. Focusing on the service viewpoint, the Solution Elements aim to help organizations to introduce MBSE PMT as well as their implementation service partners to achieve better implementation results and to handle or even overcome the observed challenges.

2. CHALLENGES OF MBSE IMPLEMENATION

Starting as software developing company, Dassault Systèmes' self-understanding is that of a solution provider, enabling customers to complete all tasks within product development, from idea generation to production planning, in an end-to-end software ecosystem. The 3DEXPERIENCE platform provides a broad range of interconnected tools for MBSE tasks such as requirements engineering, SysML based systems architecture, parameter design and test management plus data governance tasks such as change, configuration or lifecycle management. Provided as Software-as-a-Service (SaaS), one of the core success factors for successful 3DEXPERIENCE implementation for customers are after sales services provided by Dassault Systèmes Industrial Service (DSIS). DSIS supports customers to use the 3DEXPERIENCE platform "out of the box" without adaption or configuration by guiding tool usage, supporting the adaptation of customer processes and methods and bringing customer needs back to the 3DEXPERIENCE tool developers to close gaps in SaaS updates.

Providing these services to a broad range of DSIS customers from the transportation and mobility, aerospace and industrial equipment industry for development of products such as cars, airplanes, elevators or agricultural machinery, some typical challenges within MBSE implementation projects could be observed. A summary of those challenges are shown in Figure 1 and are described in detail in the following sub-chapters.

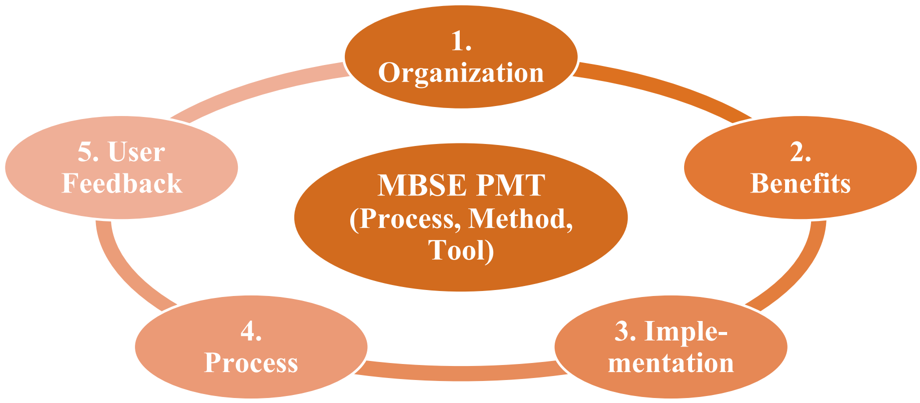

*Figure 1: Typical Challenges of implementing **3D**EXPERIENCE based MBSE PMT*

2.1. The Organization Challenge

The introduction of Model-Based Systems Engineering (MBSE) brings a paradigm shift in the way organizations approach systems development and integration. As organizations transition from traditional development methods to MBSE, one of the prominent challenges they face is the inherent shift of responsibilities among various stakeholders. According to [4] "[SE] may lead to new roles and a change in organizational structure (Re-structuring) and will certainly impact processes, methods and tools (Re-engineering)". This section explores the challenge of responsibility shifts caused by the introduction of MBSE.

In traditional development approaches, discipline engineers often had more independent roles and broader responsibilities in component development. They conducted feasibility studies, made decisions on optimal solution approaches, negotiated interfaces with other components, specified the component's technical parameters, and managed production and deployment. They also monitored performance, conducted maintenance activities, and provided technical support and expertise to stakeholders. Activities were steered by the known context, which is not always obvious [5].

However, with the adoption of MBSE, these responsibilities undergo significant shifts. MBSE emphasizes a holistic and integrated approach to system development, focusing on capturing and managing system requirements, architecture, and behaviour within a model-based environment. As a result, several responsibilities previously held by discipline engineers are now transferred to MBSE, whose role becomes more prominent.

The shift in responsibilities poses several challenges for organizations implementing MBSE. Firstly, it requires a fundamental change in the mindset and skill set of discipline engineers who must adapt to new roles and responsibilities. The transition from a component-centric mindset with a focus on the solution, to a systems-centric mindset, which strives to separate problem analysis from solution design, may require additional training and reorientation to effectively contribute to the MBSE process. Furthermore, organizations may encounter resistance to change from discipline engineers who might be reluctant to relinquish their previous responsibilities. Overcoming this resistance requires leadership, effective change management strategies, and communication to emphasize the benefits and long-term value of MBSE.

The introduction of MBSE presents organizations with the challenge of responsibility shifts, which requires the realignment of roles and redistribution of responsibilities among stakeholders. This transition requires overcoming mindset barriers, fostering effective collaboration, and managing resistance to change. Shifts of responsibilities can result in a challenge that needs to be addressed to achieve a successful implementation of MBSE, which the authors call "The Organization Challenge". According to [6] this kind of cultural change is one of the "more difficult challenges to overcome".

2.2. The Benefits Challenge

When companies introduce MBSE, they do it with a certain outcome in mind. According to the study in [7], "more than half (55%) of the interviewees hope to achieve improved predictability of projects in terms of time, quality and cost targets through SE. 40% see improvement potential for achieving time targets, 33% for cost targets and 22% for achieving quality targets, whereby the effects are interdependent and mutually reinforcing.". These goals represent high-level benefits that organizations expect MBSE to bring for the overall development process, once successfully implemented. In addition, even if these benefits are considered as qualitatively high, it is hard "to sufficiently quantify them" according to 31% of the interviewees in [7], while "non-quantifiable benefits of SE are the biggest obstacle to SE-introduction" according to [4].

Besides these common high-level benefits, there are also benefits on an operational level. These contribute to the high-level benefits, but are specific to organizations and their way of operation. Therefore, these low-level benefits are hard to qualify for service providers like DSIS, because they do not show up on a surface, but need analysis. At the other hand, to maintain acceptance amongst stakeholders and specifically users, a core challenge is to introduce beneficial outcomes during the individual steps of the implementation for a majority of the involved stakeholders constantly.

DSIS faced situations where for a given stakeholder a benefit in one part of the process was compensated by a drawback in another part of the project. For example, like shown in Figure 2, a mechanical engineer who gets requirements in a higher quality, and therefore faces a benefit (green), might struggle with learning specification languages like SysML, that are not widespread in the domain of mechanical engineering and have no time benefit in searching compared to the well-known document-based searching process, both drawbacks (red).

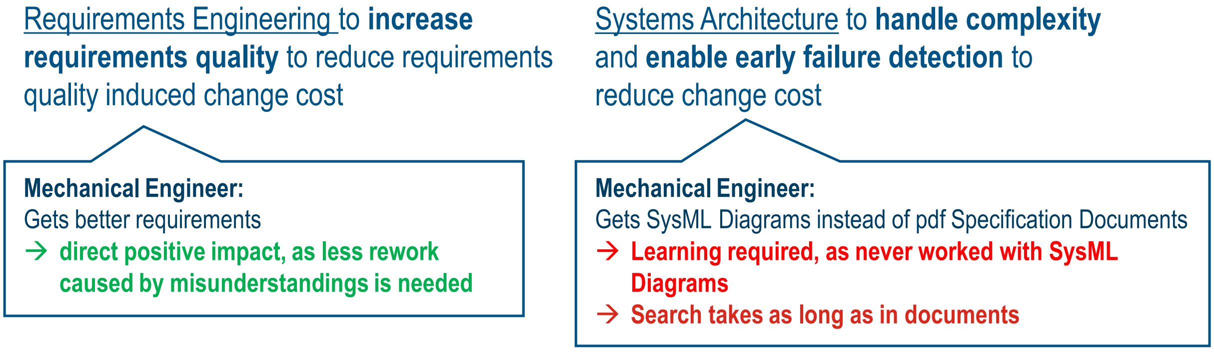

Figure 2 Example for Pains and Gains faced by a mechanical engineer during the implementation of MBSE PMT.

One challenge is now to evaluate, if in sum a stakeholder can benefit from the introduction considering all the drawbacks and all the benefits he or she will face. A second challenge is, to choose a way of introduction, where a majority of stakeholders will benefit over a large part of the implementation phase. Therefore, maintaining the acceptance of operational stakeholders throughout the whole implementation period of MBSE PMT and finding a good balance of benefits and drawbacks amongst all stakeholders needs to be considered.

2.3. The Implementation Challenge

Successful project implementation is not only depending on clearly defined goals, but also on measurable planning that allows a judgement against available budget and time as well as client acceptance at the final stage in the implementation process [8]. The authors experienced MBSE implementation projects planned for 2 to 4 years. By the end of these projects, it was planned to deliver all necessary MBSE PMT to fulfil the project goals and provide the expected benefits for the client. Consequently (almost) impossible to achieve client acceptance at earlier stages of the project, it turned out to be quite difficult to foster stakeholder acceptance during the individual steps of the implementation with all benefits connected to the final project delivery.

2.4. The Process Challenge

MBSE processes need the contribution of multiple stakeholders. This results in a way of working, where the interaction between theses stakeholder and MBSE roles need to be intense and frequent. This section will discuss this challenge in more detail.

In some situations, traditional non-MBSE processes incorporate dedicated tools for a given process or process activity. Such process-tool mapping lead to the challenge to enable interaction between sub processes of the system development process, a principle considered crucial for the successful implementation of MBSE. For example, each process having a local data model that is incompatible to other processes and their tools, resulting in the need to transform data, often even manually, which can result in error-prone duplication of data consequentially (see Figure 3).

In contrast, Model Based Systems Engineering follows the principle of taking certain perspectives on a commonly shared pool of development artefacts, expressed in a way (e.g. in

SysML), that stakeholders can use them in specification efforts and discuss them and their relations easily [9].

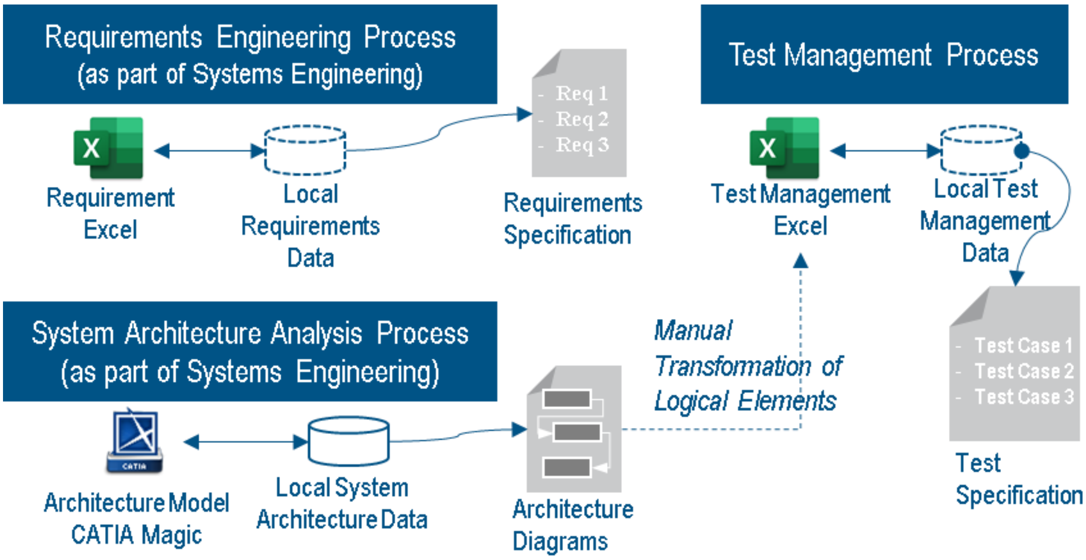

Figure 3: Traditional Approach for a test management process. Established processes run in parallel with dedicated tools. Data has to be duplicated as it is locally managed.

That is commonly done by firstly specifying authoring processes for the artefacts before secondly defining viewpoints that compile data into a view to address a specific problem. If such kind of MBSE patterns are applied, it will lead to a situation, where processes are strongly interconnected with more granular data being exchanged compared to traditional, document-based approaches (see Figure 4). The consequence is less control for the individual engineer, because of the need to rely on data created by authors that in some cases are not part of the same process or the same organization. This is what the authors refer to as the "diverse authoring dilemma".

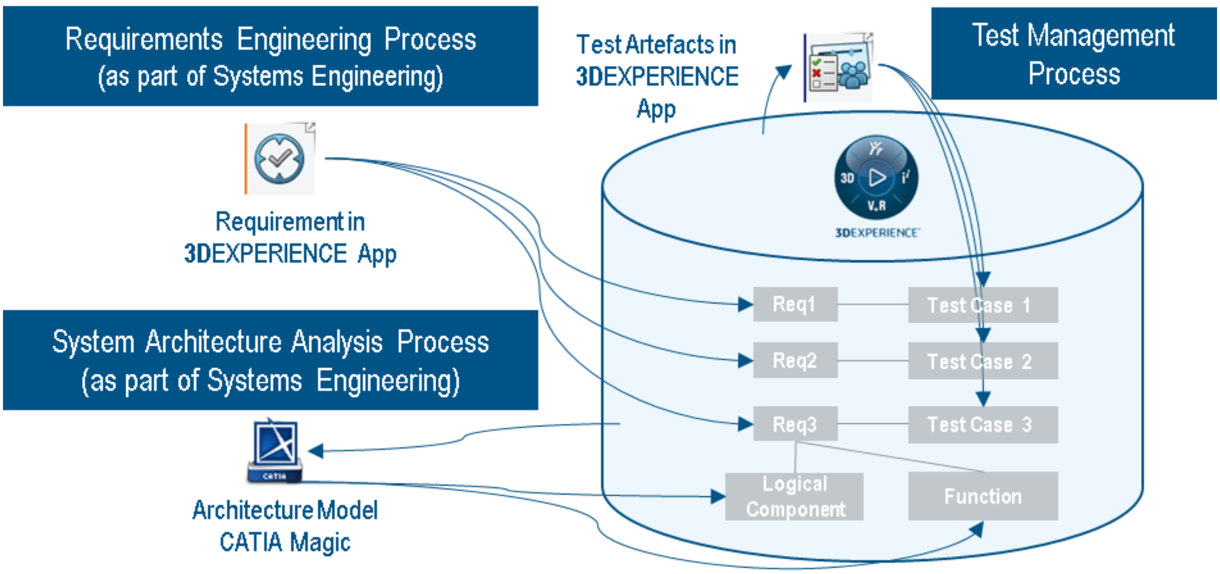

Figure 4: MBSE based Test Management approach, where data is centrally managed and accessed by process specific tools, which are strongly interwoven through the granular data. .

In summary, this section shows that even if interweaving processes by centralizing granular MBSE artefacts can avoid data duplication, and enable interaction in principle, the result can be a more interwoven process landscape, where contributors of MBSE data heavily rely on the quality of each other's results. This aligns with the [7] that states, "it is noted that methods are still cumbersome and approaches are difficult to integrate into existing processes." as well as with the statement in [4], saying, "The best processes, methods and tools do not automatically lead to acceptance".

2.5. The User Feedback Challenge

Section 2.3 The Implementation Challenge discussed how a lack of an introduction strategy could result in the reduction of client acceptance of the suggested MBSE PMT. In addition, the authors observed the challenge that benefits on a level individual users of the MBSE process are hard to communicate and to quantify (see 2.2 The Benefits Challenge). A third challenge, which can create issues with acceptance of the process, comes with the lack of user involvement and systematic gathering of feedback throughout the introduction of MBSE. Users who do not have the opportunity of giving feedback to a solution they are intended to use, will more likely not accept this solution compared to users who were given this chance. In addition, missing this input might result in an inadequate, unfit process or even the need to redesign the MBSE approach and finally in potential failure to apply MBSE.

3. SOLUTION ELEMENTS TO SUPPORT MBSE IMPLEMENTATION

The descriptions in Chapter 2 show the five challenges to be heavily interwoven. It could be observed that these challenges are not unique but reoccurring on a regular base in DSIS MBSE implementation projects. Thus, it can be assumed that applying todays DSIS “standard” implementation procedures may not help to overcome the challenges.

Aiming to understand the challenges and the reasons behind them, an analysis is processed within the following five subchapters. Based on this analysis and by applying industrial experience from multiple authors and (service) experiences in 3DEXPERIENCE-based MBSE PMT, **five Solution Elements** are proposed. These Solution Elements aim to support future MBSE implementation to overcome the described challenges. Application examples are provided per Solution Element to help the reader to understand both the analysis and the solution proposal. The chapter closes with a description of the solution element interdependency forming an interwoven Implementation approach.

3.1. Stakeholder Support

One element connects all the challenges described in chapter 2: The need to involve the various stakeholders that are either part of the implementation project or that are impacted by its results, the (successful) implementation of MBSE PMT.

For each of the challenges, specific stakeholders and their needs can be identified:

- The Organization Challenge involves multiple stakeholders that experience changes in responsibility and tasks within their organization when MBSE is implemented
- Stakeholders that experience changes in PMT are addressed by the Process Challenge with modifications of heavy interwoven processes, methods and tools often lead to resistance of involved users.
- The Benefits Challenges addresses stakeholders from the development process that need to gain benefits from MBSE introduction. The need can be different for different roles in the development process: While top management would need to gain benefits on the level of overall development process such as a faster “time to market”, a developer would need to gain benefits on his specific processes, methods and tools (e.g. better access to specifications)
- The Implementation Challenge addresses the need to enable client acceptance and approval in early project stages, as projects focusing on end but not intermediate goals.
- The final User Feedback Challenge addressing the need for early involvement of the later user to enable systematic gathering of feedback throughout the MBSE Implementation.

Analysis of the challenges allows the differentiation between two types of customer stakeholders with different objectives: **Stakeholders from Customer Management** are the type of stakeholders, which aim to gain benefits on the level of overall development process. Support of customer management is seen as of great importance advocating and driving MBSE within implementation projects [10][8]. Customer Management is also the type of stakeholder responsible for final decisions in client acceptance and approval of the solution [8]. Taking lead roles in customer organization, stakeholders from customer management are of huge importance when it comes to organizational changes.

Stakeholder identification and management are already established in typical DSIS MBSE implementation projects. As of today and as shown in Figure 5 (top), “top-down” supporters for the project from customer management are already identified in pre-sales activities and maintained by Sales and Customer Care. With the big impact of customer management support and their decision to the (service) MBSE implementation project, it is proposed to establish an additional **stakeholder specific service support** as (continuous) maintenance for stakeholders from customer management. The stakeholder specific service support shall enable customer management to support the MBSE implementation, to take decisions and to process (successful) acceptance and approval. The proposed support shall contain a provision of detailed MBSE solution capabilities as well as their benefits and costs (see also chapter 3.2 and 3.3), a timely perspective on implementation and a support in the final evaluation of implemented capabilities (see also chapter 3.4 and 3.5). Industrial practice shows "tangible information" such as images, metaphors or videos to be useful in communication [6]. Supporting material thus have to address the perspective of the customer management by comprehensible end-to-end views and benefits on company/department level.

The second type of stakeholders can be summarized as **MBSE PMT applicants.** This type includes customer stakeholders that are applying MBSE Processes, Methods and Tools after successful Implementation. It also includes customer stakeholders that are interfacing with MBSE PMT by delivering information and/or artefacts to MBSE PMT or consuming information and/or artefacts generated by MBSE PMT. This group of stakeholders can be quite diverse when it comes to specific needs, as it could include stakeholders from business, project planning, design or manufacturing with very different knowledge, way of working and views. After successful MBSE implementation, stakeholders of this type experience changes in organization, processes, methods and tools and thus need to be convinced to establish a "bottom-up-support" [10]. As these stakeholders are representing the later users of the implemented MBSE PMT, their continuous feedback is crucial to develop a solution that is applicable for their daily work, useful to achieve the specific objectives and usable in application. Furthermore, those stakeholders can have a quite big impact on customer management when it comes to management decisions, acceptance or approval.

As MBSE PMT applicants are as of today not identified in pre-sales activities of typical DSIS implementation projects, it is proposed to establish a **MBSE PMT applicant's management**, shown in Figure 5 (bottom). Its first step is to identify all customer stakeholders applying or interacting with MBSE PMT after implementation. Based on the analysis, the stakeholder's specific needs shall be analysed. In case of stakeholders that are delivering or consuming to information or artefacts of MBSE PMT, the "interaction context" of those stakeholder has to be understood to understand their specific needs. Therefore, the specific processes, methods and tools of these stakeholders have to be analysed to understand the needs in context and to enable the choice of a MBSE PMT as solution. Based on the understanding of the specific needs, a proposal for a stakeholder specific MBSE PMT has to be developed and shared to the involved MBSE PMT. After this initial phase of establishing a bottom-up-support, it is proposed to also establish a **stakeholder specific service support.** The stakeholder specific service support shall enable MBSE PMT applicants to support the MBSE implementation with continuous feedback and to support the implemented MBSE PMT towards customer management. Therefore, it is proposed to provide MBSE solution capabilities beneficial for the specific needs of the MBSE PMT applicant (see also chapter 3.2 and 3.3).

One example could be the provision of SysML models with views and services especially prepared for the needs of the mechanical engineer described in chapter 2.2. In order to present information and solution in a "tangible" format for the PMT applicant, supporting material shall not only contain imagines or videos but shall enable "hands on" experience of solutions, e.g.

with PMT demonstrations in the tool. Experience in DSIS implementation projects showed "agile" solution provision with provision of small, working partial solutions to be especially effective in communication with MBSE PMT applicants.

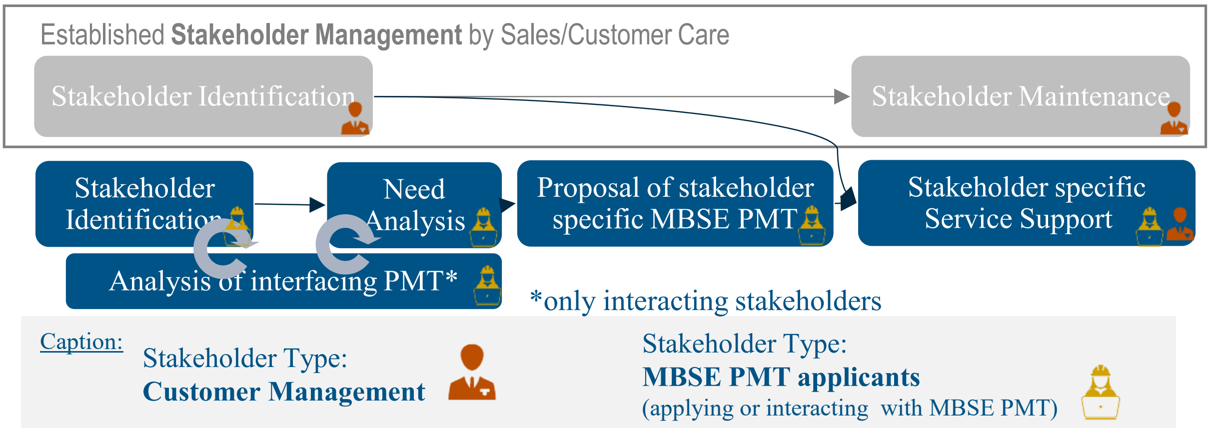

Figure 5: Stakeholder Support process

3.2. MBSE as-a-Whole

During the definition of MBSE PMT, engineers are confronted with the challenge how to adequately define MBSE processes that have the characteristic of intense interaction with actors of other processes (see 2.4). To handle these challenges, at the one hand, a process definition is needed to define, which interaction should take place as well as a tools definition, to specify, how this interaction happens and which interfaces are used. For the efficiency of these definitions, the timely manner in which the MBSE Processes/Methods and Tools are defined is crucial.

A sequential approach, where process, method and tools are considered after each other, seems not sufficient, since the ability to perform a process and the applied method depends on the abilities and constraints of the tools, resulting in time consuming iteration loops between process, method and tool. A more preferable way is, to consider process, method and tool in parallel. This matches with the result in the study in [10]. A majority (67% agreed or somewhat agreed) of the interviewees stated that to "...consider processes, methods and tools in synergy." is the desirable way over a sequential introduction of processes, methods and tools.

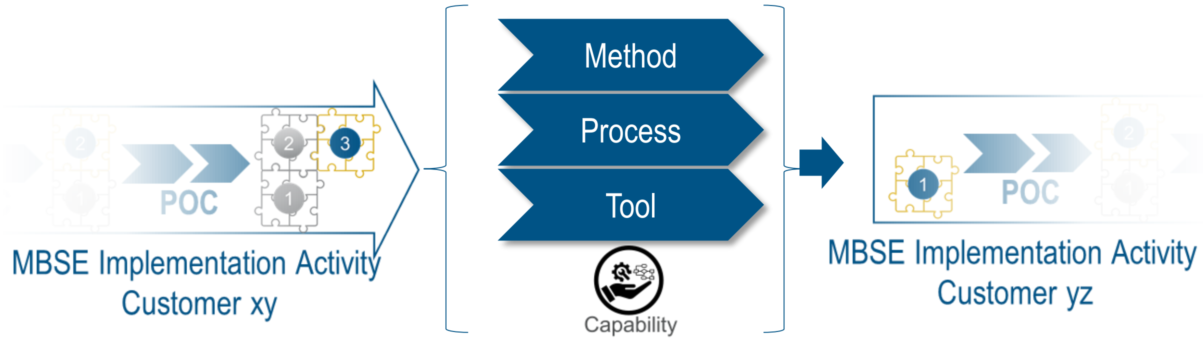

Figure 6: Proposed approach to derive a MBSE capability and to use it in following implementation activities

Based on the common definition of a capability as "the ability to achieve a desired effect under specified standards and conditions through combinations of means and ways to perform a set of tasks. […]" [11], the authors define a MBSE capability as "the experience based ability to achieve a certain MBSE outcome through combination of methods and tools to perform the activities in order to create this outcome." Furthermore, MBSE capabilities are derived based on experiences made during successful MBSE implementation activities performed earlier to provide a starting point for such activities in the future (see Figure 6). Their definition consist of the components stated in Table 1.

Table 1 MBSE Capability Components

Component	Description
Capability ID	Identifier for Capability
Content	Description of the desired outcome.
Process	Specification of process activities that results in the outcome.
Solutions	Tools that proved usable for supporting the process.

Since these capabilities reflect successfully applied solutions for DSIS customers, they can be used to compose a first iteration of MBSE PMT for a new customer and therefore shorten the time in an early definition phase.

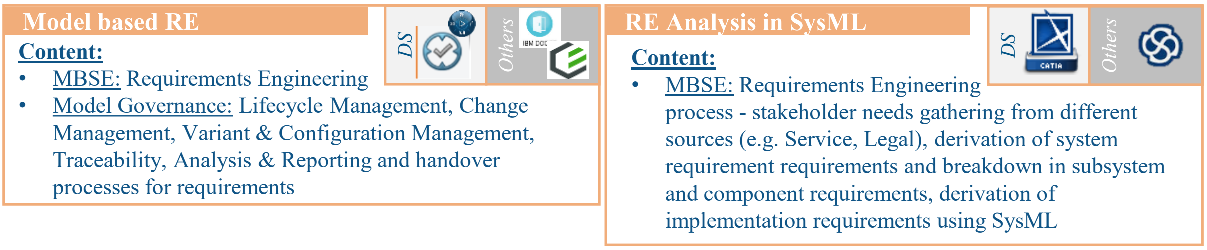

*Figure 7: Samples of MBSE Capabilities to define core MBSE process activities. Aspects of governance and definitions of enabled processes combined with tool mapping *DS =Dassault Systèmes*

Two examples for MBSE capabilities are shown in Figure 7. “Model Based RE” defines the capability to perform model based Requirements Management using a Requirements Management tool to enable Lifecycle Management, Change Management and other governance processed for the Requirements. “RE Analysis in SysML” describes a structured requirements gathering and refinement process starting from initial stakeholder needs gathering over refinement into system, subsystem and component requirements up to final refinement into implementation requirements. SysML tools are used to perform the required analysis activities. This example highlights the relevance to take both, the perspective of the process as well as of the tool: Not only the process specifies, what kind of outcomes need to be produced, but also the functionality of the tool defines what process outcomes it can create. Having these two capabilities defined, each of them can be either applied in a solution architecture, separately or combined, depending on the needs of the customer.

3.3. MBSE Solution Bricks

The decision for the “right” MBSE capabilities requires qualifying the MBSE implementation project to identify the effort and cost required to implement it. Aiming to enable both customer management as well as MBSE PMT applicants to gain their respective stakeholder specific benefits, it is required to identify both the benefits on company/department level as well as the benefits on MBSE PMT applicant level.

The solution element of **MBSE solution bricks** are proposed to address these needs by providing the following content:

- A MBSE Capability as described in chapter 3.2.

- **“Gains”** specific for the MBSE Capability: Benefits that can be gained by an implementation of the MBSE Capability for both customer management and MBSE PMT applicants.
- **“Pains”** specific for the MBSE Capability: An estimation of implementation effort, implementation costs and implementation time for changes in organization, process, methods and tools.

Figure 8 shows exemplarily the MBSE solution brick to implement the MBSE Capability “Requirements Analysis in SysML” described in chapter 3.2. The core “gain” of this MBSE capability lays in the improved requirements quality by refinement of non-technical stakeholders needs into technical system, subsystem and component requirements. These requirements act as a technical base for system design across domains and are directly usable in system verification. A further refinement into domain specific implementation requirements reduces effort for MBSE PMT applicant from domain development such as mechanical, electric/electronic or software-design designers, as the “translation” into implementation otherwise are today in the designers responsibility. With the new implemented solution brick, the MBSE PMT therefore provides a service that directly create benefits by effort reduction

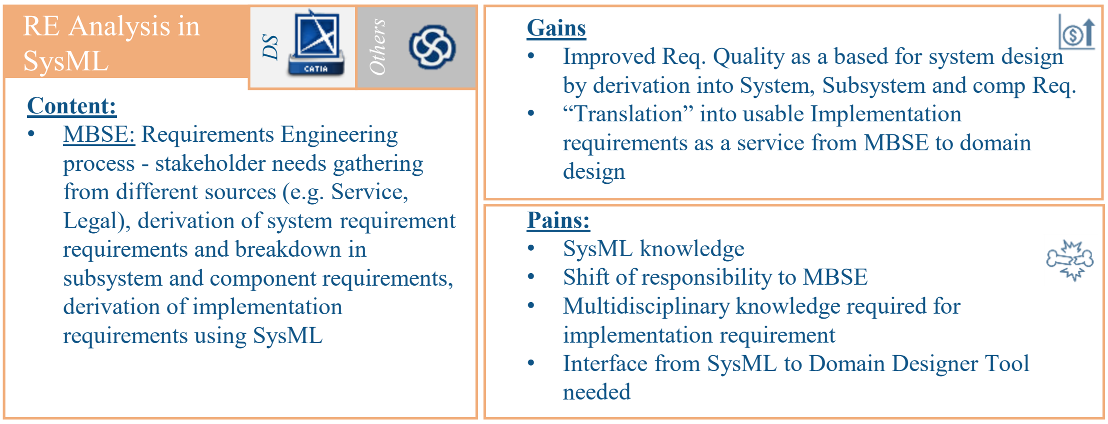

Figure 8: Sample of a “MBSE Solution Brick” combining MBSE Capability with Gains / targeted benefits and Pains / required implementation effort

As the structured refinement of requirements needs Analysis in SysML, the needs for SysML knowledge can be identified as one core “pain” that needs to be accepted. A shift of responsibility to MBSE is required as MBSE takes over “translation” tasks previously under responsibility of domain designers – this can necessitate organizational changes. Enabling the benefits implementation requirements can need further organizational changes, as requirement engineers need multidisciplinary knowledge to translate system requirements into implementation requirements directly usable for the domains. To handover the requirements, a (tool-) interface between the Requirements SysML tool to the Toolsets of the domain designers is required. In best case, the interface enables the exchange according to the need. In reality, interfaces often have to be configured and sometimes have to be newly created within the implementation project.

3.4. MBSE Implementation Plan

Analysis of project management best practices show “initial planning” to be a key success enabler for successful projects [12]. Industrial applicants agree that MBSE implementation projects shall be planned in a stepwise approach and should start with small scoped pilot projects [10].

The proposed solution element MBSE Implementation Plan follows these considerations by establishing the following solution principles:

- Step-by-Step implementation plan.
- Each MBSE Implementation Step to implement a bundle of one(? or) more multiple dependent MBSE Solution Bricks.
- Each MBSE Implementation Step to deliver gains for both stakeholder types of customer management and MBSE PMT applicants.
- Target oriented bundling of the MBSE Solution bricks to achieve the optimal set of benefits considering implementation effort, cost and time and to use synergies, if possible.
- Short implementation time per MBSE Implementation Step to enable "agile" solution provision with provision of small, working partial solutions.
- Consideration of "tactical" solutions required to create working (and thus tangible, experienceable and testable) partial solutions rather than to focus on final solution only **Error! Reference source not found.** shows an exemplarily MBSE implementation plan.

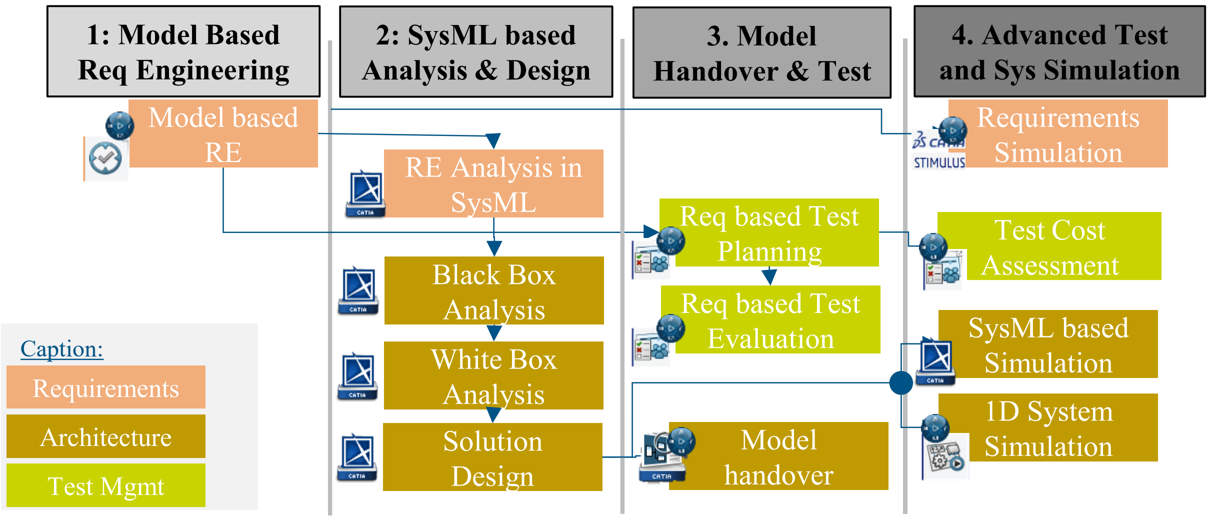

Figure 9: Exemplary MBSE Implementation Plan

Twelve (12) MBSE Solution bricks for Requirements Engineering, Systems Architecture and Test Management are planned to be implemented within four (4) MBSE Implementation Steps. The proposed bundling of MBSE Solution Bricks is chosen to address different MBSE PMT applicants per MBSE implementation step. Step 1/Model Based Requirements Engineering targets to enable requirements engineers to work with requirements model rather than documents in order to gain benefits of model based collaboration and data management. The second Step is chosen to include SysML based Requirements and System Analysis and Solution design MBSE Implementation bricks in order to enable Requirement Engineers and System Architects to use synergies and to enable the shift from document based specification into SysML based system specification. Step 3 addresses domain designers by implementing the handover of the SysML specification to domain designers and domain test engineers to enable the structured validation and verification of domain design results. The final Step 4 intends to implement an improvement of the SysML based system specification by using simulation to improve Requirements as well as system Architecture Models quality. As testing is costly, it is intended to implement a Test cost assessment to increase the quality of test planning for validation and verification.

3.5. Proof of Concepts

Within chapter 2.5, the authors stated that user acceptance could suffer, in case user feedback is not gathered and considered properly during the implementation of MBSE PMT. In addition, anticipated benefits for users might not always overlap with actual benefits of desired profiteers of MBSE PMT.

In accordance with the opinions of a majority (97%) of interviewees [10] that agreed or somewhat agreed with the statement that "build[ing] up acceptance for MBSE by demonstrating its benefits e.g., through positive examples", the authors propose to follow a **proof of concept approach**. This approach assumes that MBSE should be considered a service to the organization and the stakeholders in the system development process. The proof of concept has the function of evaluating benefits with the stakeholders and iterate the capabilities until an agreement about a positive trade-off between the pains and gains of the proposed solution bricks (see 3.3) can be reached. By performing these steps for the overall solution but also for each implementation step, value can be ensured, acceptance can be created and implementation risks can be lowered.

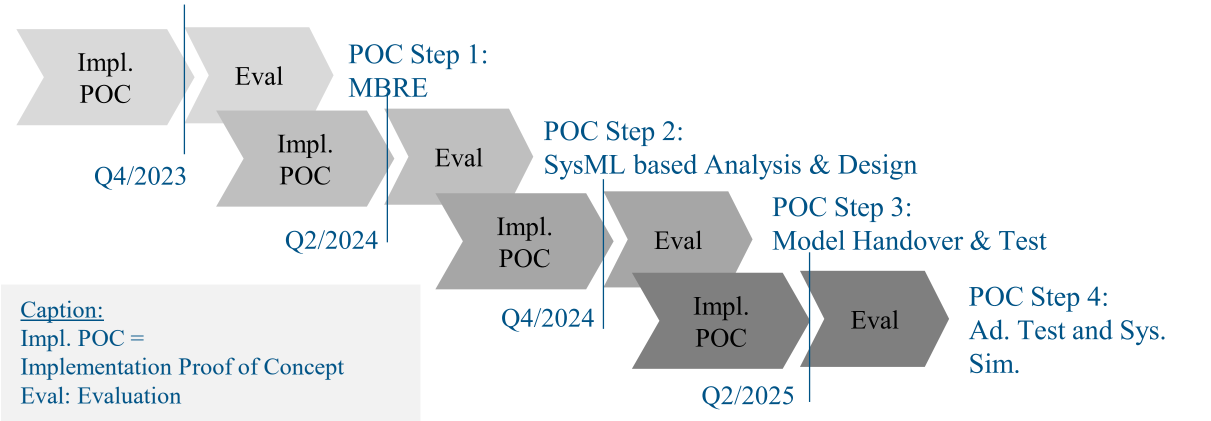

Figure 10: Exemplary Step-by-Step POC (Proof of Concept) based Implementation planning including Iteration and Evaluation Phases

Figure 10 shows an example to execute POCs for each implementation step. Each POC starts with an implementation phase, where the POC is prepared and tailored to the stakeholder pains before demonstrated. In the following evaluation phase, stakeholders can experience the concepts of the planned implementation step, give feedback and make improvement suggestions. These results are input for the refinement of the proposed MBSE PMT step.

3.6. Interwoven Solution Elements

The five solution elements and their dependency are visualized in Figure 11. The figure shows an interaction loop starting with a structured **Stakeholder Support** for both types of customer stakeholders, customer Management and MBSE PMT applicants, in order to manage expectations and to ensure focus of the organization during the transformational processes during MBSE implementation.

MBSE as-a-Whole is established, introducing MBSE capabilities, which consider process, method and tool together to bring a dedicated benefit (gain) to the user. **MBSE Solution Bricks** enrich the MBSE capabilities with an application scenario expressed by potential pains to be accepted, coming together with anticipated gains, to provide an instrument to find the suitable capability for the right situation. An **MBSE Implementation Plan** brings the solution bricks into a step-by-step sequence of implementation steps, aiming to provide incremental benefits. **Proof of Concepts** are performed to get actual user feedback, validate this anticipated benefit by demonstrating to stakeholders, thus closing the interaction loop back to the **Stakeholder Support.**

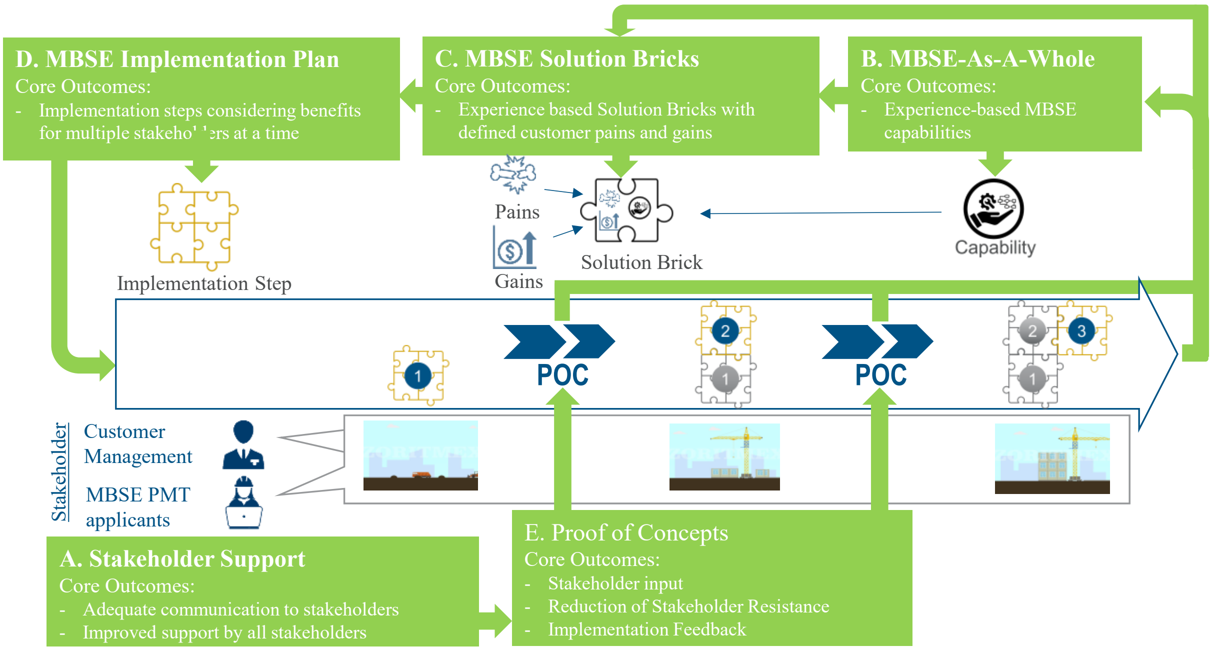

Figure 11: Interwoven Solution Elements to support MBSE Implementation.

Figure 12 shows the mapping by addressing the Solution Elements to the challenges described in chapter 2. It is shown that a full coverage is achieved – each challenge is addressed by (at least) one solution element. The visualization highlights the importance of Stakeholder Support acting as a "clamp" to cover all challenges, but also the high interdependency between the Solution Elements.

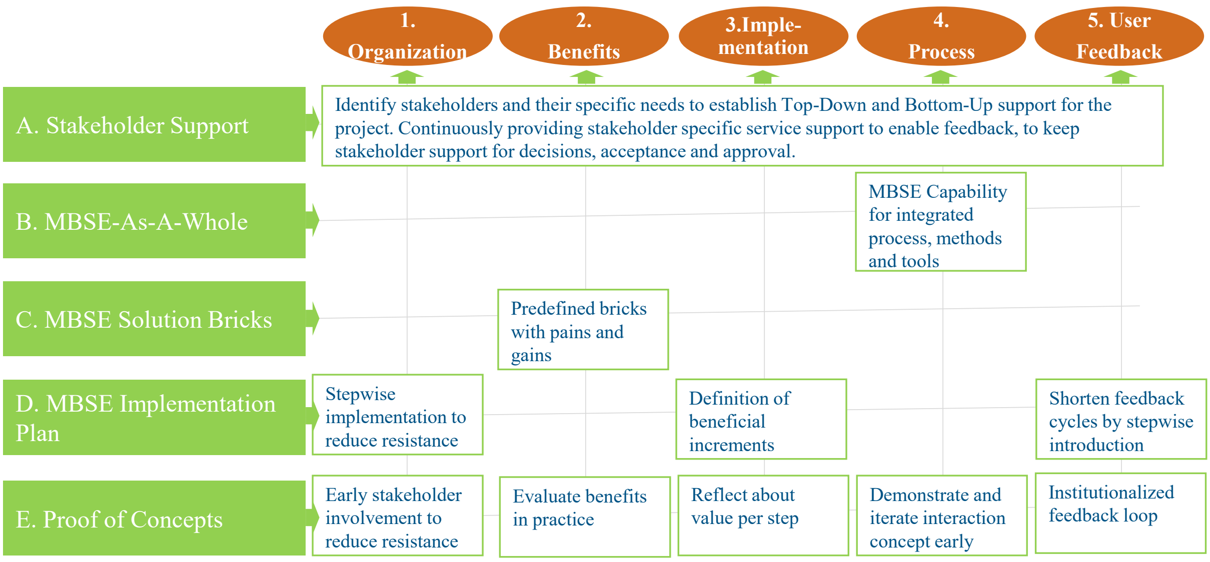

Figure 12: Mapping of Challenges of MBSE Implementation to Solution Elements

The high interdependency enables the "harvesting of low hanging fruits" for the customer: MBSE PMT that can generate valuable benefits at low cost, with low effort and are quickly implementable. These **low hanging PMT** can support customer management as benefits can be shown rather than just described (or promised). Furthermore, MBSE PMT Applicants can experience and even test the solutions and discussions can be done on the objects of implementation rather than on concepts.

4. SUMMARY & OUTLOOK

After describing typical challenges observed by DSIS when implementing 3DEXPERIENCE based MBSE PMT (Process, Methods, and Tools) together with the customer, the challenges were analysed and five Solution Elements were proposed to support MBSE Implementation. Within the following chapter, a summary is taken by discussing the value of the Solution Elements and their applicability into industrial practice. After a brief description of the current maturity of the Solution Elements, an outlook about next steps is provided.

4.1. Summary

In this paper, critical challenges during the implementation of MBSE PMT were reported. Understanding these challenges is crucial for organizations and service providers like Dassault Systèmes Industrial Service (DSIS) to address problems effectively. Identifying and understanding the challenges enable the development of solution approaches to handle or even overcome them.

The five Solution Elements proposed by the authors aim to facilitate future improvements for DSIS or other service providers when implementing MBSE in collaboration with customers. The Solution Elements offer several advantages for DSIS or other service providers.

Firstly, they emphasize continuous stakeholder support and enablement, ensuring that customers receive the necessary guidance and resources throughout the implementation process. This is a stakeholder management method, which can be applied to address customer concerns effectively during MBSE PMT implementation but also other service projects. The application of proof of concepts, specifically focusing on low hanging PMT solutions enable customers to experience and test the solutions in real projects, fostering discussions and feedback based on tangible results rather than abstract concepts. It allows service providers to demonstrate the benefits of MBSE PMT and gain insights for further improvements. Thirdly, the concept of a library of experience-based solution bricks, which not just address process and tool in parallel, but relate them to potential customer gains and pains, provides an approach to systematically make project success reusable for future projects.

The application of the proposed Solution Elements at Dassault Systèmes Industrial Service (DSIS) is already underway, although it is not yet fully implemented. First steps have been processed:

- Stronger focus on continuous stakeholder support and enablement in DSIS MBSE implementation projects. This includes actively involving customers in the implementation of MBSE PMT as well as preparing management-compliant material to facilitate understanding and buy-in.
- DSIS has successfully applied proof of concepts by introducing “low hanging PMT” in a customer project. During that activity, it was possible to improve a solution concept with multiple stakeholders in few weeks, gaining acceptance and improving the understanding of stakeholder needs.
- DSIS is currently in the process of building up a library of solution bricks. These bricks represent application scenarios to address specific customer pains and offer anticipated gains. They also serve as a repository of suitable capabilities for the use in projects.

In conclusion, understanding the challenges and having a set of interwoven solution elements to overcome them, leveraging ongoing efforts can enhance the ability of DSIS or other service providers to create solution architectures in collaboration with customers. By applying the solution elements, service providers can improve stakeholder support, increase customer involvement, and drive the successful implementation of MBSE PMT. The current state of implementation shows promising progress, laying the foundation for future advancements in the field.

4.2. Outlook

Moving forward, there are areas that require attention and further development in order to enable the applicability of the interwoven Solution Elements at Dassault Systèmes Industrial Service (DSIS).

Firstly, the "development phase" of the approach needs to be finalized. This includes the establishment of a comprehensive library for solution bricks, encompassing a broader range of application scenarios. Moreover, the implementation strategy must be applied across projects to gain practical experiences and validate its effectiveness. This iterative process of application, learning, and improvement is crucial for refining and optimizing the solution bricks and the overall approach.

Additionally, a connection of the Solution elements to the existing, DSIS Model Based Solution Architecture Framework based on UAF (Unified Architecture Framework) needs to be investigated. This not just allows applying model-based methodologies for the solution bricks, but also has the potential to make the solution bricks accessible to a broader user base.

Finally, the approach requires an evaluation process. This evaluation will assess the extent to which the Solution Elements effectively address the challenges identified and therefore deliver the intended benefits. Performing this evaluation will provide insights and feedback for further refinement and enhancement of the proposed approach.

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Icons from The Noun Project (https://thenounproject.com, last access: 30.06.2023) are used in the following figures:

- Figure 5: Stakeholder Support process
- Figure 6: Proposed approach to derive a MBSE capability and to use it in following implementation activities.
- Figure 11: Interwoven Solution Elements to support MBSE Implementation.

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