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A Survey-Based Framework

Assessing Effectiveness and Efficiency in MBSE Deployment & Methodology

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A Survey-Based Framework: Assessing Effectiveness and Efficiency in MBSE Deployment & Methodology

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Abstract. The aerospace industry has seen a significant shift towards Model-Based Systems Engineering (MBSE) with increasing complexity of systems, and the need for a sophisticated methodology for modelling them. MBSE and Systems Modeling language (SysML) have also been promising considering these growing challenges, and have shown capability in managing these systems and system life-cycles consistently. The implementation of MBSE has shown operational and monetary advantages across all industries, and there have since been several frameworks and methodologies in place for managing the models and their data. There have also been efforts towards design space alternatives and trade-off exploration. However, it is observed that there is a need to understand how effective these methodologies are and are they adequate to meet the expected granularity. It is often challenging to evaluate the effectiveness of MBSE considering the various modelling approaches and varying modelling standards. This paper attempts to create a framework to measure the efficiency and effectiveness of MBSE, from an aerospace industry perspective. The paper identifies and focuses on certain key drivers for this framework and how they can be implemented within a model. As part of the framework, it consists of an extensive survey designed to evaluate the maturity and state of implementation of MBSE. The paper describes the approach for this survey and how it would act as a feedback loop into the proposed framework. A simple model navigation strategy has been implemented as part of the framework for ease of use and reuse of the MBSE models, which has been seen as one of the difficulties for the model users and viewers. The framework examines a generic use case to identify its key performance indicators and how they can be used to measure the effectiveness of MBSE, as well as initial checks for the deployment of the process, method and tool (PMT). This included a scoring system, which checks if the method meets, does not meet or exceeds the expectations. In order to understand the efficiency of MBSE, the paper looks at an example survey methodology, while considering factors such as traceability, reusability, variability and trade-off analysis. This further provides an insight, providing an Interim Corrective Action Plan (ICAP) and a Permanent Corrective Action Plan (PCAP) showcasing the return on investment of MBSE approaches in an aerospace industry context, allowing the community to deploy MBSE based on application needs. The objective of the paper is therefore to share these results with the community in order to build a more robust standard for MBSE and to help close these gaps observed within the aerospace domain.

Keywords. MBSE, SysML, Framework, Effectiveness, Efficiency.

Introduction

The aerospace domain grows in both complexity and uniqueness every year, with newer technologies and missions always around the corner. Systems engineering enables efficient and comprehensive development of these missions with fewer risks and better execution. Furthermore, Model-Based System Engineering (MBSE) and Systems Modeling Language (SysML) provides valuable capabilities and is an improviser for traditional systems engineering.

MBSE is now being used vastly in the aerospace domain, with good return on investment (ROI) even with increasing complexities of the systems [1]. Deployment of MBSE in various enterprises and organisations has enabled the MBSE community to develop and grow. There have been several MBSE methodologies and approaches developed over the period [2,3]. There are a number of observable benefits of MBSE that have impacted the development of the aerospace industry. However, for an organisation, it is often vital to analyse the methodologies and deployments, and their effectiveness, so as to ensure the benefits are not marginal or superficial to the efforts and investments.

Benefits of MBSE

Understanding the capabilities and said benefits of MBSE beforehand is reasonably a prior requirement for the analysis. The benefits arise from the evidence within the MBSE community. Observable evidence is collected and aggregated over the course of MBSE adoption. Whereas the measurable evidence is usually seen at a later maturity stage or mission phase, and more often than not has a clear frame for measurement [4]

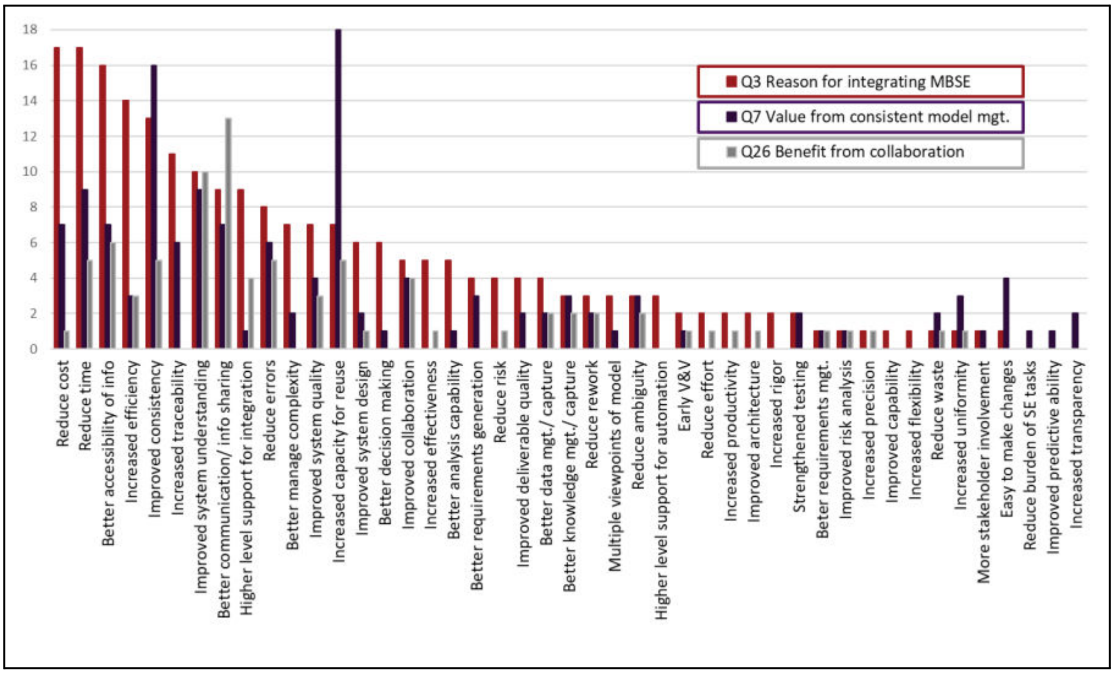

Figure 1: Benefits of MBSE from survey results [5]

The MBSE deployment provides several benefits such as, increased efficiency, reduced cost and time, reusability, traceability and improved change management. The complexity of systems and their requirements is easily managed, visualised and customised using MBSE [6,7]. However, with deployment comes challenges and push backs, which are to be expected when shifting from a traditional systems engineering approach. Especially considering the numerous methods and frameworks that can be used for effective MBSE. So, the question flows down to understand if the deployment has been effective and how efficiently it has been deployed using the available frameworks.

3. Effectiveness and Efficiency of MBSE

An organisation deploying and using MBSE is often at crossroads trying to find measurable evidence of the benefits MBSE has to offer. It is naturally understood that MBSE supports problem space definition [8] and design space exploration [9] using various approaches, however it tends to change with varying use cases. This could lead to comparing apples to oranges and gets harder without a well defined baseline.

Effectiveness

In order to measure effectiveness of MBSE and understand if the outcome of the deployment is in line with the expected results, it is crucial to have this baseline or prerequisites. The baseline creates certain boundary conditions and allows for a fairer analysis. Effective MBSE can then be measured by extending this baseline across the overall modelling activities [10].

Efficiency

Efficiency of MBSE can be interpreted in a number of ways as it is dependent on the objective of the deployment. The results and impact of MBSE compared to the efforts invested in its deployment and development, is one way to measure it. The more generic approach is to compare traditional systems engineering and MBSE on the same project. These measurements usually take into consideration the quality, time and cost perspectives.

There have been a few studies that gather data for a certain set of users and experts to compile the results as the impact of MBSE. The data includes the challenges and the observable benefits of the MBSE deployment [11]. There are surveys that show the state of practice of MBSE and the areas that need improvisation or change [12,13]. Although these surveys showcase gaps and challenges, they only extend to provide insights. There are studies that provide some corrective measures and best practices [14,15]. However, they tend to be extremely specific to the particular study, with a few generic ones.

There is a noticeable need for a method for providing the measurable evidence for the benefits of MBSE. One that can be implemented to any given case, and also provides detailed corrective measures while identifying the source, and depicting the degree of ineffectiveness and inefficiency.

4. Framework for measurement

Approach

Measuring the effectiveness and efficiency using survey data is simple and unequivocal. The data collected can then be analysed to understand the gaps and furthermore provide valuable recommendations [5]. There are existing frameworks that try to evaluate and compare the different MBSE methodologies based on several structural assessments [16,17]. Nonetheless, the questions asked for the evaluation only provide the assessment but not the required recommendations with regards to deployment, and fail to identify the cause for gaps in methodology.

The framework was developed primarily focused on an aerospace industry but is possible to be extended to other industries as well. The aerospace industry has been well acquainted with systems engineering and is adapting rapidly with the emergence and advancement of MBSE. The framework derived in this paper makes meticulous effort in accumulating the vital drivers using a survey for MBSE and to find a clear means to quantify the collected data. This allows for benchmarking the condition of MBSE implementation and further elaborates on the areas that require refinement [5].

For the measurement, the MBSE aspects are broken down into two primary categories, Deployment and Methodology. The Methodology is the MBSE setup or framework used to deliver MBSE solutions. For example, it refers to frameworks such as R-MOFLT, Object-Process Methodology (OPM), RePoSyD, ARCADIA and RFLP. Whereas, deployment is the initial process of adoption of MBSE across an organisation. The categorisation aids in narrowing down the possible issues and analysing the data.

These categories are further broken down into several subcategories that contain crucial MBSE aspects. These subcategories were cumulatively derived from several handbooks and previous surveys, in order to cover most if not all the vital MBSE related concepts and its peripherals.

1. Systems engineering essentials
2. MBSE awareness
3. MBSE deployment
4. MBSE usage
5. Model management and workforce
6. MBSE technical management
7. MBSE technical management strategies
8. Metrics
9. Model quality
10. Data management
11. Model sharing and reuse

12. MBSE adoption
13. Modelling environment
14. Modelling Environment Analysis

Prerequisites

The prerequisites are to be followed as part of the survey. They are key to derive reliable data and analysis from the survey.

1. The survey should be conducted with balanced demographic inclusion and representation (SE/MBSE management, modelling, methodology development teams).

2. The survey should be conducted at the program level that is currently implementing SE/MBSE for at least one decision gate.

3. The survey should be deployed through the proper authority and getting a prior approval of the SE/MBSE governance team and management.

4. Textual responses should not contain export-controlled or classified information, and survey questions should avoid eliciting such information.

Analysis

Once the prerequisites are actualised, the data received at the conclusion of the survey are mature and exhaustive to be analysed. There are of course various different analyses that can be derived from the results of a given survey. The objective of the survey framework is to utilize the results to obtain quantitatively, the effectiveness and efficiency of MBSE at a given enterprise or organisation.

The analysis data and the score derived from the measurement system can be utilised by two major stakeholders. One being the MBSE deployment team at the organisation to recognise the issues if they lie in deployment or in the method and further narrow down to make reliable changes. Another is an organisation attempting to compare different methodologies, and utilise the score from the analysis to potentially benchmark them and find one that is inline with its requirements.

The framework further, from the analysis provides a guideline sequence that would support the deployment and development teams to work towards viable solutions to improve their effectiveness and efficiency.

The framework also extends this capability to provide an Interim Corrective Action Plan (ICAP) and a Permanent Corrective Action Plan (PCAP) in order to make the right decisions for the deployment and the methodology, depending on any given score and standing.

Assumptions and limitations

The framework developed for the measurement considers the current state of MBSE and its capabilities. The framework only works under the assumption that it is applied for an organisation with an already established MBSE system and a working methodology that is being followed. The survey data gathered also would require validation in order to have reliable analysis, that is not covered in this paper.

5. Focus on the subcategories

Systems engineering essentials

As the name suggests this subcategory consists of questions to primarily understand the fundamental systems engineering stance. These fundamentals help to address the MBSE capabilities and strategies that would be built on them. The understanding of stakeholder requirements, system life cycle phases and incremental development plan is crucial for the deployment of MBSE.

MBSE awareness

It is required to understand the state of MBSE awareness in the organisation and pinpoint the need for training and upskilling. It is vital for the management to understand what MBSE is, what it is capable of and where it is being deployed.

MBSE deployment

The subcategory consists of a group of questions directly related to the MBSE deployment such as governing entity for model quality, nominal deployment cost and understanding the requirement and application of systems engineering and MBSE for any given use case or project.

MBSE usage

The subcategories from this point try to capture the intricate perspective of the deployment. MBSE to begin with, can be deployed completely from end to end and integrated with the overall system development plan. It is also essential for it to be part of the business process of the organisation.

Model management and workforce

Through this subcategory the survey attempts to understand the structure that has been developed to support the deployment and how inclusive the framework is. This allows for reliable modelling strategies [18]. The workforce and competencies required for the model management and delivery are scrutinised.

MBSE technical management

Technical management of data and its review can be supported by MBSE. With MBSE the data can be easily traced throughout the entire system lifecycle.

MBSE technical management strategies

The strategies implemented for technical management should be compliant to the Systems engineering management plan [19]. The subcategory questions the existing method to measure the ROI of the MBSE deployment and the resilience of the framework of MBSE.

Metrics

Metrics is one of the integral subcategories of the framework. It looks into the Measure of Effectiveness (MoE) and Measure of Performance (MoP) that is in place as part of the methodology. A methodology would be incomplete without MoE and MoP [3, 20] to understand the difference between the simulated model and the actual scenario. Another key characteristic of MBSE is to provide trade-off analysis for design alternatives and facilitate trade space exploration ideally integrated within a model [21-23]. The modelling methodology should be able to support and use a generic referential that would help maintain consistency across all modelling activity [24].

Model quality

The modelling methodology requires verification and validation strategy. Conducting peer reviews ensure modelling consistency and requirement satisfaction. It is also necessary that the modelling methodology is capable enough to be easily understood by stakeholders.

Data management

The data within a model is critical for the evaluation of a model and the methodology. The data stored within a model would not be useful unless it can be shared, transferred and traced for requirement analysis. The management of this data and the modelling activities are most effective when it is iterative and recursive, and the methodology for it works independent of the tools. Model variability allows for efficient use of MBSE and provides multiple solutions for a given problem [25-27]. The subcategory also questions methods for data exchange, interoperability and document generation.

Model sharing and reuse

This subcategory discusses if the methodology developed is capable of accommodating model reusability and if they are libraries created and maintained for the same. This allows for efficient modelling activity and avoids rework and repetitive activities.

MBSE adoption

Although the framework works towards capturing the measurable evidence. It is also essential to ask if the methodology has allowed for the observable evidence to come through and be recognised.

Modelling environment

The modelling environment should be fail proof in case of potential data losses and should have redundancies. The modelling would ideally incorporate a navigation window and a standard template to increase ease of access and maintain consistency.

Modelling Environment Analysis

From an aerospace perspective, data and information security and access has to be analysed. Many times the information is confidential and required to be cyber secure while also being able to be accessed with ease by the users.

6. Survey

Survey methodology

The survey was conducted swallowing the prerequisites and sent to several MBSE users. The questionnaire covers all the previously mentioned sub-categories. The questions are likert type questions that can be answered with agree, disagree, neutral, strongly agree and strongly disagree. The questions have been given weightages according to their critically and importance. There is a scoring for the answers that will be discussed in the following chapters.

The analysis derived from the survey data would be used along with the scoring system to evaluate the effectiveness and efficiency of the deployment and methodology.

The results shown later in this paper are intended to demonstrate the approach of the survey and the calculations for scoring a pre-defined framework. They may not necessarily showcase the actual results due to confidentiality reasons.

Survey demographics

In order to validate the survey questionnaire, the voluntary survey was sent out to approximately 300 systems engineers with professional experience ranging from 1 to 20 years. Primarily the survey took feedback on these questions from the engineers. It was focused on systems engineering roles in the aerospace industry. The pool of recipients represented various roles, including framework developers, systems engineering method experts, MBSE project owners, model based systems engineers and MBSE tutors. Among them 116 responses were recorded. The survey contributors were given a month's time to answer the questions.

While the survey did not aim to collect detailed demographic data such as the precise years of experience for each candidate or the specific size of their team or organisation, all respondents were established professionals. The recipients were informed regarding the nature of the survey and purpose.

The participants were equally weighed irrespective of their experience as the survey questions were designed to address commonality and genericity allowing it to be conducted without needing further classifications. They were requested to answer the survey based on their direct working experience, itself based on the common framework used by the participants. The goal was to get a wide scope of views and determine high-level patterns and similarities across levels of experience and roles, rather than dividing the analysis by these factors.

Survey questions

The survey questions are listed out in table 1 and grouped in their respective categories in terms of (Deployment [D] and Methodology[M]) and their subsequent subcategories. The weightage for the questions are also shown next to the respective questions.

Table 1. Survey question and weightages

Categories	D/M	Questions	Weightage (a)
1.Systems engineering essentials	D	There is an understanding about the need from the stakeholders	5
	D	There is an understanding about the Problem Statement / Opportunity Statement the system is trying to address	5
	D	The problem statement is validated before the deployment of SE	5
	D	There is an understanding about the System's Boundary	5
	D	There is an understanding about the system of interest and its context	5
	D	There are sufficient trained resources / Sufficient Support for SE deployment	5
	D	There is an understanding about the Systems Engineering Processes	5
	D	There is an understanding of system life cycle phases	5
	D	There is an understanding about the method to manage the life cycle phases (V cycle, waterfall etc)	5
	D	There is a defined Systems Engineering Management Plan (SEMP) for system development	5
	D	There is an understanding about the incremental system development plan	5
2.MBSE Awareness	D	There is an understanding about MBSE	5
	D	There is an understanding about difference in SE and	5

		MBSE	
	D	There has been formal training for MBSE in place	5
	D	MBSE has been deployed previously	2
	D	There is an awareness of different MBSE methods / framework	3
3.MBSE Deployment	D	The method has sufficient scope to help system level certification by external entity	4
	D	There is a central governing entity to ensure model quality	3
	D	The nominal deployment cost has been identified	4
	D	The support from system expert and related key stakeholders are secured	4
	D	There is an understanding of particular application of MBSE in a given project / use case	4
4. MBSE usage	M	The MBSE integration is done end-to-end (Conceptual study-end of life)	4
	M	MBSE deployment is integrated with overall system development plan	4
	M	MBSE integration with overall product planning is at enterprise level (It is part of Organization's Business Process)	4
	M	MBSE process and tools are part of end-to-end digital continuity and product development	2
5. Model management and workforce	M	MBSE standard modelling framework that is being used is consistent and accepted across the organisation	4
	M	The MBSE standard framework is being followed for your regular modelling activity	4
	M	The MBSE standard framework is generic and can accommodate any use case	4
	M	There is a defined process for model management, access and project usages	4
	M	There are defined roles to deploy MBSE	4
	M	There is awareness of the competencies and deliverables associated with these roles	4
	M	There is a support community for MBSE deployment across organisations	4
6.MBSE Technical management	M	Systems lifecycle's technical processes are managed using MBSE	4

	M	MBSE supports the technical review processes	5
7. MBSE Technical Management Strategies	D	The MBSE deployment is compliant with SEMP (Systems Engineering Management Plan)	4
	D	There is a method identified to measure the ROIs for the MBSE deployment	4
	D	The MBSE standard framework is inline/flexible to accommodate organisation's current future project plans	2
8. Metrics	M	MBSE modelling has made measurable improvements for projects	2
	M	Methodology has Measure of Effectiveness (MoE) for a model	5
	M	Methodology has Measure of Performance (MoP) for a model	5
	M	MBSE methodology is providing inputs for trade-off analysis	4
	M	MBSE tools work alongside with other tools to provide an interoperable environment	3
	M	The methodology has flexibility to adapt to new changes	5
	M	MBSE methodology has a generic referential to maintain consistency across all projects	5
	M	There is a peer review for the modelling activity	2
9. Model quality	M	There is a process followed as part of modelling for Verification and Validation	5
	M	There is a quality check of model data after every modelling activity	5
	M	There is a provision to scale the model	5
	M	The models are capable to communicate the intricate details with diverse stakeholders	5
10. Data management	M	There is a system (Standardised Process) in place for data transfer between tools	5
	M	The methodology includes requirements management and traceability	5
	M	The data management works independent of tools	2
	M	The methodology accommodates and uses variability modelling	3
	M	The modelling and data management is an iterative process	5

	M	The modelling methodology is recursive	3
	M	The methodology for MBSE has been developed to be used in an agile environment	2
	M	There is a semantic layer for data exchange	3
	M	There is means for documentation generation if and when needed	3
	M	There is a defined process and tool chain for data exchange and interoperability	5
11. Model sharing and reuse	M	The existing models are reusable	5
	M	Model libraries exist for reusability	3
	M	Model Libraries can be easily instantiate	3
12. MBSE adoption	M	The adoption has led to early detection of errors / issue	4
	M	The adoption has led to improved risks analysis and mitigation	5
	M	The adoption has led to fewer errors during system development	5
	M	The adoption has led to reduction in development time	5
	M	The adoption has led to reduced development cost	5
	M	The adoption has reduced ambiguity of customer needs / requirements	4
	M	The adoption has reduced ambiguity of system / system of system understanding	4
13 Modelling environment	M	The modelling environment is secure for data retrieval in case of a data loss	5
	M	Navigation window / Standard homepage / template is being used while modelling	3
14. Modelling environment Analysis	D	The modelling environment is cyber secured (The modelling environment complaints with cyber security)	3
	D	Model can be accessed by multiple users	3

7. Effectiveness and Efficiency Scoring

Example calculation

The survey data becomes precise with a higher number of participants. The answers have a different measuring system for the benchmarking score and effectiveness score as seen in Table 2.

Table2. Response score

For benchmarking	Response score (b)
Strongly Disagree	-2
Disagree	-1
Neutral	0
Agree	1
Strongly Agree	2
For effectiveness	**Response score (c)**
Strongly Disagree	0
Disagree	0
Neutral	0
Agree	1
Strongly Agree	2

The benchmarking score is to give an overall score for the methodology. This uses a negative scoring system to exemplify the degree of missing required elements in a methodology and to ensure a clearer recommendation path. The differences between the standing of the different methodologies can be observed with the help of the negative scoring system.

However, the effectiveness scoring uses between 0-2. The disagree, strongly disagree and neutral scores are score 0 to signify the ineffectiveness of the deployment and methodology and to calculate the percentage of effectiveness.

Calculation:

Following the collected survey data, the benchmarking and effectiveness scores are calculated. The benchmarking score specifically applies to questions related to methodology alone, while effectiveness calculations are integral to the overall analysis.

The survey questions are aligned with their respective categories and subcategories (deployment/methodology) as indicated in Table 1.

Table 3. Example survey results

Survey responses (Example)				
Sample questions	**Weightage (a)**	**Person 1**	**Person 2**	**Person 3**
Q1	3	Agree	Disagree	Strongly agree
. . .	. . .	. . .	. . .	. . .
Q75	5	Strongly agree	Disagree	Agree

A. Benchmarking

The Benchmarking is calculated in following steps:

1. Conversion of Responses to Response Score (b)

The survey responses fall within the range of 'Strongly Agree' to 'Strongly Disagree.' The initial step involves capturing these responses using the corresponding rating scores as mentioned in Table 2 from the benchmarking section.

Table 4. Conversion of Response to Response Score

1. Conversion of responses to response score (b)	Weightage (a)	Person 1	Person 2	Person 3
Q1	3	1	-1	2
. . .	. . .	. . .	. . .	. . .
Q75	5	2	-1	1

2. Individual Response Calculation

Individual Response Score (d) = Weightage(a) * Response Score (b) (1)

Table 5. Individual response calculation

2. Individual response calculation	Weightage (a)	Person 1	Person 2	Person 3
Q1	3	3	-3	6
. . .	. . .	. . .	. . .	. . .
Q75	5	6	-3	3

3. Average Score (v) calculation

Here (Q1,d1), showcases the calculated “Individual Response Score (d) for (Question 1, Person 1)

Average Score = (Sum of all Individual Response Scores (d) / Number of responses considered)

(2)

4. Nominal Score (n) and Maximum Possible Score (m) calculation

Nominal Score = Weightage(a) * 1

(3)

* For the nominal score, "1" is considered as the multiplication factor considering the response is "agree" to the question. This score represents the interim target. The nominal score is set as 50% of the maximum possible score.

$$\text{Maximum Possible Score (m)} = \text{Weightage(a)} * 2$$

(4)

For the Maximum Possible score, "2" is considered as the multiplication factor considering the response is "strongly agree". This score represents the permanent target.

5. Sum of average (v) , nominal (n) and maximum possible score (m) calculation.

$$\text{Benchmarking Score} = \text{Sum of all Average Score} = (v_1 + v_2 + v_3 \ldots + v_n.)$$

(5)

$$\text{Sum of Nominal Score} = (n_1 + n_2 + n_3 \ldots + n_n.)$$

(6)

$$\text{Sum of Maximum possible score} = (m_1 + m_2 + m_3 \ldots + m_n.)$$

(7)

Table 6. Benchmarking score

	3. Benchmarking Score	**4. Nominal Score (n) & Maximum Possible Score (m)**	
Question	**Average Score (v)**	**Nominal Score (n)**	**Maximum Possible Score (m)**
Q1	2.25	3	6
. . .	. . .	. . .	. . .
Q75	2.75	5	10
5. Sum of All	**140**	**189**	**378**
	Benchmarking score		

B. Effectiveness calculation

Following the benchmarking calculation the effectiveness is calculated

6. Conversion of Responses to Response Score (c)

The survey responses fall within the range of 'Strongly Agree' to 'Strongly Disagree.' The initial step involves capturing these responses using the corresponding rating scores as mentioned in Table 2 from the effectiveness section.

7. Individual Response Calculation

$$\text{Individual Response Score (d)} = \text{Weightage(a)} * \text{Response Score (c)}.$$

(8)

8. Average Score (v), Nominal Score (n) and Maximum possible score (m)

The steps 4,5,6 are repeated and followed respectively.

9. Effectiveness (E)

$$\text{Effectiveness Score} = \text{Sum of all average score} \tag{9}$$

Table 7. Effectiveness score

	8. Effectiveness Score	**8. Nominal Score (n) & Maximum Possible Score (m)**	
Question	**Average Score (v)**	**Nominal Score (n)**	**Maximum Possible Score (m)**
Q1	3	3	6
. . .	. . .	. . .	. . .
Q75	3.5	5	10
9. Sum of All	**251**	**296**	**592**
	Effectiveness Score	**Nominal**	**Maximum possible**

C. Efficiency calculation

For the evaluation of the efficiency the qualitative data has been considered while following the implementation of in an use case with well-defined and recognized outputs. These outputs are validated with evidence for its qualitative standard. This analysis was undertaken with the intention of critically assessing the performance, specifically in the context of quality improvement, cost reduction, and time consumption. The objective was to elucidate how MBSE yields tangible advantages with the help of the framework.

Table 8. Response score

Response (f)	**Rating**	**Rational**
1	Very Low	The impact is minimal, almost negligible
2	Low	The impact is small, but noticeable. It may have a minor effect, but it is not a significant factor overall
3	Moderate	The impact is moderate. It has a noticeable effect but it is not a dominant or decisive impact
4	High	The impact is substantial
5	Most	The impact is extremely

		significant

1. Efficiency in quality (Q)

The questions were designed to assess the precise impact of the deployment and methodology on the improvement on the delivery's quality. While designing these questions the respective prior survey questions were kept in mind in order to check their tangible output with same question weightage. Few of the sample questions and sample responses are stated as below, similarly for all other categories and subcategories the questions can be designed to check to what extent the methodology was able to deliver better quality results compared to planned.

Table 9. Survey questions with response [Impact:quality specific] (Example)

Q #	**Example Question [Impact:Quality]**	**Weightage (a)**	**Person 1**	**Person 2**	**Person 3**
Q1	To what extent is understanding stakeholder needs prioritised?	5	5	2	2
Q2	At what extent are the problem/opportunity statements communicated and understood?	5	5	5	4
Q3	To what extent do all the problem statements are validated properly meeting vs actual ?	5	3	3	1

Similar to effectiveness calculation, the individual response score was calculated.

Individual Response Score = Weightage (a) * Response (f) (10)

Table 10. Individual response score calculation

Q #	**Example Question [Impact:Quality]**	**Weightage**	**Person 1**	**Person 2**	**Person 3**
Q1	To what extent is understanding stakeholder needs prioritised?	3	25	10	10
Q2	At what extent are the problem/opportunity statements communicated and understood?	4	25	25	20
Q3	To what extent do all the problem statements are validated properly meeting vs actual ?	5	15	15	5

Similarly the Average score, Nominal Score, Maximum Possible Score (m) and sum of all (average, nominal, maximum possible score) were calculated.

Efficiency Calculation			
Q #	Average (v)	Nominal (n)	Maximum Possible Score (m)
Q1	15	7.5	15
Q2	23.3	10	20

Q3	11.7	12.5	25
Sum of All	50	30	60
	Quality Efficiency Score (Q)		

Quality Efficiency score (Q) = Sum of all average

(11)

2. Efficiency in time (T) & cost (C)

Similar to the efficiency in quality , the questions were set in terms of focusing on the time saving parameters and a survey was conducted to capture the responses.

Sample example Questions for reference:

Table 12. Survey questions
[Impact:time specific] (example)

Q #	Example Question [Impact:Time]	Weightage (a)
Q1	Is the modelling methodology recursive, potentially saving time by building on existing models?	3
Q2	How often the existing models are useful to potentially save time on recreating models ?	4
Q3	To what extent MBSE adoption resulted in reduction of system development time vs plan?	5

Table 13. Survey questions
[Impact:cost specific] (example)

Q #	Example Question [Impact:Cost]	Weightage (a)
Q1	To what extent MBSE adoption resulted in reduced development costs compared with budget, potentially through efficiency gains?	3
Q2	Has MBSE adoption reduced ambiguity in customer needs/requirements, potentially saving costs related to misinterpretation and supporting better system validation and certification?	4
Q3	Has MBSE adoption reduced ambiguity of system/system of system understanding, potentially saving costs related to misinterpretation?	5

Similarly the Time Efficiency (T) and Cost Efficiency (C) were calculated following the same calculation steps considered for the Quality Efficiency (Q) calculation.

3. Overall efficiency

The overall efficiency was calculated by averaging the Efficiency in quality (Q), time (T) and cost

(C).

Overall Efficiency Score (O) = Average (Q, T, C)

(12)

8. Analysis and Recommendations Derivation

Effectiveness analysis

1. Category wise analysis (Percentage [%])

A comprehensive analysis is done first by aggregating all the effectiveness scores within each category as shown in Table 8. Subsequently, calculated the percentage of these scores in relation to the Maximum Possible Score as shown in Table 3.

These scores served as indicators, revealing the deficiencies within each category and guiding the sequence of attention required to attain the initial target, often represented as the nominal or passing line. The next step involves formulating an interim corrective action plan (ICAP) based on these findings .

Table 14. Category wise effectiveness score [%] (example)

Categories	From Average Effectiveness Score	Nominal [Passing Score]	Max. Possible
Systems engineering essentials	42%	50%	100%
MBSE Awareness	40%	50%	100%
MBSE Deployment	55%	50%	100%
MBSE Usages	31%	50%	100%
Model management and workforce	36%	50%	100%
Technical management	44%	50%	100%
Technical Management Strategies	50%	50%	100%
Metrics	40%	50%	100%
Model quality	50%	50%	100%
Data management	40%	50%	100%
Model sharing and reuse	41%	50%	100%
MBSE adoption	45%	50%	100%
Modelling environment	32%	50%	100%
	42%	50%	100%

2. Category-wise Graph Analysis (Percentage [%])

The graph in Figure 2 is plotted with the effectiveness percentage for each category. The initial graph allows to compare the deployment and method

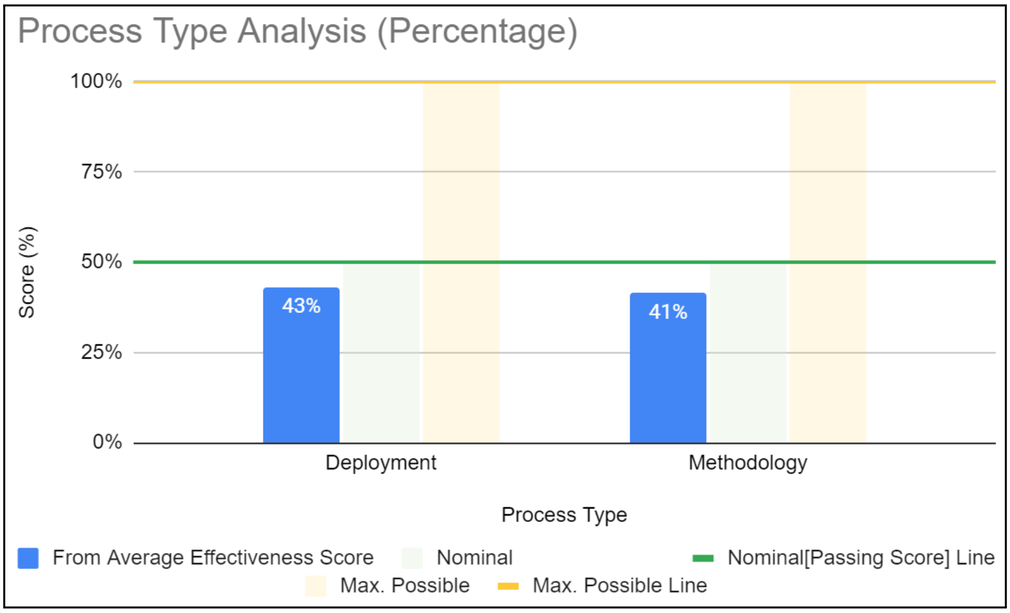

Figure 2. Graph for category wise score

3. Sub Category-wise Graph Analysis (Percentage [%])

The graph in Figure 3 is plotted with the effectiveness percentage for each sub-category that is deployment and methodology.

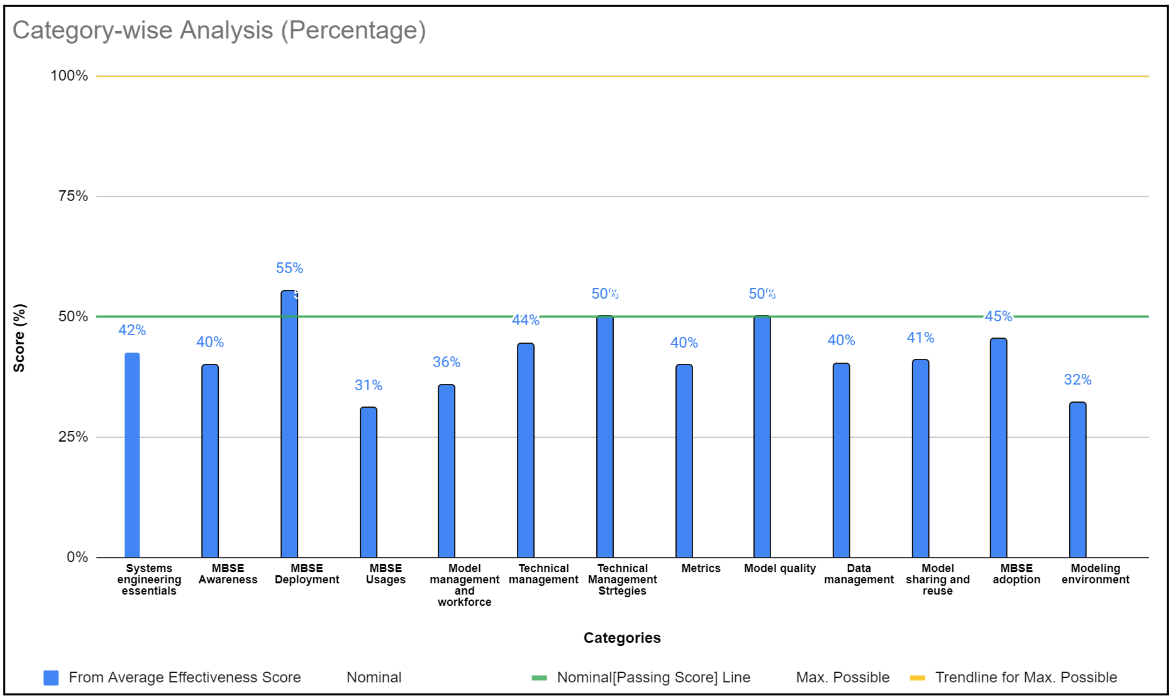

Figure 3. Graph for subcategory wise score

Efficiency analysis

Similar to the effectiveness analysis , the efficiency analysis was conducted for comparison of efficiency in quality (Q) , time(T) and cost (C) with respect to the categories and subcategories with ensuring the shortcoming in terms of nominal and maximum possible score. The improvement target is aimed with the recommendations as explained in further steps.

Recommendations

The recommendations are usually the missing element once the gaps are identified. The framework is capable of pinpointing the source of these issues and providing the valuable recommendations according to the analysis.

The survey results are fed to a model that consists of an interim corrective action plan (ICAP) and the activities are mapped to the stakeholder accountable to deliver the process.

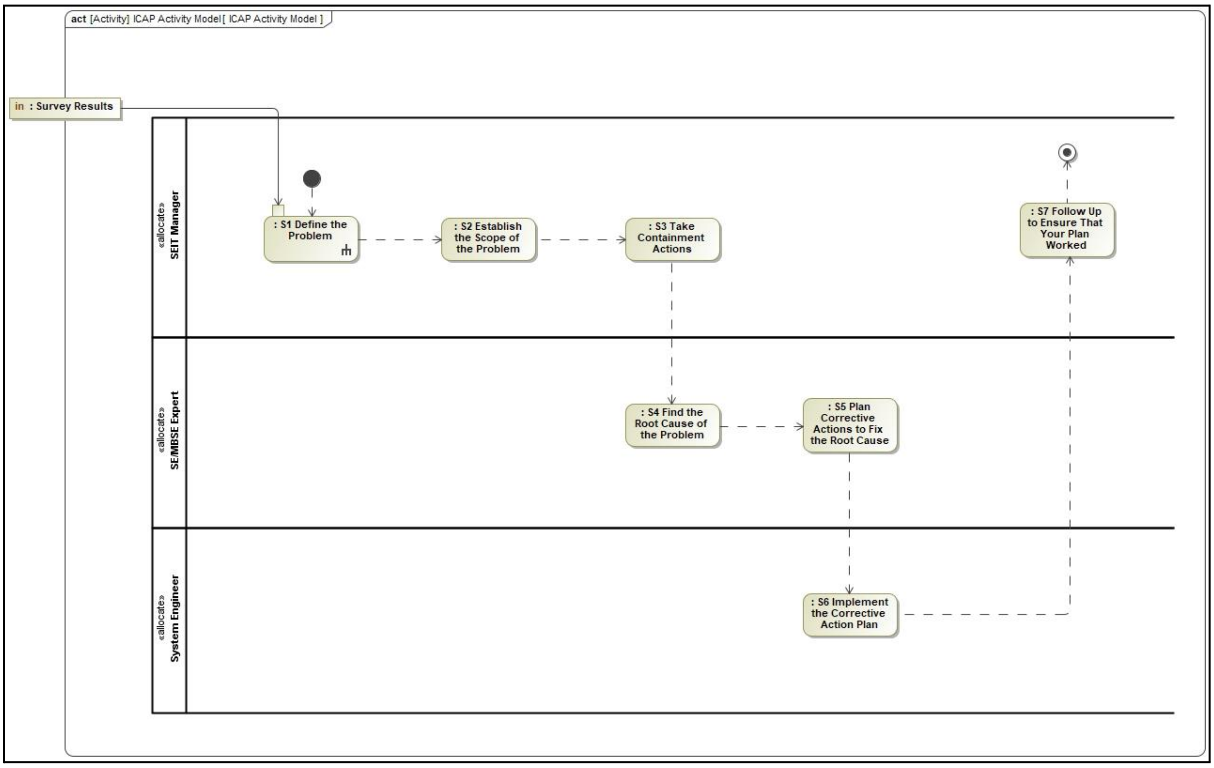

Figure 4. ICAP Activity diagram for recommendation

In Figure 4. The activity is mapped to their respective stakeholder and the sub-activity, however the actions inside are specified in vertical swimlane; swimlane describes which specific stakeholder will act.

Similar to the effectiveness analysis , the efficiency analysis was conducted for comparison of efficiency in quality (Q) , time(T) and cost (C) with respect to the categories and subcategories with ensuring the shortcoming in terms of nominal and maximum possible score. These improvements target the recommendations as explained in further steps.

In Figure 5 & 6. The activity diagram guides the user with the appropriate corrective action plan based on the scores taken in as input in the form of an .xl or .csv file with excel sync feature of the tool. This provides a direct input to the responsible actors to implement the allocated corrective action plan/s.

The simulation of the activity diagram provides the best optimistic conditional recommendation based on the survey score and responsible actors to implement it. The approach is defined in order to reach the optimal score across the categories in both deployment and method.

ICAP simulation provides recommendations only to reach an optimal value which is 50 %. A Permanent corrective action plan (PCAP) also follows the same principle recursively in order to raise the value above 50%. This is essential to ensure no recurring issues or challenges during the development and deployment of the framework. This framework could be further enhanced with utilising techniques such as standard deviation , custom weightage mechanism meeting organisations needs.

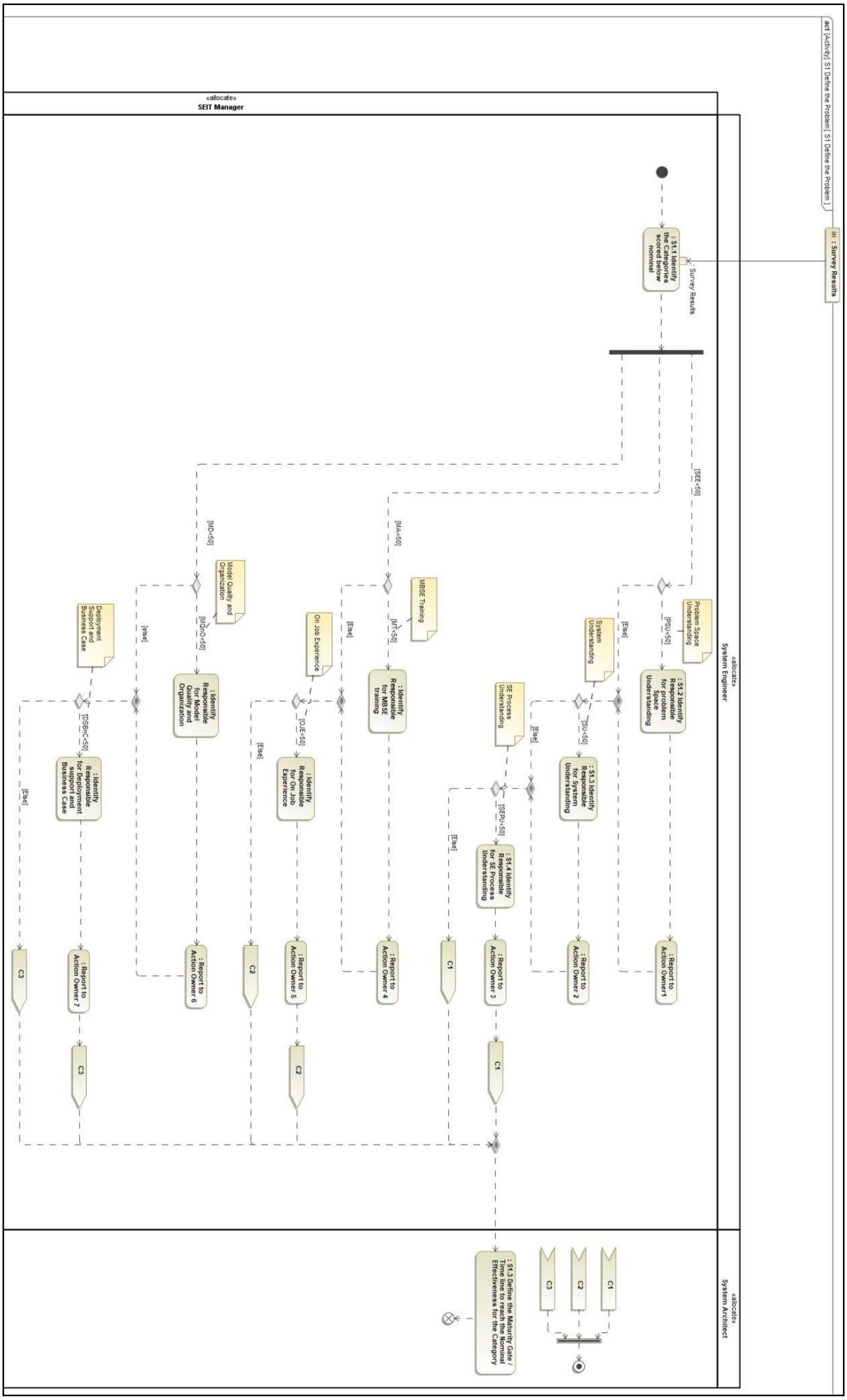

Figure 5. ICAP S1 diagram

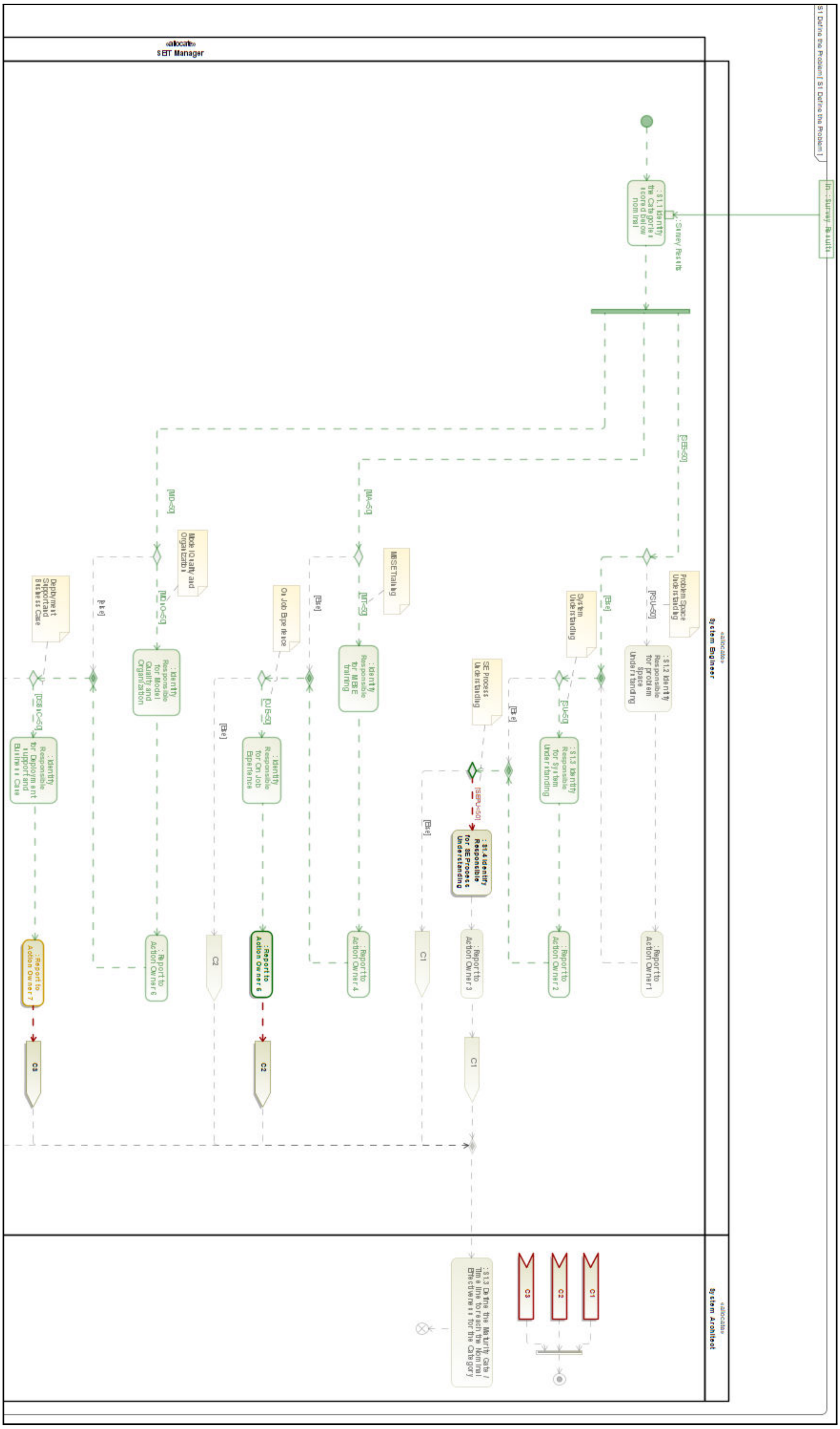

Figure 6. ICAP simulation

9. Challenges

The evaluation of successful MBSE deployment and the framework practised is sometimes obscure with changing domain and use case.

The structuring and formulation of a comprehensive, formulised and generic measuring system presents a significant challenge, primarily attributed to the evolution of methodologies, changing means of implementation, and diverse use cases. This complexity is further increased by the difficulty in selecting methodologies, making it challenging for individuals to compare different options and making a choice for best suitable one.

Another set of challenges include rationalising and agreeing on the weightages assigned to the survey questions, as this job is quite subjective and may vary depending on goals. In addition to that, there are challenges in terms of demonstrating the effectiveness and efficiency for the MBSE deployment and methodology in both short-term and small-scale projects. These challenges stem from the difficulties of adapting MBSE to projects with constrained timelines and resources.

In survey data collection and analysis, a significant challenge lies in validating the accuracy and impartiality of survey data and responses. This validation process is crucial for ensuring the reliability of the collected information.

Overall, these multiple challenges underscore the nature of navigating diverse methodologies, weighting survey questions, and demonstrating the applicability of MBSE in varying project scope.

10. Conclusion

The study started with an attempt to understand the fundamental gaps within an MBSE framework. A previously developed framework can be investigated so that it stands to be effective and efficient regardless of the changes or adaptations. This requires questioning all the objectives that the framework set out to meet. It is a critical necessity with the SE and MBSE domain to have an observable, measurable and an affirmative framework to evaluate its success.

In order to address this need it becomes essential to evaluate a given method for its effectiveness and efficiency. During the development of this paper, a multifaceted framework which is characterised by several wide range of topics emerged.

To ensure its soundness, a survey methodology was considered, which enabled a brief exploration and focused analysis of both deployment and methodology strategies across various vital sub-categories of SE/MBSE deployment.

The focused analysis not only served to showcase the shortcomings and gaps at a detailed level, but it was also significantly supported by recommendations from both ICAP and PCAP perspectives to address them.

The two significant outcomes of the study include providing a framework to compare the different methodologies for the community interested in adopting MBSE. It also aims at providing scope and guidance to deployment teams and a methodology for the development teams for its improvement.

From individual analysis of the survey results, we could observe that the groups that struggled with the fundamentals of SE, also found the deployment a challenge or rather uncertain of its rationale. It becomes the responsibility of the deployment team to not only upskill but also better rationalise a developed framework. The overall survey presented the areas of MBSE usage and MBSE environment. Several such analyses can be drawn from this framework and its measurement system, which in turn can help build a more robust system for MBSE framework development and its deployment.

This holistic framework would stand to support a systematic means to gauge the deployment and methodology for various frameworks that exist today, by identifying the gaps and recommending steps to improve.

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Biography

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