Maturity assessment of Systems Engineering reusable assets to facilitate MBSE adoption

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Abstract: To enable the transition towards Model-Based Systems Engineering, it is necessary to provide engineering assets models during system architecture design phases. As promoted in the software community, systematic reuse allows significant gains in development productivity and quality. Thus, to develop a reuse strategy, a maturity scale facilitates determining the maturity level at which a company operates. In this way, it is possible to assess the progress margins and therefore estimate necessary efforts to improve maturity through a corresponding action plan. For this reason, this article proposes a scale to evaluate the maturity of the Systems Engineering assets reuse process.

Keywords: **Model-Based Systems Engineering, Engineering Assets, Maturity Evaluation, Reuse**

1. INTRODUCTION

Current engineering practices no longer adequately address the complexity of systems (Corbets, Willy, and Bischoff 2018). Therefore, this observation requires the development of new Systems Engineering approaches capable to face this challenge, such as Model-Based Systems Engineering (MBSE). MBSE provides a rigorous framework for specification and design processes when the right methods and tools are implemented and used. However, the authors of various surveys (Chami et al. 2018; Huldt and Stenius 2018; Vogelsang et al. 2017) report that industry is still struggling to adopt these new methodologies. Indeed, many inhibitors remain because of:

- maturity levels on processes and methods: in some cases, the transition to MBSE also implies the adoption of the Systems Engineering (SE) methodology, which requires a major evolution of engineering practices;
- tools capabilities: depending on the method to be applied, the interface or the modelling language used, MBSE tools have to be customized, which can be time consuming and costly;
- the transformation process: an evolution of engineering practices can generate resistance to change from individuals, which requires a long process of support and training. If the transformation doesn't provide adequate tools and training it will extend the adoption duration.

One of the facilitators of the transition towards MBSE is the promotion of engineering know-how (Wu et al. 2020). These assets, based on past experiences, accelerate and improve the efficiency of new engineering cycles. The capitalization and reuse of engineering assets process is originally an informal and individual practice. However, with the increasing complexity of systems, its systematization quickly became essential to meet modern economic challenges. It first took the form of documents, describing the knowledge and know-how of engineers. For a long time, documents have been the main standard for the dissemination of engineering assets within companies. However, it now appears to be insufficient to cope with the quantity of explicit and implicit data, knowledge, and know-how necessary to develop a modern complex system. The capitalization and reuse process needs to evolve, so that it can accompany the transition from a document-based SE approach to a MBSE approach. With this objective, the article proposes an approach to assess the maturity of reusable engineering assets (OMG 2005). The proposed approach seeks first, from the state of current practices, to know the current level of maturity. The latter allows, in a second step, to evaluate and establish the efforts required to raise maturity.

The paper presents in section 2 the "reuse" act as an enabler for the transition towards MBSE. Then, in section 3 a state-of-the-art presents the interest of being able to assess the maturity of reuse process. To do this, section 4 introduces a maturity scale dedicated to reuse engineering assets. In section 5, the maturity calculation method is explained. Finally, section 6 discusses the next step towards a more detailed scale.

2. REUSE AS AN ENGINEERING FACILITATOR

For a wider adoption of MBSE, several evolutions seem necessary in terms of organization, methods, and tools to ease the change management. In this sense, it is possible to draw inspiration from the notion of engineering "simplexes", which is based on the concept of “simplexity” defined by (Berthoz 2009) as a means used by living beings to solve problems of interactions or perceptions, to react or solve problems quickly. Alain Berthoz explains that this notion is based on a set of resources available in the human body. He cites, for example, the neural mechanisms of anticipation (e.g., to hit a ball, a tennis player anticipates his position in relation to his racket), or the various internal models available to the brain that allow it to perform, for example, mental simulations of actions performed by others. Humans therefore have at their disposal mechanisms, simulation models, which allow them to analyze their own universe and thus measure relevant variables in it to help them build solutions.

Five principles are added to these resources to structure the processes of “simplexification”. These are: the inhibition of reflexes by the brain centers of the executive functions (principle of inhibition); the selection of relevant information for action (principle of specialization); the prediction of the probability of a future event based on memory (principle of anticipation); the detour by auxiliary means (principle of detour); the control of one source of information by a second or the change of points of view (principle of cooperation).

It is possible to transpose these principles within engineering domains and to observe the influence of experience on “simplexification”. For example, it is easy to guess that the principle of anticipation will be more efficient for a senior engineer, who had time to refine his internal models. For engineers, the action of reusing knowledge and know-how from their experiences or from previous projects means that they have applied these simplifying principles. They have therefore built simplexes both on the system of interest (which is the system whose life cycle is being considered) or on systems engineering activities (which aim to develop the system of interest). However, this means that such simplexes are kept in their mind, and that a junior engineer can’t directly access simplexes of a senior engineer. It is then necessary to formalize these simplexes to share them, so that they can be reused by other engineers. In other words, "good practices" or engineering assets are simplexes and their dissemination within a company is essential to perpetuate know-how and to have a common body of knowledge.

The hypothesis that is done in this article is that these practices should be capitalized and reused as “patterns”. Such patterns have to be “Mined” from current practices and previous projects, then “Matured” and stored in a library of patterns, to be finally “Implemented” in future projects.

3. MATURITY OF REUSE PROCESS

The previous sections have demonstrated the importance of engineering reusable assets to facilitate the deployment of a MBSE approach. This process consists in highlighting engineering know-how, with a view that provides a reuse capacity for other engineers. The objective is thus to set up a systematic reuse process to achieve significant gains in productivity and development quality (Garcia et al. 2007).

However, the implementation of a systematic capitalization and reuse process requires measuring the maturity of this process at a given point in time. The development of a scale provides a framework for assessing an organization's level of maturity. It helps to determine the effort required to increase maturity and improve the efficiency of asset reuse.

To do this, there is a set of maturity models in the literature, proposed to respond to specific issues. For example, research in the software community has proposed various models and practices for carrying out reuse activities. The Reuse Capability Model (RCM) provides a method for determining the reuse capability of an organization's software activities (Rine and Sonnemann 1998), defining five levels for assessing and planning improvements to an organization's reuse capability. The levels are defined from the lowest (level 1) to the highest (level 5):

- Level 1: Ad hoc – no reuse process.
- Level 2: Opportunistic – libraries supporting projects.
- Level 3: Integrated – reuse and development process integrated.
- Level 4: Leveraged – distinct product-line life cycle with specialized processes.
- Level 5: Anticipating – applications optimize reuse.

Iteration of this model has been proposed, such as the Reuse Capability Maturity Model (RCMM) which focuses also on reuse and describes the basic to ensure a well-planned and controlled reuse oriented software development (K. S 2010).

However, these maturity models need to measure different aspects to really assess an organization's level of reuse. It is necessary to perform this assessment in several dimensions, which implies that a complete maturity model must cover several criteria. Thus, it will be possible to create a correlation between the different axes to obtain a result as close as possible to the evaluation need. In this sense, the RiSE maturity model proposed by (Garcia et al. 2007) includes four perspectives dealing with organization, business, technology, and process issues. The main objective of the RiSE maturity model is to support the incremental adoption and implementation of software reuse practices. More recent work by (Younoussi and Roudies 2016) has compiled and compared maturity models to provide a classification of each model according to criteria and parameters. Thus, they show that the reuse approach must be adapted to the desired objective. As one of the hypotheses of the work presented in this article is that know-how can be capitalized in the form of patterns, it is therefore necessary to consider the concept of pattern in the maturity model.

In the Systems Engineering (SE) community, different maturity models have also been proposed and evaluated. For example, (Cornu et al. 2012) have proposed using a maturity model to assess the capacity of an organization to deploy different SE processes. (Demirci 2010) also proposed a maturity model to determine the capacity to use MBSE as an engineering approach. At each level, maturity indicators are associated with different specific aspects of modeling

(modeling process, model quality, skills, tools...). Going back a bit further, another maturity model for SE, the Systems Engineering Capability Maturity Model (SE-CMM) (Software Engineering Institute 1995) has been developed: it describes the essential elements to be integrated in a company's SE processes to ensure “good” SE. Then, the CMM evolved into Capability Maturity Model Integration (CMMI) (Software Engineering Institute 2010), including "systems" aspects for developments. However, in the CMMI and as in the maturity models presented previously, the aspects of recovery and reuse of engineering assets are not considered. In fact, the scope of evaluation of these maturity models reduces reuse to a single indicator, without giving any criteria for assessing the level of maturity achieved.

It is therefore necessary to provide companies with the ability to assess their level of performance on their reuse process and thus make recommendations for improvement. To do this, a dedicated maturity scale is proposed below.

4. A MATURITY SCALE FOR THE ENGINEERING REUSABLE ASSET PROCESS

Faced with all the available data, it is necessary to identify engineering assets that will have sufficient value to be reused. Otherwise, reuse is to the detriment of the understanding of the manipulated objects and ultimately serves the end user through a lack of added value (Niu et al. 2013). It is therefore necessary to have applied a capitalization approach prior to applying a reuse approach. In other words, the implementation of a reuse process cannot take place independently of a capitalization process. In this article, different aspects of reuse are considered to cover the entire SE reusable asset process: in addition to the identification and reuse processes, a library-based engineering asset classification process is added to create a catalog that can be easily understood by end users, and that facilitate the reuse of engineering assets. This involves, first, the proposition of a multi-axial maturity scale (Fig. 1), each axis of which is composed of 6 levels of maturity inspired by the CMMI.

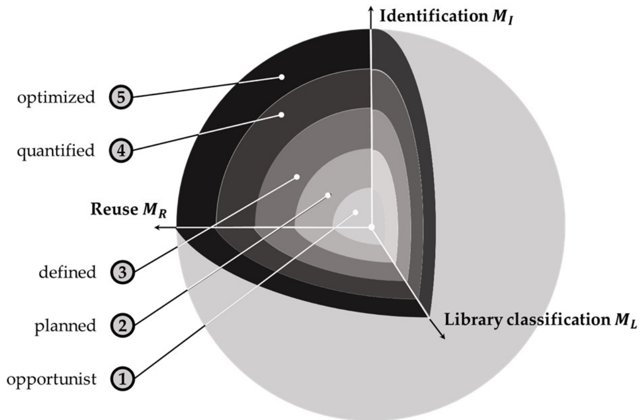

Fig. 1. Multiaxial maturity scale for systems engineering reusable assets

These levels allow to assess the individual maturity levels that are specific to the Identification, Library Classification and Reuse processes (M_I, M_L, M_R). Although this maturity scale is inspired by the CMMI, it proposes to adapt the proposed maturity levels to make them specific to the needs relating to the reuse of SE assets (Table 1). In a second step, the levels on each axis will allow to calculate a global maturity level (M_{SERA}), as proposed in section 5.

Table 1. Description of each maturity level

		Axis		
		Identification	**Library classification**	**Reuse**
Maturity level	**0**	No identification of reusable elements	No library classification	No reuse from previous projects
	1	**Opportunistic** identification of reusable elements from previous projects, without method (uncomplete vision)	Awareness: "I already saw something like this"; **Opportunistic** oral sharing of reusable elements: "we already done this way", use of paper board…	**Opportunistic** reuse by copy/paste from previous projects, without method; manual adaptation
	2	**Planned** identification of reusable elements, without method (uncomplete vision)	**Planned** sharing of formalized elements (communication, archiving…) identified as reusable (texts, models…)	**Planned** reuse by copy/paste from previous projects, without method; manual planned adaptation
	3	**Defined** identification method: classification in function of defined abstraction levels	**Defined** capitalization method: sharing organized around a sharing structure	**Defined** reuse method: defined selection of reusable elements and transitions between defined abstraction levels
	4	**Quantified** measure of defined identification method efficiency (identification time, costs…)	**Quantified** measure of defined capitalization method efficiency (classification time…)	**Quantified** measure of defined reuse method efficiency (direct reuse or adaptation time…)
	5	**Optimization**: continuous improvement of identification method	**Optimization**: continuous improvement of classification method	**Optimization**: continuous improvement of reuse method

The proposed maturity scale is justified by the progressive nature of the improvement of a reuse approach. Indeed, it is necessary to structure the reuse approach step by step by developing the necessary concepts as it progresses (example: library in level 3).

4.1 Maturity level 0: no reuse

No reuse action is performed at the enterprise level. The identification of engineering assets does not take place at the individual level, which has not led to an awareness of the value of reuse.

4.2 Maturity level 1: opportunistic reuse

There is no intention for reuse at the enterprise level. The scope of engineering reusable assets concerns only engineers. Thus, at their scale, no library classification is carried out, as they only use a small set of assets that can evolve according to the project. Table 2 gives maturity indicators for identifying level 1 practices.

Table 2. Maturity criteria for level 1

Identification	- No defined process/method - No defined objective - At the engineer's discretion (risk of lack of skills)
Classification	- No defined process/method - No defined objective - No library available or no classification because identification in "one shot".
Reuse	- No defined process/method - No defined objective - Single reuse, little or no sharing with other engineers

4.3 Maturity level 2: planned reuse

No reuse action is performed at the enterprise level. At this level, the domain is that of intention and therefore lacks structure. Table 3 provides maturity indicators to identify level 2 practices.

Table 3. Maturity criteria for level 2

Identification	- No defined process/method - Defined objectives - Collective will
Classification	- No defined process/method - Defined objectives - Unstructured libraries available
Reuse	- No defined process/method - Defined objectives - Reuse without guide

4.4 Maturity level 3: defined reuse

At this level, processes are defined, and the approach is applied at the enterprise level. A library is formalized and shared with the various stakeholders. Table 4 gives maturity indicators for identifying level 3 practices.

Table 4. Maturity criteria for level 3

Identification	- Defined processes/methods - Defined objectives
Classification	- Defined processes/methods - Defined objectives - Libraries available, with categorization, and shared
Reuse	- Defined processes/methods - Defined objectives - Reuse with guide

4.5 Maturity level 4: quantified reuse

At this level, a set of performance indicators are measured and made available to users. This allows engineering resources use and cycle times to be measured during development. Table 5 gives maturity indicators to identify level 4 practices.

Table 5. Maturity criteria for level 4

Identification	- Level 3 Indicators + - Measurement of time, cost of capitalization of engineering assets
Classification	- Level 3 Indicators + - Measurement of time, cost of classification, search for engineering assets
Reuse	- Level 3 Indicators + - Measurement of number of uses, adaptation time, number of searches, development time

4.6 Maturity level 5: optimized reuse

At this level, previously defined performance indicators are exploited to provide predictive capabilities to the tools used. This enables the optimization of the approach's performance indicators by accelerating engineering cycles and guiding users during development. Table 6 gives maturity indicators for identifying level 5 practices.

The criteria have been defined following the progressive approach of increasing the maturity of SE reusable assets. They also have to take into account that no backtracking is supposed to be possible.

Table 6. Maturity criteria for level 5

Identification	- Level 4 Indicators + - Capitalization aided by learning the tool (faster, more mature)
Classification	- Level 4 Indicators + - Automatic adaptation of the library according to the user's needs. - Anticipated classification by the tool
Reuse	- Level 4 Indicators + - Anticipated reuse (e.g. word recognition,…) by the tool

At the engineer's level, project constraints, the organization or the lack of awareness, leads to a context where, levels 1 or 2 of the proposed scale, cannot go beyond. The only way to go further is to deploy a real company policy, based on a defined methodology (Wu et al. 2019).

5. GLOBAL MATURITY EVALUATION

The particularity of this scale lies in the dependencies between the different axes. Indeed, the final objective is to reuse engineering assets to disseminate know-how, in particular to facilitate and accelerate future developments. However, the reuse of assets is only possible when they have first been identified. Otherwise, it is impossible to measure the added value brought by reuse. Moreover, in the context of complex technical systems, it is necessary to be able to classify these assets in a library or catalog to create a common base of know-how for reuse in future projects. It thus appears that the "Identification" axis is the starting point of the methodological approach aimed at, and therefore that the level of maturity of this axis constrains the other axes. Then comes the "Classification in library" axis, which makes it possible to perpetuate what has been previously capitalized, but also to facilitate the search for engineering assets. Indeed, this supports the next axis, "Reuse". In other words, intrinsic rules exist for the level of maturity on each axes of the scale, such as: $M_R \le M_I$ and $M_L \le M_I$. Thus, because of this dependence, only some combinations of level of maturity are possible (Table 7). Indeed, there can be no "reuse" at the maximum level of maturity if the "identification" and "library classification" axes have not reached a sufficient level of maturity.

Based on these levels of maturity, which cannot be individually satisfactory, it is necessary to be able to calculate an overall maturity level for the SE reusable asset process. Due to the dependencies between each axis, it appears that the overall maturity level cannot be higher than the lowest maturity level on the axes. Under these conditions, it is possible to define a global maturity level for the reuse of engineering assets (M_{SERA}) such as:

$$M_{SERA} = \min\left[M_I, M_L, M_R\right] \qquad (3)$$

However, considering only the lowest level of maturity does not provide a sufficiently fine assessment of the overall maturity level. In the following cases (Table 8), the overall maturity level is always the same and does not consider the maturity levels of all axes.

Table 7. Possible combinations of maturity levels

M_I	M_L	M_R
1	1	1
2	1	1
2	2	1
2	2	2
3	2	2
3	3	2
3	3	3
4	3	3
4	4	3
4	4	4
5	4	4
5	5	4
5	5	5

Table 8. Example of the calculation of the global maturity level with the formula (3)

	M_I	M_L	M_R	M_{VSEA}
Situation 1	1	1	1	1
Situation 2	2	1	1	1
Situation 3	2	2	1	1

Therefore, to refine the overall maturity measurement, it is more interesting to consider the "positive advances" along each axis. In the trivial case where $M_I = M_L = M_R$, then $M_{SERA} = M_I = M_L = M_R$.

In the other cases, formula (3) becomes:

$$M_{SERA} = \min\left[M_I, M_L, M_R\right] + \frac{M_I - M_L}{3} + 2 \times \frac{M_L - M_R}{3} \qquad (4)$$

Thus, the examples from Table 8 change to:

Table 9. Example of the calculation of the global maturity level with the formula (4)

	M_I	M_L	M_R	M_{SERA}
Situation 1	1	1	1	1
Situation 2	2	1	1	1.3
Situation 3	2	2	1	1.7

Formula (4) thus makes it possible to refine the calculation of M_{SERA} by providing an indication of the efforts to be carried out for the passage to the higher level of global maturity. Thus, it is easier to reach $M_{SERA} = 2$ in situation 3 compared to situation 2, and so on.

6. CONCLUSION AND PERSPECTIVES

With the maturity scale thus defined, it is possible to establish the current maturity level of engineering assets reuse within a company. In future works, the 3 axes of the maturity scale will be refined and completed in order to take into account strategic and operational management decisions. It will also include MBSE assets such as model identity card, assessment of model maturity (for example depending on various metrics such as version number and number of instantiations…), and tools supporting model reuse… Since the scale will be more detailed, a weighting system will be added to the overall maturity calculation. This will allow the calculation of a maturity status that is sensitive to continuous improvement process.

Once the maturity level is estimated, it is necessary to provide a guide to reach the desired level of maturity. If one considers that the current maturity level of reuse reached in companies does not exceed level 1 or 2, it is often because of the lack of resources available for the definition of a methodological approach allowing to reach higher levels (with at least a definition of processes). Therefore, future works concern the proposition of a methodological approach to implement a method adapted to the needs of agility and complexity management expected by customers. As demonstrated in this article, it is necessary to provide engineering assets during system architecture design phases. For that reason, the proposition, based on the concept of patterns for the capitalization and reuse of engineering assets (know-how), will allow engineers to integrate engineering assets during the development of a new project, especially during system modeling activities.

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