Comparison Framework for PLM Maturity Models

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Abstract. Throughout the recent years research about maturity models as well as their application possibilities has vastly increased in all sorts of organizations and institutions. The range of the topics they address has expanded as much as the way they can be structured and applied. One area, where the use of maturity models can have a great impact, is product lifecycle management (PLM). PLM is becoming more and more essential for companies as a way of staying competitive on any market due to enhanced understanding of complex processes and increased efficiency in the use of information throughout all stages of the lifecycle. In this regard, maturity models can be beneficial as methods to assess the organizations' product lifecycle processes, illustrate improvement opportunities and even customize a roadmap to exploit them. However, considering the complex application options of maturity models, it can be difficult to choose an appropriate model for a certain purpose. This paper will provide a comparison framework for maturity models in the PLM area. The collected attributes as well as their categorized comparison shall provide guidance in choosing the correct maturity model depending on the user requirements.

Keywords: maturity model, product lifecycle management (PLM), model comparison

1 Introduction

Nowadays, companies and organizations consistently strive for improving their ongoing business to preserve their position in the market. In order to do that they need to maintain their competitive advantage by reducing their overall costs, being innovative with their products and services, and ensuring their customers' satisfaction with supreme quality. As stated by the Total Quality Management (TQM) principles taught by Shewhart, Juran, Deming and Humphrey, "The quality of a product is largely determined by the quality of the process that is used to develop

and maintain it". Additionally to the quality of the utilized process, the choice of technology and people that provide the connection will guarantee a high level of quality throughout the entire company.

One way of pursuing the above-mentioned goals is to implement the use of maturity models. These models help to analyze the current state and the progress made over a period of time concerning processes or structures, assess their current level of maturity, identify strengths and weaknesses, and possibly propose improvement solutions. Also, the use of maturity models by itself will enhance the awareness of the employees being assessed and this alone could have positive effects within the organization.

However, since there is a vast amount of maturity models to choose from, depending on the specific goal, the application domain, and several other criteria, how should someone know which one to choose? This paper will try to provide an answer to this question by examining existing maturity models based on specific criteria that have been collectively put into a comparison framework. A few attempts have already been made to structure these criteria and organize them in classification systems. However, the still increasing number of maturity models entails problems of retrievability and reusability, which this paper shall help to overcome. [8]

2 State-of-the-art analysis

To get a better understanding of the topic of maturity models and their influence on the PLM domain, this paper will briefly describe their evolution as well as their current, interrelated use.

2.1 Maturity models

As mentioned above maturity models provide excellent support in assessing the maturity of an entire organization with the aim of improving the competitive advantage on dynamic markets. Starting off in 1987, the Software Engineering Institute (SEI) introduced the Capability Maturity Model (CMM), one of the first models to assess the maturity of processes and the predecessor of many-to-follow maturity models. [13] Following the official CMM version 1.0 in 1991, the CMM Integration was launched in 2002, which eventually lead to the most current CMMI version 1.3, released in 2010. Especially addressing software development, the SEI introduced the concept of having five maturity levels (initial, managed, defined, quantitatively managed, optimizing), indicating the process capabilities expected at a certain level. These process capabilities describe a range of expected results achieved by following the observed software process. Each level also contains a number of key process areas, regulating which goals to achieve according to a set of activities. These key process areas will mostly be considered as business dimensions in other models. Lastly, a detailed description of how to conduct improvement activities is covered in the key practices, which in concerning the

CMMI are included in five common features. Some models use the CMMI structure as a reference frame, although many others choose a different approach, mostly due to specific domain requirements.

Since maturity models start to become more and more popular, many different variations in their development have been attempted. As stated by Fraser (2002), all maturity models shall include six basic components, which will be necessary for them to be well-structured: (1) a number of levels (typically three to six), (2) a descriptor for each level (such as the CMMI's differentiation between initial, repeatable, defined, managed, and optimizing processes), (3) a generic description or summary of the characteristics of each level as a whole, (4) a number of dimensions (such as the "process areas" in CMMI), (5) a number of elements or activities for each dimension, and (6) a description of each element or activity as it might be performed at each level of maturity. As stages (1) to (4) are usually met with ease, some models struggle with clear definitions for stages (5) and (6). Regarding those models the idea and fundamental structure is often well designed, but they lack detailed descriptions for the implementation and/or improvement activities, which leads to less appreciation by end users due to limited practicality.

As of today, research related to maturity models heavily focuses on the development, including basic descriptions, more detailed conceptualizations, and approaches with different scientific structuring methods, e.g. design-oriented research or Delphi studies. About a third of all researches concentrates on the application of maturity models, e.g. to specific domains, with the help of maturity assessments, or transferring this knowledge to other contexts. Only very few works conduct empirical studies or simulations, compare maturity models, or conclude model validations of some sort. This paper shall reduce this gap by providing a new concept for model comparison. [16]

2.2 Product Lifecycle Management

Similar to the term maturity there are various ways of defining the area of PLM. A widely-spread definition used by Stark (2005) states 'Product Lifecycle Management (PLM) is the activity of managing a company's products across the complete lifecycle, from the early stages of conception to the final disposal or recycling of the product.' PLM can rather be considered a concept than a system due to its focus on maintaining sustainable market advantage by addressing flexibility and innovation. [2] This concept can be considered as a combination of business rules, processes, methods, and guidelines including descriptions for the practical implementation. [11]

The concept of PLM is very powerful as mentioned benefits include shorter time-to-market, increased innovative ability and profits, fewer engineering changes late in the lifecycle, higher efficiency, and less product faults. [15] Other drivers for the use of PLM consider the demand of more complex products with regard to functionality and components, shorter product lifecycles, customization options because of higher demand standards, management of eventually more complex

supply chains, as well as factoring in the increasing regulations concerning safety and environmental issues as mentioned by Batenburg *et al* [2].

Since the PLM concept addresses very common business goals that are pursued by different organizations Batenburg *et al* [2] also state that it has been used in various industries, including e.g. the automotive and transport sector, aerospace and defense, process industry, life sciences and heavy machinery. However, this versatility needs specific application adjustments with respect to the addressed domain and industry. One way to cope with these adjustments is the use of maturity models. They can either be used to assess the maturity of an organization with respect to their readiness to introduce the PLM concept or assess the maturity of an already implemented PLM system in regards to the efficiency of processes, structures, etc. Some of these models provide further guidelines and roadmaps for the improvement of specific gaps and aspects. However, it is always important to realize the strength and weaknesses of the available maturity models in the field and choose the most suitable with regard to the organizations' requirements.

3 Development of an assessment framework

As stated in Wendler's study [16], there is a significant lack of research in the area of maturity model validation, which by his means covers maturity model comparisons. Therefore, the aim here is to develop a comprehensive framework to facilitate a fair comparison of the models with respect to their different attributes. Although there have already been attempts to classify, categorize, compare, and evaluate maturity models, the intent of this paper is to develop a framework considering all important general aspects that could be relevant for a comparison on the base of explicit literature research analysis. The basic structure of the framework consists of three attribute dimensions, similar to the dimensions addressed by Mettler [7]: *general attributes*, *design attributes*, and *usage attributes*.

3.1 General attributes dimension

The *general attributes dimension* will cover two blocks of attributes. The first block will include the "basic information", which represents top level information that is necessary to get a simple distinction between all kinds of models. This includes the name of the model, the acronym (if existent), the primary source (where information was collected), the addressed topic, the origin (academic or practitioner-based), the year of publication, the granted access (free or charged), and the addressed audience (management- or technology-oriented). The second block "structure details" will go more into detail on aspects like the covered business dimensions and maturity levels as well as possible testing parameters.

3.2 Design attributes dimension

This dimension will focus on design related issues concerning the maturity models. That includes the main purpose of the model, which can be either *descriptive*

(the application is a single point encounter with no intention of maturity improvement or analysing performance relationships), *prescriptive* (analyzing domain relationships in order to boost business performance and thus increase the business value, therefore identifying gaps and creating a road-map for improvement), or *comparative* (performing an industry-wide benchmark across different organizations to compare similar practices). [3] As mentioned by Mettler [7] the concept of maturity covers the focus of the model, including *process maturity* (to which extent a specific process is explicitly defined, managed, measured, controlled, and is effective), *object maturity* (to which extent a particular object like a software product, a company report or similar reaches a predefined level of sophistication), and *people capability* (to which extent the workforce is able to enable knowledge creation and enhance proficiency). Additionally, Kärkkäinen [5] introduced a fourth *customer* dimension (capability for management of all customer-related data, information and knowledge concerning the whole product lifecycle), which will be factored into the comparison. The composition shows that a model can either be concluded as a *maturity grid* (text descriptions for each activity at each maturity level with moderate complexity), a *Likert-like questionnaire or hybrids* (questions are statements of 'good practice' to score the relative performance; hybrids combine this with a maturity grid), or *something else* (e.g. the CMMI). [4] As for the chosen assessment approach, the model can either be *staged* (the model matures the organisation as a whole) or *continuous* (improves capability of specific processes within the organization). [14] Whether a model is designed to be *one-* or *multi-dimensional* (being adaptable to multiple domains) will be covered in the scope as well. The flexibility or rather adaptability of a model can either be represented as a change in its *form* (e.g. the underlying meta-model or model schema, the descriptions of the maturity levels or question items) or its *function* (e.g. how maturity is assessed). [8] Lastly, the reliability of the model will be addressed. When there is at least one testing available, it can be assumed that the model has been *verified*. Only until a model has been thoroughly tested and accepted by many practitioners it could be considered as *validated*.

3.3 Usage attributes dimension

The *usage attributes dimension* covers five attributes mainly concerning application issues. First off, the method of application is defined by either being done by a *self-assessment*, *a third-party assisted assessment*, or be concluded by *certified practitioners*. A variety of instruments is used for this application, including *document reviews*, *work groups*, and/or *questionnaires*. When self-assessing support for the application is needed. If there are any, this support could include *textual descriptions or handbooks*, or a *software assessment tool*. Since not all of the observed models *provide specific improvement guidelines* when trying to advance from one level to the next, this attribute shows importance to be covered. As for the practicality of evidence, *implicit improvement activities* for future development of the model as well as *explicit recommendations* are covered. Lastly, some models might need specific training for correct application. This training can range from *basic* to *extended*, depending on the level of detail and the desired purpose of use.

4 Results of the assessment framework

The comparison framework as described in Chapter 3 is applied to a variety of maturity models in the PLM area, including the PLM framework proposed by Batenburg *et al* [2], the Capability Maturity Model Integration (CMMI), Version 1.3, by the CMMI Institute [13, 14], the Configuration Management Maturity Model by Niknam *et al* [9], the EDEN Maturity Model by the BPM Maturity Model eden e.V. (all information translated from German) [1], the addition of a customer dimension of PLM maturity based on Batenburg's model by Kärkkäinen *et al* [5], the Knowledge Management Capability Assessment Model by Kulkarni *et al* [6], the PLM Maturity Reference Model by PLM Interest Group [10] the Product lifecycle management model by Saaksvuori *et al* [11], the PLM Maturity Model by Savino *et al* [12], and the PLM Components Maturity Assessment by Zhang *et al* [17]. The comparison is based on the available literature about the aforementioned models, which were found and reviewed by the authors in order to extract the categorized information with respect to the comparison framework's requirements.

The results of the *general attributes dimension* are listed in Table 1 below. Although the scope of their application might vary, all models are associated to the PLM domain. Most of the models are academically based, although some have a rather practitioner-based background. Seven of the ten described models are entirely free to access and for three of them some fees shall be paid for a granted access to assessment tools and extensive documentation or professional assistance in the application of the model. Although most of them have different termed business dimensions, similarities and correlations can be found. For example, Kärkkäinen's model proposes adding another dimension to the Batenburg model. Concerning the number of business dimensions, there is a vast variety of approaches to be found. Some models focus on only four to five dimensions, coping with the covered subject in a more general matter, while other models show up to 15 or 16 dimensions. In case of the Savino and Zhang models, they use the TIFO(S) framework for their coverage, which provides another layer of structure. The observed maturity levels range from four to six and, similar to the business dimensions, they have different labels. For more than half of the models testing is available and has been concluded in different industries. Concerning the CMMI, due to its popularity and widespread acceptance, there are two annual reports that cover the main status of their usage and the maturity of their clients.

Table 1 - General attributes dimension

General attributes dimension										
Attribute category	Model									
	Batenburg (1)	**CMMI** (2)	**CM3** (3)	**EDEN** (4)	**Kärkkäinen** (5)	**Kulkarni** (6)	**PLM1G** (7)	**Saaksvuori** (8)	**Savino** (9)	**Zhang** (10)
Name	PLM framework for the assessment and guidance of PLM implementations	Capability Maturity Model Integration, Version 1.3	Configuration Management Maturity Model	EDEN Maturity Model for BPM	Defining the Customer Dimension of PLM Maturity	Knowledge Management Capability Assessment Model	PLM Maturity Reference Model	Product lifecycle management	PLM Maturity Model	PLM Components Maturity Assessment
Acronym	-	CMMI-DEV, V1.3	CM³	EDEN	-	KCMA	-	-	-	PCMA
Primary source	[1]	[10]	[7]	[1]	[4]	[6]	[8]	[9]	[12]	[17]
Addressed topic	PLM	Process Improvement	Configuration Management	Process Management	PLM adoption	Knowledge Management	PLM	PDM/PLM	PLM implementation	PLM Components
Origin	Academic	Academic	Academic	(Academic) / Practitioner-based	Academic	Academic / Practitioner-based	Practitioner-based	Academic	Academic	Academic
Year of	2006	2010	2013	2009	2012	2004	2007	2004	2012	2013
Access	free	free (materials, books available) /charged (e.g. consultants)	free	charged	free	free	charged (access to materials, consultants)	free	free	free
Audience	both	both	management-oriented	management-oriented	both	both	management-oriented	both	technology-oriented	both
Business dimensions (BD)	1. Strategy & Policy 2. Management & Control 3. Organization & Processes 4. People & Culture 5. Information Technology	16 Key Process Areas including: 1. Configuration Management 2. Integrated Project Management 3. Measurement and Analysis 4. Project Planning 5. Risk Management 6.-16. […]	1. Strategy & Performance 2. Process 3. Information Technology 4. Organization & Value-stream 5. Knowledge & Support	170 single criteria within: 1. Goals 2. Strategy 3. Methods 4. Organization 5. Measurement 6. Competencies 7. Communication 8. Documentation 9. IT	1. Strategy & Policy 2. Management & Control 3. Organization & Processes 4. People & Culture 5. Information technology 6. Customer Orientation	Knowledge Capability Areas (KCA): 1. Expertise 2. Lessons learned 3. Knowledge documents 4. Data	1. Data 2. People 3. Processes 4. Technology 5. Knowledge	1. Process 2. Structures 3. IT systems 4. PLM strategy 5. People in PLM change management	15 PLM Components within the 4 TIFO Areas: 1. Technoware-IT 2. Infoware 3. Functionware 4. Orgaware	15 PLM Components within the 5 TIFOS Areas: 1. Technoware-IT 2. Infoware 3. Functionware 4. Orgaware 5. Sustainware
Number of (BD)	5	16	5	9	6	4	5	5	15	15
Maturity levels (ML)	I. Ad Hoc II. Departmental III. Organizational IV. Inter-organizational	I. Initial II. Managed III. Defined IV. Quantitatively Managed V. Optimizing	I. Initial II. Managed III. Standard IV. Optimizing	0. Chaotic I. Rudimentally II. Advanced III. Consistent IV. Controlled V. Sustainable	I. Chaotic II. Conscientious III. Managed IV. Advanced V. Integration	0. Difficult / Not possible I. Possible II. Encouraged III. Enable / Practiced IV. Managed V. Continuously Improved	I. Ad-hoc II. Managed III. Defined IV. Quantitatively managed V. Optimized	I. Unstructured II. Repeatable but intuitive III. Defined IV. Managed and measurable V. Optimal	I. Lowest II. Low III. Medium IV. High V. Top	I. Ad-hoc II. Managed III. Defined IV. Quantitatively managed V. Optimized
Number of ML	4	5	4	6	5	6	5	5	5	5
Testing of the MM	Yes	Yes*	Yes	Yes	Not available	Yes	No access	Not available	Yes	Yes
Number of questions	40	-*	53	No access	-	145	-	-	Not available	Not available
Number of respondents	23	-*	67	No access	-	~750	-	-	~250	Not available
Basic features of the participants' organizations	A: Medium size (15-1000 employees) B: Large size (Over 1000 employees) - Equipment and transport companies (A:3/B:5) - ICT solution providers (A:1/B:5) - Product software companies (A:6/B:1) - Financial service (A:1/B:1)	*As one of the very few maturity models the CMMI has been tested on many occasions in different industries and organizations. The latest testing results found in the 'Maturity Profile Reports' of September 2013 stated around 6,000 concluded appraisals.	Distribution: - 72% in private sector - 28% in public sector Industry sectors: - aerospace (33%) - transportation (12%) - military, defence, government (12%) - automotive (11%) - IT (11%) - others (21%)	-	-	One leading manufacturing company in semiconductor industry - 2 Business Units - All knowledge workers Strong focus on model validation within the organization: - Translation validity - Criterion-Related Validity	-	-	SME's of electromechanical sectors based in southern Italy	Italian prefabrication company (one of the most important companies in the precast and construction field in southern center of Italy)

The results of the *design attributes dimension* are listed in Table 2 below (unclear or unverified information in parentheses). All of the observed models present a minimum of "descriptive" purpose meaning that they can at least be used to assess the maturity of the organization or certain processes. Seven of them still provide certain prescriptive actions for improvement and only three provide options for benchmarking. Mostly all of them feature process, and more or less object and people maturity concepts, only few models can be considered to have covered the customer dimension. The composition spreads out very diverse throughout all attribute options, although the Likert-like questionnaires / hybrids and other concepts are used most of the time. Only two models are considered multi-dimensional, being able to be applied to almost any domain. Most models are in some way mutable, whether it is by adapting the form, function, or both. Many models feature at least a basic test, but only few models have concluded thorough testing, which might lead to consider them as being validated.

Design attributes dimension											
Attribute category	Attribute	Model									
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Main purpose	*Descriptive*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Prescriptive	✓	✓		✓	✓	✓	✓		✓	
	Comparative		✓		✓					✓	
Concept of maturity	*Process*	✓	✓	✓	✓	✓		✓	✓	✓	✓
	Object	✓	(✓)	✓		✓	✓	(✓)	✓	✓	✓
	People	✓	(✓)	✓		✓	✓	(✓)	✓	✓	✓
	Customer		(✓)	✓		✓		(✓)			
Composition	*Maturity grid*								✓		
	Likert-like quest./hybrid	✓		✓	✓	✓					
	Others		✓				✓	✓		✓	✓
Assessment approach	*Staged*		✓	✓	✓		✓	✓	✓	✓	✓
	Continuous	✓	✓		✓	✓					
Scope	*One-dimensional*	✓		✓		✓	✓	✓	✓	✓	✓
	Multi-dimensional		✓		✓						
Mutability	*Form*	✓	✓	✓	✓	✓		(✓)	✓	(✓)	
	Functioning	✓	✓	✓	✓	✓	(✓)	(✓)			
Reliability	*Verified*	✓	✓	✓	✓		✓	(✓)		✓	✓
	Validated		✓		✓		✓				

Table 2 - Design attributes dimension

The results of the *usage attributes dimension* are listed in Table 3 below (unclear or unverified information in parentheses). Most of the models use a self-assessment as the application method. Certified practitioners are usually only available with models that are used by institutions or consultant agencies and that come with a charge. The instrument for application divides up quite evenly between all possible attributes, although the charged models tend to rather strive towards using work groups than only document reviews or questionnaires. An often used supporting tool for the application is a software assessment tool, which has been provided by five of the ten observed models. Also, the charged models seem to provide more support in general. About half of the models exhibit guidelines for specific improvement activities based on the achieved maturity level. Almost all

of the models show regular implicit improvement activities. The adaption to the dynamically changing requirements is very relevant and important for future usage purposes. A downside of the charged models is the required training. Depending on the intensity and future plans of use the training can be more or less extended.

Usage attributes dimension										
Attribute category	Attribute	Model								
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Method of application	*Self-assessment*	✓	✓		✓	✓	✓	✓	✓	✓	✓
	Third-party assisted assessment		✓	✓							
	Assessment by certified practicioners		✓		✓			✓			
Instruments for application	*Document reviews*		✓		✓	✓			✓		
	Focus groups		✓		✓			✓			
	Questionnaire	✓	✓	✓	✓		✓			✓	✓
Support of application	*No supporting materials*					✓	✓		✓	✓	✓
	Textual description or handbook		✓		✓			✓			
	Software assessment tool	✓	✓	✓	✓			✓			
Guidelines for specific improvement activities	*Not provided*			✓		✓	✓		✓	✓	✓
	Guidelines provided	✓	✓		✓			(✓)			
Practicality of evidence	*Implicit improvement activities*	✓	✓	✓	✓	✓	✓	✓	✓		✓
	Explicit recommendations		✓		✓						
Required training	*None*	✓		✓		✓	✓		✓	✓	✓
	Basic		✓		✓			✓			
	Extended		✓								

Table 3 - Usage attributes dimension

5 Conclusion

As illustrated in Wendler's study [16], only a fraction of the research in the field of maturity models strives into the direction of validation. With this paper we tried to provide a more comprehensive maturity model comparison framework based on general categories extracted from literature. The few past categorization and comparison approaches have thoroughly been analyzed to develop a framework that covers all the important attributes. The comparison result is aiming to not only reduce the search time for specific models, allow easier communication, identify differences and similarities, and thus enhance retrievability, but also provide a baseline of attributes needed for a high-quality development of future models. Thus, this framework can serve as a benchmark for future PLM maturity model developments.

However, since the comparison approach only covers a qualitative evaluation, a weighting system regarding individual preferences could be implemented to add further detail to the analysis and to be able to rate the models more precisely with respect to their intentioned application and organization needs. A possible approach on adding quantitative value to the comparison might be to use plus and minus values instead of checkmarks, which could eventually add up to show a preference of certain models in specific categories. Additionally, because the PLM area is generally becoming more important to companies and organizations, further research on "which models might also be suitable for this domain" (e.g. due to their mutability) should be concluded. Since in this paper only models with easy

access and available documentation were covered, further research on models with limited access might provide an even more comprehensive overview.

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