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Systematic Literature Review of Software Process Capability/Maturity Models

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Abstract

Software process improvement and assessment guided by a maturity level or a process capability profile based on a capability/maturity model is now well established in practice as a successful means for improving software intensive organizations. Therefore, a wide range of software process capability/maturity models have been developed evolved and adapted over the past years. In this paper, we present the results of a systematic literature review on this type of models. Our results show that there exist a large variety of models with a trend to the specialization of those models for specific domains. We also identified that most of those models are concentrated around the CMM/CMMI framework and the standard ISO/IEC 15504 (SPICE).

1. Introduction

Software process improvement and assessment guided by a maturity level or a process capability profile based on a capability/maturity model is now well established in practice as a successful means for improving software intensive organizations. Many capability/maturity models have been developed. This article presents a systematic literature review on these models.

This article is organized in 6 sections. As a basis, we discuss relevant terminology in Section 2. Section 3 presents the motivations for this research and related work is discussed in Section 4. Section 5 presents the systematic literature review, detailing the extracted data and the analysis of the results. Section 6 presents the conclusions and outlines future work.

2. Terminology

This systematic literature review is on models of best practices for software processes, based on good engineering and process management principles, organized with the concept of process capability and/or maturity, suitable for assessing and/or improving processes. As there is not a standard name for this type of models, the term Software Process Capability/Maturity Model is used in this article. This term and its rationale are extension of the term Process Capability Model proposed by Salviano and Figueiredo [1].

Examples of this type of models are the CMMI-DEV model [2] or the exemplar ISO/IEC Process Assessment Model [3]. These models are used as an evaluative and comparative basis for process improvement and/or assessment assuming that higher process capability or organizational maturity is associated with better performance. An eSourcing Capability Model, as, for example, the eSCM-CL[1] model, when used for software outsourcing, is also a Software Process Capability/Maturity Model. A Process Reference Model, as, for example, the Competisoft[2] model, is a Software Process Capability/Maturity Model as well. There are other models of best practices organized with different concepts, which are not considered Software Process

[1] http://itsqc.cmu.edu/models/escm-cl/index.asp
[2] http://alarcos.inf-cr.uclm.es/Competisoft/

Capability/Maturity Models. The ISO 9001:2008 Quality management systems – Requirements [4], for example, is a model of best practices organized as a set of requirements without considering the concept of process capability. Therefore, ISO 9001 is not a Process Capability/Maturity Model.

Some of these models are defined as national or international standards. For example, the exemplar model ISO/IEC 15504-5 [3] is defined as an international standard, in contrast to the MOPROSOFT model that is defined as a Mexican national standard. Therefore the term *model* in used in this article to refer also to a model defined as a standard.

3. Motivation

In the last decade, a multitude of software process capability/maturity models has been developed and is evolving rapidly [5] [6] that cover many different disciplines, including not only engineering aspects, but also medical, project management, quality assurance topics, etc. Among these are several different groups of Software Process Capability/Maturity Models developed by the international community, such as, the ISO/IEC community and SEI community. ISO/IEC developed the current ISO/IEC 15504 international standard for process assessment, also known as SPICE (Software Process Improvement and Capability dEtermination) [3] and ISO/IEC 12207 for processes of the software life cycle [7]. ISO/IEC 15504 (SPICE) works as a framework for process capability/maturity models, as, for examples, the ISO/IEC 15504-5 model for software engineering. The SEI community developed the CMMI framework [2], in which the CMMI-DEV model is an example of a model. In each of these cases, these models indicate a quest to provide best practice collections that represents an accumulated knowledge base for a specific area of interest. Today, models that identify software process best practices are still progressing in terms of the breadth and depth of their coverage, viewpoint and the maturity of the models themselves [8].

And although those software process capability/maturity models are broadly applied in practice [9] several issues can be observed. Due to the variety of models and the significant and unique value-added increment each of the models provides, the diversity of emphases and perspectives could be counter-productive [10], especially when due to market or customer requirements an organization has to adhere to multiple models or standards. In this context, initiatives focusing on the integration and harmonization of existing models into one single model, such as, e.g. the Enterprise SPICE initiative[3] are underway.

On the other hand, since the set of potential software projects, products and environments is vast, a set of key practices has to be generic in order to accommodate various business and organizational uses and, thus, typically, has to be refined and adapted within a specific context. This is not an easy exercise, as tailoring rules do not always exist, or are not consistent or sufficiently detailed [8]. Therefore, a trend is the development of domain specific adaptations of capability/maturity models, such as, S4S [11], AutomotiveSPICE [12], etc. in order to facilitate the application of such models in specific contexts [13]. Yet, on the other side, we can also observe a trend to expand existing models, such as, the system expansion of the ISO/IEC 15504 [3] or the addition of a maturity component.

In order to elicit the state of the art of this variety of software process capability/maturity models today, we present the results of a systematic literature review performed to identify existing models as well as to identify trends regarding the development of those models.

4. Related Work

Several other authors have already reviewed the state of the art with respect to software engineering models. Among them the well known presentation of the "Frameworks Quagmire" first presented in [5] and actualized in [6], which investigates software and system process standards, recommended practices, guidelines, maturity models, and other frameworks. Yet, although the work presents an ample description on generic models as well as integration efforts, it does not cover domain-specific models.

With a primary focus on standards, Moore [14] presents in 1999 a survey of more than 315 standards, guides, handbooks, and other prescriptive documents maintained by 46 different organizations.

In [8], the authors evaluate current process standards under the perspective of seven criteria, covering professional and organization viewpoints.

Other related work, such as [10] focuses more on why those models are different, and proposes strategies for integration, rather than providing a systematic overview on the existing models.

In another work, a "Method Framework for Engineering Process Capability Models" has been developed as an element of a methodology on "Process Capability Profile to drive Process Improvement"

[3] http://www.enterprisespice.com

(PRO2PI-MFMOD) [15]. This Method Framework is based on a previous systematic review of the authors of five successful experiences in which different processes were used to develop different process capability models.

In this context, the intention of our work is to provide an overview on the current available software process capability/maturity models, the domains for which they have been developed and the source models from which they developed.

5. Systematic Literature Review

In order to review the current available software process capability/maturity models, we performed a systematic literature review following the procedures described by [16]. The research question, we focused on is: Which software-related process capability/maturity models are developed/expanded/adapted or harmonized?

We examined all published English-language articles on software process capability/maturity models available on the Web (via digital libraries and databases), published between January 1990 and April 2009. We limited the articles to peer reviewed work, including only papers published in journals or conference proceedings. We included any kind of article on software-related process capability/maturity model or standard. On the other hand, we excluded any publication, which did not explicitly describe a software process capability/maturity model or standard, such as, mappings between models, model analyses on any kind, models with a different focus than the software process, etc.

We used IEEEXplore, the ACM Digital Library, Compendex EI, the ISI (Institute for Scientific Information) Web of Science, ScienceDirect and WILEY Interscience database.

We used the following search strings:

In IEEE XPLORE*: (standard <or> model <or> framework) <and> ("software process" <or> "software processes" <or> "software engineering") <and> (assessment <or> improvement <or> capability <or> maturity) <and> (CMMI <or> 15504 <or> 12207 <or> "MPS.BR" <or> CMM <or> SPICE <or> iso <or> standards) published since 1990*

In ACM Digital Library: *((Abstract:standard) or (Abstract:model) or (Abstract:framework)) and ((Abstract:"software process") or (Abstract:"software processes") or (Abstract:"software engineering")) and ((Abstract:assessment) or (Abstract:improvement) or (Abstract:capability) or (Title: maturity)) and (CMMI or 15504 or 12207 or "MPS.BR" or CMM or SPICE or iso or standards) published since 1990*

In Compendex/Engineering village: *((standard OR standards OR model or framework) AND ("software process" OR "software processes" OR "software engineering") AND (assessment OR improvement OR capability OR maturity) AND (CMMI OR 15504 OR 12207 OR "MPS.BR" OR CMM OR SPICE OR ISO OR standards)) wn KY {english} WN LA*

In ScienceDirect: *title-abstr-key((standard OR standards OR model or framework) AND ("software process" OR "software processes" OR "software engineering") AND (assessment OR improvement OR capability OR maturity) AND (CMMI OR 15504 OR 12207 OR "MPS.BR" OR CMM OR SPICE OR ISO OR standards))*

In WILEY Interscience: *((title: standard*) OR (abstract: standard*) OR (title: model) OR (abstract: model) OR (title: framework) OR (abstract: framework)) AND ((abstract: "software process") OR (abstract: "software processes") OR (abstract: "software engineering")) AND ((abstract: assessment) OR (abstract: improvement) OR (abstract: capability) OR (title: maturity)) AND (CMMI OR 15504 OR 12207 OR "MPS.BR" OR CMM OR SPICE OR iso OR standards)*

The initial search run in April/May 2009 returned 1477 papers in total. In a first step, we quickly reviewed titles and abstracts. Irrelevant and duplicate papers were removed. This left us with 61 publications, which were included in the review (Table 1). In order to organize the identified models, we classified them by the domain for which they are developed and identified the source models on which they are based.

5.1 Data extraction

In the systematic literature review described in the previous section, we identified 52 Software Process Capability/Maturity Models. These models are listed in Table 1. Each model is characterized by its domain, a sequential identification (from m01 to m52), its name and/or initials, a reference for the paper where it is described, and a list of the source models on which it is based. Some of the models were described in more than one paper. In this cases (m08, m21, m24, m30, m31, m38, m41, m44) we list both references.

Table 1. Software Process Capability/Maturity Models

Domain	Id	Capability/Maturity Model	Ref	Based on
Automotive systems	m01	AutomotiveSPICE Process Assessment Model	[17]	ISO/IEC 15504 (SPICE)
Business Process	m02	Business Process Maturity Model (BPMM)	[18]	CMM/CMMI, ISO/IEC 12207, and ISO/IEC 15288
Component Based Software Engineering	m03	Integrated Component Maturity Model	[19]	CMM
	m04	OOSPICE Process Assessment Model for Software Component-based Development	[20]	ISO/IEC 15504
Data Warehouse Systems	m05	Data Warehousing Process Maturity Model	[21]	CMM

Documentation	m06	Software system documentation process maturity model	[22]	CMM
E-Government	m07	EGMM - E-government maturity model	[23]	CMM, PMMM
E-Learning	m08	e-learning maturity model	[24] [25]	CMM, ISO/IEC 15504 (SPICE)
Software and System Engineering, including development, services and acquisition.	m09	ISO/IEC 15504-5 Process Assessment Model	[26]	ISO 9000, ISO/IEC 12207, ISO/IEC 15288
Information Systems	m10	Extending information system integrability index with CMM model	[27]	CMM
Software and System Engineering, including development, services and acquisition.	m11	iCMM – Integrated Capability maturity Model	[28]	CMM, ISO 9000, EIA/IS 731 Systems Engineering Capability, Malcolm Baldrige National Quality Award, CMMI, ISO/IEC TR 15504, ISO/IEC 12207, ISO/IEC CD 15288
Knowledge Management	m12	Knowledge Management Maturity Model	[29]	CMM
Maintenance	m13	Software Maintenance Maturity Model	[30]	ISO/IEC 14764 and ISO/IEC 12207
Measurement	m14	MIS-PyME software measurement maturity model-supporting the definition of software measurement programs	[31]	GQ(I)M
Medical Systems	m15	CMCM - Configuration Management Capability Model	[32]	CMMI and ANSI/AAMI SW68
Software Quality Assurance	m16	Framework for assessing the use of third-party software quality assurance standards	[33]	ISO 9000-3 and CMM
Network	m17	Concepts for a network maturity model	[34]	CMM, ISO/IEC 15504 (SPICE)
Open Source Software	m18	Process Maturity Model for Open Source Software	[35]	CMMI-DEV, ISO/IEC 15504 (SPICE)
Performance Engineering	m19	PEMM - Performance Engineering Maturity Model	[36]	CMM
Product Line Management	m20	Evolving Standard Process Reference Models for Product Line Development	[37]	ISO/IEC 12207
Product Quality	m21	Product Process Dependencies	[38] [39]	ISO 15504, ISO 9126, Bootstrap
Railway/Safety	m22	CMMI RAMS extension based on CENELEC railway standard	[40]	CMMI SE-SW, CENELEC 50126, 50128, 50129
Requirements	m23	Formal Specifications Strategies Maturity Model	[41]	CMM
	m24	Requirements CMM	[42] [43]	SW CMM
Security Engineering/ Service Oriented	m25	A CC-based Security Engineering Process Evaluation Model	[44]	ISO/IEC 15408, SSE-CMM
	m26	Development system security process of ISO/IEC TR 15504 and security considerations for software process improvement	[45]	ISO/IEC 15504, ISO/IEC 15408
	m27	Lessons learned with the systems security engineering capability maturity model	[46]	CMM
	m28	Representation of knowledge in Information Technology Service Capability Maturity Model (IT Service CMM)	[47]	SW CMM
	m29	Research on third party logistics service capability maturity model	[48]	CMM
SME (Small and Medium Enterprises)	m30	MARES Process Assessment Model	[49] [50]	ISO/IEC 15504
	m31	SATASPIN Software Process Improvement Network in the Satakunta Region	[51] [49]	ISO/IEC TR 15504
	m32	Developing International Standards for Very Small Enterprises	[52]	Moprosoft (ISO/IEC 12207, ISO/IEC 15504, ISO9001, CMMI, PMBOK)
	m33	Software processes in developing countries	[53]	ISO/IEC 12207, ISO/IEC 15504
	m34	Software Quality Improvement Model for Small Organizations	[54]	ISO 9000, CMM, ISO/IEC 15504 (SPICE), SPIRE and others
	m35	Dynamic CMM for Small Organizations	[55]	CMM
	m36	Competisoft Process Model for Software Process Improvement:	[56]	SW CMM, ISO 9000, ISO/IEC 15504, PMBOK, and others
	m37	Initiating Software Process Improvement in Small Enterprises: Experiment with MicroEvaluation Framework	[57]	SW-CMM, ISO/IEC 15504 (SPICE)
	m38	MPS.BR - Brazilian software process reference model and assessment method	[58] [59]	CMMI and ISO/IEC 15504 (SPICE)
Software and System Engineering, including development, services and acquisition.	m39	CMM (or SW-CMM) / CMMI-DEV	[60]	SW-CMM, The Systems Engineering Capability Model (SECM) , The Integrated Product Development Capability Maturity Model (IPD-CMM)
Software Engineering	m40	BOOTSTRAP	[61]	CMM, IS0 9000, DoD-STD 2167ª, ESA Software Engineering Standard PSS-05-0
Space	m41	SPICE for SPACE	[11] [62]	ISO/IEC TR 15504, ISSO/IEC 12207, ECSS-E40: Space Software Engineering ECSS-Q-80: Space Software Product Assurance
SPI Implementation	m42	SPI implementation maturity model	[63]	CMMI
Telecom	m43	Trillium	[64]	CMM, ISO 9000, Bellcore TR-NWT-000179, Bellcore TA-NWT-001315 , Malcolm Baldrige National Quality Award, IEEE Software Engineering Standards Collection, IEC Standard Collection
Testing Assurance	m44	Test Maturity Model (TMM)	[65] [66]	CMM, Gelperin and Hetzel's Evolutionary Testing Model, Beizer's Progressive Phases of a Testers' Mental Model

	m45	SAMM - Modern software assurance and a five-level model of software assurance maturity	[67]	CMM
	m46	MB-V2M2 - Metrics Based Verification and Validation Maturity Model	[68]	TMM and CMM
	m47	TIM- Test Improvement Model	[69]	CMM, TMM
	m48	Criticality-Based V&V Capability Model(CB-VVCM)	[70]	IEEE Std.1012, IEEE 1012 and CMMI
	m49	A framework for the V&V capability assessment focused on the safety-criticality	[70]	IEEE Std.1012, IEEE Std.7-4.3.2, 1228 and RG 1.168, CMMI, ISO 9001
XP (eXtreme Programming)	m50	XPI - XP Based Process Improvement Framework	[71]	XP
	m51	extreme Programming Maturity Model (XPMM)	[72]	CMMI, PSP
	m52	AHAA-reference model for Agile, hybrid assessment method for automotive, safety critical smes	[73]	CMMI, AutomotiveSPICE

In Table 1, some models are represented by more than one name/initials. For example, the CMM model is also known as SW-CMM. The ISO/IEC 15504-5 is also known as ISO/IEC 15504, and SPICE. Previous versions of ISO/IEC 15504-5 are known as ISO/IEC TR 15504-5. The CMMI-DEV model is also known as CMMI and its previous version is known as CMMI–SE/SW. In spite of the name or initial used, in the original article, each set of synonymous names or initials refer to basically the same model.

5.2 Analysis of the results

We identified 29 domains for which models are being developed. Three models focus on the most generic domain of Software and System Engineering, including development, services and acquisition (m09, m11 and m39).

Here we can observe that besides the evolution of new versions of existing models (such as, the evolution of the CMM/CMMI framework) there exists a clear trend to the specialization of models to specific domains. Currently, there is a large variety of specific models for the most diverse domains, including, for example, knowledge management, automotive systems, XP, e-learning, etc. Domains, which seem to have received considerable attention and for which several different domain-specific models have been developed, include, particularly, the Security engineering service oriented domain, the SME (Small and Medium Enterprise) domain and the Testing assurance domain. We identified nine models directed to SMEs (models m30 to m38). Six models are related to the testing/assurance domain (models m44 to m49). Five models (m25 to m29) are focusing on the Security engineering service oriented domain.

Most of these models (38 of 52, 73%) have been developed using as a reference one (21 of 52, 40%) or two (17 of 52, 33%) source models (Figure 1). Only a few models (14 of 52, 27%) have been based on three (4 of 52, 8%) or more (10 of 52, 19%) source models.

In total, we identified a set of 45 models used as sources for the development of the 52 models identified in Table 1. Analyzing, the models used as a basis, we can observe (Figure 2) that the majority is based on the CMM model (31 of 52, 58%), followed by the usage of the ISO/IEC 15504 Standard and its exemplar model as a foundation (19 of 52, 36%) and by the usage of CMMI framework and its most popular model (CMMI-DEV) (11 of 52, 21%). Several models also are based on ISO/IEC 12207 (8 of 52, 15%) and ISO 9000 (9 of 52, 17 %). The remaining 40 source models are used only in one, two or three models.

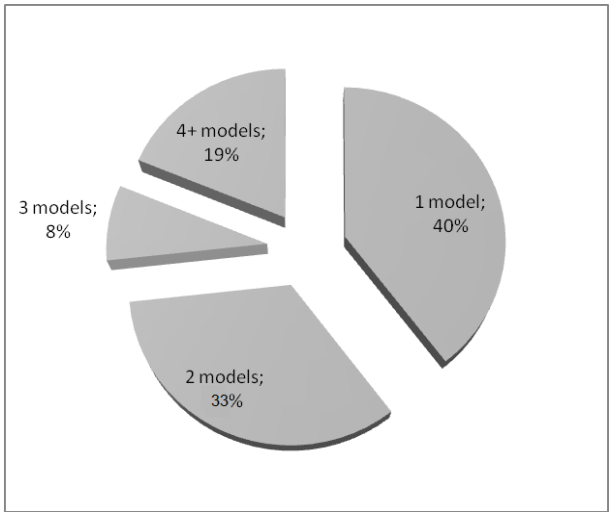

Figure 1. Percentage of number of source models used

We can also observe that almost all of these models are either being developed based on the CMMI and/or ISO/IEC 15504 (SPICE) (50 out of the 52 models (96%)). Only two models (m14 and m50) are not based on CMM, CMMI and/or ISO/IEC 15504 (SPICE) as reference source.

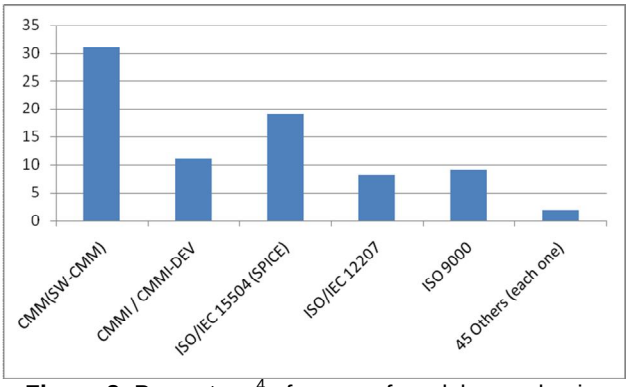

Figure 2. Percentage[4] of usage of models as a basis.

We further observed that these models are developed in the most diverse ways. Some models and principally the ones defined as standards are developed by following a high-level process for the development of standards involving the community in different stages and with varying degrees of participation [18] [19]. Yet, other models seem to be developed by a small number of researchers without a significant involvement of the community. As a consequence, these models in general also seem to have a lower adoption rate and/or are rapidly discontinued.

This, in general, also demonstrates that, although, there exist a large effort on adapting and customizing those models, there does not exist a detailed methodological support, with exception of the ISO/IEEE guidelines for the development of standards and the CMMI stewardship in order to guide such a specialization in a systematic way.

6. Conclusion

In this paper, we present results of an ongoing research on the current state of the art of software process capability/maturity models based on the results of a systematic literature review. The main results presented are a term and definition of models, a systematic identification of these models in literature, and an initial analysis.

Our results show that there exist a large variety of models with a trend to the specialization of those models for specific domains. We also identified that most of those models are concentrated around the CMM/CMMI framework and the standard ISO/IEC 15504, indicating these two frameworks as the most relevant sources for the development of such models.

Currently, we are completing the results of the literature review by running a survey among the model's authors. The objective of the survey is to elicit additional information, such as, the adoption rate of the models as well as mainly to understand how the capability/maturity models have been developed. Based on the results of the literature review and the survey, we intend to propose methodological support, particularly, for the domain-specific adaptation of such models.

[4] As could be seen on Table 1 and Figure 1, some reference models are based on more than one base model, so the sum of the percentages is more than 100%.

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