Proposing an ISO/IEC 15504-2 Compliant Method for Process Capability/Maturity Models Customization

Jean Carlo Rossa Hauck[1,2], Christiane Gresse von Wangenheim[3],
Fergal Mc Caffery[2], and Luigi Buglione[4]

[1] Graduate Program in Knowledge Engineering and Management - Federal University of Santa Catarina – Brazil
[2] Regulated Software Research Group & Lero - Dundalk Institute of Technology – Ireland
[3] Graduate Program in Computer Science (PPGCC) - Federal University of Santa Catarina – Brazil
[4] ETS/Engineering.IT - Rome - Italy
{jeanhauck,gresse}@gmail.com,
fergal.mccaffery@dkit.ie, luigi.buglione@eng.it

Abstract. The customization of software process capability/maturity models (SPCMMs) to specific domains/sectors or development methodologies represents one of the most discussed and applied trends in ICT organizations. Nonetheless, little research appears to have been performed on how theoretically sound and widely accepted SPCMMs should be developed to high quality. The aim of this paper is therefore to elicit the state-of-the-art regarding the processes adopted to develop such models and to propose a systematic approach to support the customization of SPCMMs. Such an approach is developed based on ISO/IEEE standard development processes integrating Knowledge Engineering techniques and experiences about how such models are currently developed in practice. Initial feedback from an expert panel indicates the usefulness and adequacy of the proposed method.

Keywords: Maturity Models, Standards, Knowledge Engineering, SPCMM, ISO/IEC 15504.

1 Introduction

Various Software Process Capability/Maturity Models (SPCMMs [1]) have been developed by the software engineering community, such as, CMMI-DEV [2] and ISO/IEC 15504 [3], and their use for software process improvement and assessment is well established in practice. These generic models have been customized to specific contexts [4] because diverse software development domains have specific process quality needs that should be addressed. Regulated software development domains have specific standards, such as in health care, which must be covered by the software development process in order to provide the necessary alignment to these domain-specific standards. Consequently, there is a current trend to the development of customizations of those generic process models for specific domains, such as SPICE4SPACE [5], OOSPICE [6] Automotive SPICE [7], etc. Despite this trend, most of the SPCMMs customization initiatives do not adopt a systematic approach for

the customization of those generic standards and models [8]. Furthermore, literature detailing how SPCMMs are developed / evolved / adapted is also extremely rare [9]. Standardization organizations, like ISO or IEEE, define high-level generic processes for developing and publishing standards. However, they do not describe how to customize existing models or provide detailed technical support for the specific development of SPCMMs. The contribution of this paper is the proposal of a method for customization of SPCMMs, based on an analysis of how existing customizations have been performed, integrating standard development procedures from a Knowledge Engineering viewpoint and aligned to the requirements of ISO/IEC 15504-2 for Process Reference Models (PRM) and Process Assessment Models (PAM).

In section 2, the requirements for SPCMMs are presented. Section 3 presents methods for SPCMMs development. In section 4, the method is proposed, and section 5 presents the first results from its pilot application. Conclusions are presented in section 6.

2   Requirements for SPCMMs

Different sets of requirements have been proposed for models expressing the capacity and/or maturity of processes. Becker et al. [10] propose seven criteria including: (i) comparison with existing models, (ii) iterative development, (iii) model evaluation, (iv) multi-methodological procedure, (v) identification of the relevance of problem, (vi) problem definition, (vii) published results and (viii) scientific documentation; based on the guidelines for design science. According to Matook & Indulska [9], reference models for software process quality must meet the following requirements: generality, flexibility, completeness, usability and comprehensibility.

Regarding their structure, generally speaking, software process capability maturity models (SPCMMs), have different characteristics. Lahrmann & Marx [11] propose a basic rationale of the structural characteristics of this type of model, as shown in Table 1.

Table 1. SPCMMs characteristics [11]

Criteria	Characteristics		
Dimensions	One-dimensional	Multidimensional	Hierarchic
Representation	Continuous	Staged	
Audience	Unique	Multiple	
Assessment approach	Qualitative	Quantitative	

The requirement that characterizes the structure of software process standards and reference models (to enable classification as SPCMMs) is the fact that they have at least two dimensions: the process and dimension of capability/maturity dimension.

In a more specific way than these generic requirements, the ISO/IEC 15504-2 standard [3] establishes specific requirements for the development dimensions of the process (PRM – Process Reference Model) and capacity (PAM – Process Assessment Model) of SPCMMs, which can be summarized as follows:

PRM
- **R1** - Declaration of the specific domain and community of interest, including aspects of consensus achievement;
- **R2** - Description of processes including: unique title, purpose and outcomes;
- **R3** - Presentation of the existent relationships between processes;

PAM
- **R4** - Statement of scope and coverage of the model;
- **R5** - Indication of the capability levels selected from a measurement framework for the processes, starting at level 1;
- **R6** - Mapping for the selected processes of the chosen PRM(s) ;
- **R7** - Details of performance indicators of the processes, mapped to the purposes and outcomes of selected the processes of PRM(s);
- **R8** - Detailed process attributes of measurement framework;
- **R9** - Objective evidence that the requirements are fulfilled.

The next section attempts to identify approaches that can possibly meet the existing proposed requirements for a SPCMM.

3   Existing Methods for SPCMMs Customization

This section presents three perspectives in an attempt to establish an overview of the development and customization of SPCMMs: proposals for approaches that support this type of development, process of standards development and main steps and techniques used in practice.

3.1   Existing Methods for the Development of Capability/Maturity Models

Although diverse software process capability/maturity model customizations have already taken place [8], research on how to perform such customizations in a systematic way is sparse. One of the few works in such direction was proposed by de Bruin et al. [14], introducing a six-step sequence for the development of Maturity Assessment Models. Although their work considers specific domain needs, it does not address in detail the customization of domain-specific best practices from generic models.

Mettler [15] performs a deeper analysis on the fundamentals of process maturity models, putting the main phases described in [14] under a design science research perspective. In this context, the phases are compared to a model user perspective of the maturity models, indicating a need for more formal methods and studies. Maier, Moultie & Clarkson [16] define a guide for development of Maturity Grids that consists of tools to assess the required abilities of an organization to deliver a product or a service. The purpose of the guide covers a wider range of models, not focusing on SPCMMs.

Salviano et al. proposed the generic framework PRO2PI [17] for the development of process capability/maturity models, based on the authors' previous experiences of developing diverse models with a 7-step process. However, no details are provided in relation to the research activities and techniques that would be required to provide support for the customization of SPCMMs. Matook and Indulska [9] proposed a QFD-based approach for reference modeling incorporating the voice-of-the-reference-model users, presenting a measure for the quality of such models. Becker et al. [10]

also proposed a general process for the development of Maturity Models that aim to cover a set of defined requirements. However, the work did not address the question of the evolution of the model after its publication.

As it can be seen, from the few existing approaches for developing models of maturity and/or process capability, none of them is specifically targeted to meeting the requirements of the ISO/IEC 15504-2 standard. Furthermore, they are not specifically targeted to SPCMMs customization.

3.2   Processes for the Development of Standards

Some SPCMMs have been developed in the form of standards, supported by some regulatory body or group of international standards [12]. Standards are, in general, developed according some principles [13]: (i) consensus: in the development of a standard wide range of interests are taken into account: manufacturers, vendors, users, governments, research organizations, etc; (ii) industry wide: standards must provide global solutions for industries and customers worldwide; (iii) voluntary: standardization is an activity based on voluntary involvement of all interests in the community. For instance, ISO standards are developed in a three-phase process [13]:

- **Phase 1:** in general, the perceived need for a new standard comes from an industry sector, which communicates this need for a national member body. This need is then evaluated and, once approved, the scope of the new standard is set, involving working groups composed of experts from different countries.
- **Phase 2:** this is the phase of consensus-building. After defining the scope, it begins the negotiation between group members to detail the contents of the standard.
- **Phase 3:** final approval and generation of draft standard is given at this phase, where it needs to receive the approval of at least two-thirds of all members of the group and 75% of those voting. After this process of ballot, the first version of the standard is published.

Since being first proposed for publication a standard goes through a series of 9 stages and 7 related sub-stages of development[1], from the *preliminary* till the *withdrawal* stage.

3.3   Development of SPCMMs in Practice

In order to complete the elicitation of the state-of-the-art in this context through the analysis of how SPCMMs are developed, a systematic literature review (SLR) was performed [12]. This review was performed to systematically investigate and synthesize the existing literature relating to the subject of software process capability/maturity models (SPCMMs), focusing on this research question: *How are software process capability/maturity models created?* Details on the SLR can be found in the Web Appendix of [12].

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[1] www.iso.org/iso/standards_development/processes_and_procedures/
   stages_description/stages_table.htm

As a result of the SLR, 52 software process capability/maturity models were identified. Besides the evolution of new versions of existing models (such as, the evolution of the CMM/CMMI framework), there exists a clear trend toward the specialization of models to specific domains. Currently, a large variety of specific models exist for diverse domains, including, for example, small and medium enterprises, security engineering, knowledge management, automotive systems, XP (eXtreme Programming), etc[2].

Furthermore, it was observed that these models are developed using diverse approaches. Some models, typically the ones published as standards, have been developed by following a high-level process defined by the standardization organization. These processes involve the standards community in different stages and with varying degrees of participation [13]. However, in general, it was surprising to find very little information on how SPCMMs are currently developed. Only 21% of the papers found in the SLR [12] presented detailed information on the model development, 27% contained superficial model development information and 52% did not provide any substantial information on this aspect. The activities and techniques discovered in the detailed papers of the SLR were used within the method presented in section 4.

3.4 Discussion

The SLR demonstrated that a large variety of software process capability/maturity models have been developed and customized. However, in general there appears to be a lack of methodological support for the development and customization of such models. Therefore, in order to assist with the development and customization of models representing collections of best practices within a specific domain the processes used to develop and customize these models should be better understood and clearly presented. Access to standard processes for the development of such models could greatly assist the systematic development of such models and enable such models to be validated.

4 A Proposal for a Method for the Customization of SPCMMs

In order to promote the alignment of the customization of SPCMMs to the ISO/IEC 15504-2 requirements and to increase their quality, as well as their adoption rate in practice, a KE-based approach presented in this section was developed. The approach is based on an analysis of four elements: (i) standard development procedures; (ii) existing methods for the development of maturity models/grids; (iii) the way such customizations are currently performed; and (iv) KE techniques. From a KE viewpoint, the customization of such models relates to knowledge acquisition, collecting best practices of a specific domain by customizing generic SPCMMs to domain-specific models. A generic life cycle for KE includes [30]: (i) knowledge identification; (ii) knowledge specification and (iii) knowledge refinement. Currently, there exist several methodologies, frameworks and approaches that provide detailed support for the KE development life cycles, such as e.g., CommonKADS [31]. Furthermore, the usage and evolution of knowledge models is typically not covered

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[2] Another list – regularly updated is available at this webpage:
  www.semq.eu/leng/proimpsw.htm#quinto

by SPCMMs developed to date [12]. In addition, KE techniques have so far, not yet been applied for the customization of generic SPCMMs knowledge to specific domains. The proposed method is structured in five phases:

- **Phase 1 - Knowledge Identification:** The main objective of phase 1 is to achieve familiarization with the target domain and a characterization of the context for which the SPCMM will be customized;
- **Phase 2 - Knowledge Specification**: During this central phase, a first version of the customized model is developed;
- **Phase 3 - Knowledge Refinement**: Within this phase, the draft model is validated, balloted and refined to develop a model approved by a majority of respective community;
- **Phase 4 - Knowledge Usage**: After its publication, the model is put into use and results of its usage are collected and analyzed;
- **Phase 5 - Knowledge Evolution**: It is necessary to provide methodological support for the continuous evolution of the model once the model has been implemented in the target domain.

Table 2. Techniques used in each method phase

Method Phase	Basic Technique(s)
1. Knowledge Identification	Ontology Development [32] [33] [34] Glossary Development [35] [36] Literature Review [37] [38] [39] Systematic Literature Review [40] Goal Question Metric [41] [42] Expert Selecting [43] [44] [45] Delphi [43] [44] [45] Focus Groups [46] [47]
2. Knowledge Specification	Delphi [43] [44] [45] Perspective-Based Reading [59] [60] [61] Checklist-based Reading [62][63] Semantic Mapping [20] [21] [22] [23] [24] Domain quality requirements elicitation [53] [54] [55] Focus groups [46] [47] Structured Interview [31] Nominal group [56] [57] Software Process Quality Function Deployment [54] [53] [58] Process Selection [34]
3. Knowledge Refinement	Expert Selecting [43] [44] [45] Delphi [43] [44] [45] Guidelines of Modeling [35] [36] Behavior Engineering [64] [65] [66] Interrater Agreement [67] Checklist-based Reading [62] [63]
4. Knowledge Usage	Goal Question Metric [41] [42] Practical Software and Systems Measurement [68] [69] [70]
5. Knowledge Evolution	Model change request management [71] [14] [72]

Each phase is composed by a set of activities that are not necessarily sequentially executed using different techniques identified as relevant both from literature and from real developing SPCMMs experiences. The activities of the various phases of the method are aligned standard 15504-2 [3], providing coverage to the requirements for PRM and PAM (see Annex 1). Table 2 shows the stages and techniques used in the method, including key references for each technique.

A detailed technical report describing the proposed method is available in [73].

5   First Results and Discussion

The proposed method for SPCMM customization has been developed in parallel with the customization of a SPCMM for the Software as a Service (SaaS) domain [74] and Medi SPICE [75]. So it has been applied as an Exploratory Case Study. Exploratory Case Study is a short case study, undertaken as a first step before a larger investigation. Its function is to develop the evaluation questions, measures, design and analytical strategy for a possible larger study. It is particularly useful when there is some considerable uncertainty about processes, goals and results are achieved due to the embryonic state of research [76]. Thus, for this evaluation, an exploratory case study was defined as the study design.

5.1   A Model for Software as a Service (SaaS) Domain

SaaS is a software solution offered as a service and is developed using SOA. As the SaaS scenario requires specific quality needs, such as, security, availability and service continuation, due to its characteristics of distributed software products as services, a customization of SPCMMs has been done. The SaaS SPCMM [74] has been developed by a group of researchers at the UFSC – Federal University of Santa Catarin (Brazil), involving experts from both the SaaS and SPI domains. The model was developed through adopting phases 1 to 3 of this method. To date, phases 4 and 5 have still not been performed.

During the development, the SaaS domain was characterized and the specialists were identified. Generic SPCMMs were also analyzed and identified as a basis for the customized model. SaaS experts were interviewed in order to analyze quality and performance needs. The results were validated in a second step through a survey. Then, SPI experts identified relevant processes and basic practices with respect to the identified quality and performance needs by mapping them. The result was a draft version of the process model.

5.2   Medi SPICE

In this second exploratory case study the method was applied during the development of the Medi SPICE [3] Process Reference Model (PRM). Medi SPICE is an international project involving the Regulated Software Research Group in Dundalk Institute of Technology, the SPICE User Group (developers of ISO/IEC 15504 and related software process domain models), representatives from international medical

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[3] http://medispice.ning.com

device industry and representatives from the international standards community with the aim to develop a SPCMM containing software engineering best practices for the development and maintenance of medical device software [77].

Software development for medical devices has several characteristics that differentiate it from software development in other areas, especially as in order to market a medical device it is first essential to gain regulatory approval for the device within the particular region in which the device will be marketed. Due to these factors the software development activity in this area is heavily regulated by various bodies, through standards such as: AAMI / IEC 62304, FDA and European guidelines, ISO 14971, IEC 60601-1-4, ISO 13485, etc. Therefore, due to both the growth of software within the medical device industry and the revised definition of a medical device within the Medical device directive [78] there is now real need for Medi SPICE to assist software development organizations to put regulatory compliant software processes in place within the medical device industry.

The method was applied in the development of the Medi SPICE PRM during the period of January to December 2010. During this period phases 1 to 3 were also performed.

5.3 Observed Results

These experiences allowed us to identify strengths and weaknesses of initial versions of the proposed method in practice. One of its strengths is the involvement of specialists, although we also identified that in order to stimulate a wide adoption of the model, a much stronger involvement of the community is also required. Other strength is the methodological support which typically, for standard developments, is not available. We also observed several improvement opportunities:

- Support for a systematic mapping and harmonization of existing models;
- Better methodological support for consensus building among community representatives throughout the models development and not just elicitation of their knowledge;
- More systematic and formal support for the validation of the models.
- Integration of data-based input to the models if available in the specific domain in order to complete the expert's knowledge.

In addition, we are currently performing a systematic validation of the method through an expert panel. The main objective of this validation is to evaluate the method's ability to produce valid models (presenting generality, flexibility, completeness, usability and comprehensibility) and models aligned to the requirements of ISO/IEC 15504-2, from the point of view of specialists in maturity models in the context of an Expert Panel.

Experts discovered in the SLR [12] were invited to evaluate the method. To date, we have obtained responses from 12 SPI experts that have participated in the development of 17 different SPCMMs, with 55% having more than 10 years of experience in SPI.

A first preliminary analysis of the responses indicates that the method, in the opinion of 72% of the experts, has the potential ability to produce valid models

(presenting generality, flexibility, completeness, usability and comprehensibility). We also observed that 82% of the respondents felt that the method provides enough support for developing SPCMMs and adequately represents what is necessary to customize a SPCMM. All respondents felt that usage of the method could produce models aligned to the requirements of the ISO/IEC 15504-2 (for PRM and PAM).

6 Conclusions

In this paper, we outlined an approach for SPCMM customization by integrating a Knowledge Engineering (KE) perspective, customization experiences from literature and standard development processes. A first application of the proposed approach for the customization of a SaaS SPCMM provided a first indication that the approach can be useful for the customization of such models as well as enabling the identification strengths and weaknesses. Based on the feedback, we are currently evolving and refining the proposed approach as well as continuing its application in parallel for the customization of SPCMMs, such as, for medical devices as well as digital convergence.

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Annex 1: Mapping to ISO/IEC 15504-2 Error! Reference source not found. requirements of PRM and PAM to the method

Code	Requirement	A1.1	A1.2	A1.3	A1.4	A2.1	A2.2	A2.3	A2.4
Process Reference Model									
6.2.3.1-a	A Process Reference Model shall contain a declaration of the domain of the Process Reference Model	X							
6.2.3.1-b	a description, meeting the requirements of 6.2.4 of this International Standard, of the processes within the scope of the Process Reference Model			X				X	
6.2.3.1-c	a description of the relationship between the Process Reference Model and its intended context of use						X	X	
6.2.3.1-d	a description of the relationship between the processes defined within the Process Reference Model			X				X	
6.2.3.2	The Process Reference Model shall document the community of interest of the model and the actions taken to achieve consensus within that community of interest	X	X		X				
6.2.3.2-a	the relevant community of interest shall be characterized or specified	X			X			X	
6.2.3.2-b	the extent of achievement of consensus shall be documented	X			X			X	
6.2.3.2-c	if no actions are taken to achieve consensus, a statement to this effect shall be documented							X	
6.2.3.3	The processes defined within a Process Reference Model shall have unique process descriptions and identification						X	X	
6.2.4-a	a process shall be described in terms of its purpose and outcomes					X		X	
6.2.4-b	in any process description the set of process outcomes shall be necessary and sufficient to achieve the purpose of the process							X	
6.2.4-c	process descriptions shall be such that no aspects of the measurement framework as described in Clause 5 of this International Standard beyond level 1 are contained or implied					X		X	
Process Assessment Model									
6.3.2.1	A Process Assessment Model shall relate to at least one process from the specified Process Reference Model(s).					X			X
6.3.2.2	A Process Assessment Model shall address, for a given process, all, or a continuous subset, of the levels (starting at level 1) of the measurement framework for process capability for each of the processes within its scope.					X			X
6.3.2.3	A Process Assessment Model shall declare its scope of coverage			X					X
6.3.2.3-a	the selected Process Reference Model(s);			X		X			X
6.3.2.3-b	the selected processes taken from the Process Reference Model(s);			X		X			X
6.3.2.3-c	the capability levels selected from the measurement framework.					X			X
6.3.3	A Process Assessment Model shall be based on a set of indicators that explicitly addresses the purposes and outcomes, as defined in the selected Process Reference Model of all the processes within the scope of the Process Assessment Model; and that demonstrates the achievement of the process attributes within the capability level scope of the Process Assessment Model. The indicators focus attention on the implementation of the processes in the scope of the model.								X
6.3.4	The mapping shall be complete, clear and unambiguous.						X		X
6.3.4-a	the purposes and outcomes of the processes in the specified Process Reference Model;					X			X
6.3.4-b	the process attributes (including all of the results of achievements listed for each process attribute) in the measurement framework.					X			X
6.3.5	A Process Assessment Model shall provide a formal and verifiable mechanism for representing the results of an assessment as a set of process attribute ratings for each process selected from the specified Process Reference Model(s).					X			X
7.2	The party performing verification of conformity shall obtain objective evidence that the Process Reference Model fulfils the requirements set forth in 6.2 of this part of ISO/IEC 15504. Objective evidence of conformance shall be retained.							X	
7.3	The party performing verification shall obtain objective evidence that the Process Assessment Model fulfils the requirements set forth in 6.3 of this part of ISO/IEC 15504. Objective evidence of conformance shall be retained.								X

X – Indicates that the implementation of this activity generates, even partially, the coverage requirement in the final document