Systematic Literature Review of Software Process Capability/Maturity Models

Christiane Gresse von Wangenheim¹, Jean Carlo Rossa Hauck¹, Clenio F. Salviano² and Aldo von Wangenheim¹

¹ UFSC: Universidade Federal de Santa Catarina Programa de Pós-Graduação em Ciência da Computação / Programa de Pós-Graduação em Engenharia do Conhecimento, Campus Reitor João David F. Lima - Bairro Trindade, CEP 88040-970, Florianópolis, SC, Brazil

> ² CTI: Centro de Tecnologia da Informação Renato Archer, Rodovia D. Pedro I, km 143.6, CEP 13069-901, Campinas, SP, Brazil

gresse@gmail.com, jeanhauck@incod.ufsc.br, clenio.salviano@cti.gov.br, awangenh@inf.ufsc.br

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 а Software Process Capability/Maturity Model. A Process Reference Model, as, for example, the Competisoft² 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 initiative³ 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/Maturit	Ref	Based on
		y Model		
Automotive	m01	AutomotiveSPICE Process	[17]	ISO/IEC 15504
systems		Assessment Model		(SPICE)
Business	m02	Business Process Maturity	[18]	CMM/CMMI,
Process		Model (BPMM)		ISO/IEC 12207, and
				ISO/IEC 15288
Component	m03	Integrated Component	[19]	CMM
Based Software		Maturity Model		
Engineering	m04	OOSPICE Process	[20]	ISO/IEC 15504
		Assessment Model for		
		Software Component-based		
		Development		
Data	m05	Data Warehousing Process	[21]	CMM
Warehouse		Maturity Model		
Systems				

Engineering, including development, services and acquisition.Engineering Capability, Male Baldrige Nationa Quality Award, CMMI, ISO/IEC 12207, ISO/IEC 12207, ISO/IEC 12207Knowledge Management Maintenancem12Knowledge Management Maturity Model[29]CMMMaintenancem13Software Maintenance Maturity Model[30]ISO/IEC 14764 a ISO/IEC 12207Measurementm14MIS-PyME software measurement maturity model-supporting the definition of software measurement programs[31]GQ(I)MMedicalm15CMCM - Configuration Management Capability Model[32]CMMI and ANSI/AAMI SWSoftwarem16Framework for assessing the use of third-party software maturity model[33]ISO 9000-3 and CMMQualitym17Concepts for a network maturity model[34]CMM, ISO/IEC 1504 (SPICE)Open Sourcem18Process Maturity Model for Open Source Software[35]CMMI-DEV, ISO/IEC 1504 (SPICE)Performance Engineeringm19PEMM - Performance Engineering Maturity Model[36]CMM Engineering [37]Product Line Managementm20Evolving Standard Process[37]ISO/IEC 12207 SoftwareProduct Line maagementm20Evolving Standard Process[38]ISO 15504, ISO Soft26, 1SOProduct Line maagementm20Evolving Standard Process[38]ISO 15504, ISO Soft28, 50129Requirements maagementm22CMMI RAMS extension based on CENELEC railway stand			S - G	[22]	CMM
E-Governmentmaturity model[23]CMM, PMMME-Learningm08e-learning maturity model[24]CMM, ISO/IECSoftware and Systemm09ISO/IEC 15504-5 Process[26]ISO 9000, ISO/IECEngineering, including development, services and acquisition.m10Extending information system integrability index with CMM model[27]CMMSoftware and Systemm10Extending information system integrability index with CMM - Integrated Capability maturity Model[28]CMM, ISO 900Software and services and acquisition.m11iCMM - Integrated Capability maturity Model[28]CMM, ISO 900Software and services and acquisition.m12Knowledge Management Maturity Model[29]CMMManagement Managementm13Software Maintenance Maturity Model[30]ISO/IEC 1207, ISO/IEC 1207, ISO/IEC 1207, ISO/IEC 1207, ISO/IEC 1207, ISO/IEC 1207, Maintenance[31]GQ(I)MMedical Maintenancem13Software Maintenance measurement programs measurement programs[31]ISO/IEC 1207, ISO/IEC 1207, ISO/IEC 1207, ISO/IEC 1207, ISO/IEC 1207, ISO/IEC 1207, Maintenance[32]CMM and ANSI/AAMI SW ANSI/AAMI SW <b< td=""><td>Jocumentation</td><td>m06</td><td></td><td>[22]</td><td>СММ</td></b<>	Jocumentation	m06		[22]	СММ
E-Government m07 EGMM - E-government maturity model [23] CMM, PMMM E-Learning m08 e-learning maturity model [24] CMM, ISO/IEC Software and System m09 ISO/IEC 15504-5 Process Assessment Model [26] ISO 9000, ISO/I 12207, ISO/IEC Information System m10 Extending information system integrability index with CMM model [27] CMM Software and System m11 iCMM - Integrated Capability maturity Model [28] CMM, ISO 9000 Engineering, including development, services and acquisition. m11 iCMM - Integrated Capability maturity Model [28] CMM, ISO 9000 Knowledge Management m12 Knowledge Management Maturity Model [29] CMM Measurement m13 Software Maintenance measurement maturity model-supporting the definition of software measurement programs [30] ISO/IEC 12207. Medical m15 CMCM - Configuration Maagement Capability Model [31] GQ(I)M Software m14 MIS-PyME software measurement programs [32] CMMI and ANSI/AAMI SW Model Software m14 Preamework for assessing th					
E-Learning m08 e-learning maturity model [24] CMM, ISO/IEC Software and System m09 ISO/IEC 15504-5 Process Assessment Model [26] ISO 9000, ISO/IEC Information Systems m10 Extending information system integrability index with CMM model [27] CMM Software and System m11 iCMM - Integrated Capability maturity Model [28] CMM, ISO 9000 Software and System m11 iCMM - Integrated Capability maturity Model [28] CMM, ISO 9000 Software and System m11 iCMM - Integrated Capability maturity Model [28] CMM, ISO 9000 Software and acquisition. m11 iCMM - Integrated Capability maturity Model [29] CMM Maintenance m12 Knowledge Management Maturity Model [20] ISO/IEC 1207, ISO/IEC 1207, ISO/IEC 1207 [SO/IEC 1550 Medical m14 MIS-PyME software measurement muturity model-supporting the definition of software measurement programs [31] GQ(I)M Medical m15 CMCM - Configuration Management Capability Model [35] ISO 9000-3 and CMM Systems m16 Framewor	E-Government	m07	EGMM - E-government	[23]	CMM, PMMM
Software and System Engineering, including development, services and acquisition.ISO/TEC 15504-5 Process Assessment Model[26]ISO 9000, ISO/T 12207, ISO/TEC 15288Information Systemm10Extending information system integrability index with CMM model[27]CMMSoftware and Systemm11iCMM - Integrated Capability maturity Model[28]CMM, ISO 9000, ELA/IS 731 Syste Engineering, including development, services and acquisition.m11iCMM - Integrated Capability maturity Model[28]CMM, ISO 9000, ELA/IS 731 Syste Engineering Capability, MadeManagement Managementm12Knowledge Management Maturity Model[29]CMMMaintenance maintenancem13Software Maintenance measurement maturity model-supporting the definition of software measurement programs[31]GQ(J)MMedical Systemm15CMCM - Configuration Management Capability Model[32]CMMI and ANSI/AAMI SWSoftware Quality assurancem16Framework for assessing the use of third-party software quality assurance standards[33]ISO 9000-3 and CMMNetwork m17Concepts for a network engineering Product Linem19Performance Engineering Maturity Model[34]CMM, ISO/IEC 1504 CMMProduct Quality managementm22CMMI RAMS extension based on CENELEC railway standard[37]ISO/IEC 12207Product Quality managementm22CMMI RAMS extension based on CENELEC railway standard[38]ISO	E-Learning	m08			
SystemmaxAssessment Model12207, ISO/IECEngineering, including development, services and acquisition.m10Extending information system integrability index with CMM model[27]CMMSoftware and Systemsm11iCMM - Integrated Capability maturity Model[28]CMM, ISO 9000Engineering, including development, services and acquisition.m11iCMM - Integrated Capability maturity Model[28]CMM, ISO 9000Knowledge Management Management definition of softwarem12Knowledge Management Maturity Model[29]CMMMeasurement Maturity Modelm13Software Maintenance Maturity Model[30]ISO/IEC 14764 4 ISO/IEC 12207, ISO/IEC 12207Medical Systemsm14MIS-PyME software measurement maturity model-supporting the definition of software measurement Capability Madel[31]ISO 9000.3 and CMM anagement Capability Management Capability Management Capability Management Capability Management Capability Model[33]ISO 9000.3 and CMM and CMM AnSI/AAMI SW ModelSoftware Product Process Management Management Management Capability Model[34]CMMI and ANSI/AAMI SW CMMSoftware Product Quality Management Management Management Management[36]CMM CMM SPICE)Performance Engineering Product Line Product Line Product Quality Management Management[36]CMM CMM SE-SW, CENTEC 5004 (SPICE)Product Quality Management Management Product Quality Management <br< td=""><td>7 0 1</td><td>00</td><td>100 MPG 15504 5 P</td><td></td><td></td></br<>	7 0 1	00	100 MPG 15504 5 P		
Engineering, including development, services and acquisition. Information m10 Istemation system integrability index with CMM model Istemation (27) CMM Software and System m11 iCMM - Integrated Capability maturity Model Istemation (2a) Istemation (2a		m09		[26]	· · · · · · · · · · · · · · · · · · ·
including development, services and acquisition. 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 Syste Engineering Capability, Male Baldrige Nationa Quality Award, CMMI, ISO/IEC 12207, ISO/IEC 12207, ISO/IEC 12207, Management Maintenance m12 Knowledge Management Maturity Model [30] ISO/IEC 14764 4 ISO/IEC 12207, ISO/IEC 12207 Measurement m14 MIS-PyME software measurement maturity model-supporting the definition of software measurement programs [31] GQ(J)M Medical Systems m16 Cramework for assessing the use of third-party software quality assurance standards [33] ISO 9000-3 and CMM Software Assurance m18 Process Maturity Model [35] CMMI and ANSI/AAMI SW Model Software Performance m18 Process Maturity Model [36] CMM Software Product Line Management m18 Process Maturity Model [36] CMMI ES-SW (SPICE) Product Process Performance m19 PMM - Performance Engineering Maturity Model [36] CMMI SE-SW, (SPICE) Product Line Management m20 Evolving Sta			Assessment woder		
development, services and acquisition. Information system integrability index with CMM model [27] CMM Software and System m11 iCMM - Integrated Capability maturity Model [28] CMM, ISO 9000 Software and System m11 iCMM - Integrated Capability maturity Model [28] CMM, ISO 9000 Software and services and acquisition. m11 iCMM - Integrated Capability, Malc [28] CMM, ISO 9000 Knowledge m12 Knowledge Management Maturity Model [29] CMM Maintenance m13 Software Maintenance measurement maturity model-supporting the definition of software measurement programs [30] ISO/TEC 14764 4 ISO/TEC 12207. Medical m15 CMCM - Configuration Maagement capability model [31] GQ(I)M Medical m15 CMCM - Configuration Maagement capability Model [33] ISO 9000-3 and CMM Software m16 Framework for assessing the use of third-party software quality assurace standards [34] CMM ISO/TEC ISO/TEC 1504 (SPICE) Open Source m18 Process Maturity Model [36] CMM Product Line Management m19 PMM - Performance Engineering [36] CMM Product Quality m20 Evolving Standard Process Reference Models for Product Line Management [37] ISO/TEC 12207					15200
acquisition.Image in the system integrability index with CMM model[27]CMMSoftware and Systemm11iCMM - Integrated[28]CMM, ISO 9000Software and Systemm11iCMM - Integrated[28]CMM, ISO 9000System integrability maturity Model[28]CMM, ISO 9000ELA/IS 731 SysteEngineering, includingGabability maturity Model[28]CMM, ISO 9000development, services and acquisition.Knowledge ManagementBaldrige NationaManagementM12Knowledge Management[30]ISO/IEC 12207, ISO/IEC CD 152Knowledgem12Knowledge Management[31]GQ(I)MMaintenancem13Software Maintenance[31]GQ(I)MMeasurementm14MIS-PyME software measurement programs[31]GQ(I)MMedicalm15CMCM - Configuration Management Capability Model[32]CMMI and ANSI/AAMI SWSoftwarem16Framework for assessing the use of third-party software quality assurance standards[33]ISO 9000-3 and CMMNetworkm17Concepts for a network maturity model[34]CMM, ISO/IECOpen Source formancem18Process Maturity Model[35]CMMI-DEV, ISO/IEC 15504 (SPICE)Performance engineeringm20Evolving Standard Process Reference Models for Product Line Development[36]ISO/IEC 12207Parformance formancem19PEMM - Performance Engineering[37]ISO/IEC 12207Product Quality<					
Information Systemsm10Extending information system integrability index with CMM model[27]CMMSoftware and System Including development, services and acquisition.m11iCMM - Integrated Capability maturity Model[28]CMM, ISO 900 EIA/IS 731 System Engineering (Capability, Malc Baldrige Nationa Quality Award, ISO/IEC 12207, ISO/IEC 12007, ISO/IEC 12017, ISO/IEC 1504, (SPICE), Performance Engineering[31]ISO 9000-3 and CMM ANSI/AAMI SW CMM ISO/IEC 1504, (SPICE), ISO/IEC 1504, (SPICE), Product Line Product Line Development[33]ISO 9000-3 and CMM ISO/IEC ISO/IEC 1504, (SPICE), ISO/IEC 1504, (SPICE), Product Line DevelopmentProduct Quality magementm18Process Maturity Model Product Line Development[33]ISO 1504, ISO (SPICE), ISO/IEC 12007, ISO/IEC 12007, ISO/IEC 12007, ISO/IEC 12007, ISO/IEC 12					
Systemssystem integrability index with CMM modelImage: Constraint of the constrain	1				
Software and Systemm11 iCMM - Integrated Capability maturity Model[28] EIA/IS 731 System Engineering including development, services and acquisition.m11 iCMM - Integrated Capability maturity Model[28] EIA/IS 731 System Engineering Capability. Madel Baldrige Nationa Quality Award, CMMI, ISO/IEC 12207, ISO/IEC 12207Knowledge Managementm12 Maturity Model[29] Knowledge Management Maturity Model[30]ISO/IEC 14764 4 ISO/IEC 12207Measurementm13 Maturity ModelSoftware measurement maturity model-supporting the definition of software measurement programs[31]GQ(I)MMedical Softwarem15 measurement CApability Model[32]CMMI and ANSI/AAMI SW CMCHSoftware Maturity model[33]ISO 9000-3 and CMMSoftware Performancem18 Process Maturity Model for Open Source[34]CMM, ISO/IEC 12504, (SDIEC 15504 (SPICE)Performance Engineeringm19PEMM - Performance Product Line Product Line Product Line Product Line Management[36]ISO 15504, ISO (SDIEC 12207Performance Managementm12 Product Line Development Product Line Development Product Line Product Indevelopment Product Line Development[38]ISO 15504, ISO (SDIEC 12207Performance Product Quality Managementm20CMMI SE-SW, CENELEC 5012 S0128, 50129[39]ISO 15504, ISO (SDIEC 12207Product Quality Managementm21Product Process Product Line Development Product Line Development[38]ISO 15504,		m10		[27]	CMM
Software and System Engineering, including development, services and acquisition.m11iCMM - Integrated Capability maturity Model[28]CMM, ISO 9000 EIA/IS 731 System Baldrige Nationa Quality Award, ISO/IEC 12207, ISO/IEC 12207, Measurement programs[31]ISO/IEC 14764 / ISO/IEC 12207, ISO/IEC 1504, ISO 900-3 and CMM and ANSI/AAMI SW ASurance Networkm16Framework for assessing the use of third-party software quality assurance standards Network[33]ISO 9000-3 and CMM ISO/IEC ISO/IEC 1504 (SPICE)Performance Engineeringm18Process Maturity Model for Open Source Software[34]CMM, ISO/IEC CSOftwareProduct Line maagementm20Evolving Standard Process[37]ISO/IEC 12207, ISO/IEC 1504, ISO Dependencies <td>systems</td> <td></td> <td></td> <td></td> <td></td>	systems				
System Engineering, including development, services and acquisition.Capability maturity ModelEIA/IS 731 Syste Engineering Capability, Male Baldrige National Quality Award, CCMMI, ISO/IEC 12207, ISO/IEC 12207, ISO/IEC 12207Knowledge Maintenancem12Knowledge Management Maturity Model[29]CMMMaintenancem13Software Maintenance Maturity Model[30]ISO/IEC 12207, ISO/IEC 12207Measurementm14MIS-PyME software measurement maturity model-supporting the definition of software measurement programs[31]GQ(1)MMedical Systemsm15COMCM - Configuration masurement Capability Model[32]CMMI and ANSI/AAMI SWSoftware Quality assuracem16Framework for assessing the guality assurace standards[33]ISO 9000-3 and CMMNetworkm17Concepts for a network maturity model[34]CMM, ISO/IEC 15504 (SPICE)Open Source Softwarem18Process Maturity Model for Dependencies[35]CMMProduct Line Honduct Linem20Evolving Standard Process Reference Models for Product Line Development[36]CMMProduct Quality managementm21Product Process Reference Models for Product Line Development[37]ISO/IEC 15207 (SD/IEC 15204 (SPICE)Product Quality managementm22CMMI RAMS extension based on CENELEC railway standard[40]CMMI SE-SW, CENELEC Sol12 Sol128, Sol129Requirements managementm22Formal Specifications S	Software and	m11		[28]	CMM_ISO 9000
Engineering, including development, services and acquisition.Engineering Capability, Male Baldrige Nationa Quality Award, CMMI, ISO/IEC 12207, ISO/IEC 1207Knowledge Management Maintenancem12 Maturity ModelKnowledge Management Maturity Model[29] ISO/IEC 12207Measurement Measurementm14 MIS-PyME software measurement maturity model-supporting the definition of software measurement programs[30] ISO/IEC 12207ISO/IEC 14764 / ISO/IEC 12207Medical Systemsm15 ModelCMCM - Configuration Management Capability Model[31] ModelGQ(I)MSoftware quality assurancem16 gramework for assessing the us of third-party software maturity model[33] ISO 9000-3 and CMMISO 9000-3 and CMMNetwork Softwarem17 model-sustranceConcepts for a network maturity model[34] ISO/IEC 15204CMMI ISO/IEC 15204 (SPICE)Open Source Softwarem18 m20 Process Maturity Model for Open Source Software[36] SOftEC 15204 (SPICE)CMM ISO/IEC 15204 (SPICE)Performance Engineeringm19 PEMM - Performance Engineering Maturity Model[37] SO/IEC 15204 (SPICE)ISO/IEC 12207 ISO/IEC 15204 (SPICE)Product Line Managementm20 m2CMMI RAMS extension based on CENELEC railway standard[38] SO 1SO/IEC 15012 SO129ISO/IEC 1504, SD SO/IEC 15012 SO/IEC 15012Product Quality m21m22 Product Line Development[40] m22CMMI SE-SW, CENELEC S012 S0128, 50129Requirements m23 <td></td> <td></td> <td></td> <td>[20]</td> <td>EIA/IS 731 Systems</td>				[20]	EIA/IS 731 Systems
development, services and acquisition.Image: Services and acquisition.Baldrige Nationa Quality Award, CMMI, ISO/IEC TR 15504, ISO/IEC 12207, ISO/IEC 12207, ISO/IEC 12207, ISO/IEC 12207, ISO/IEC 12207Knowledge Managementm12Knowledge Management Maturity Model[29]CMMMaintenance Maintenancem13Software Maintenance Maturity Model[30]ISO/IEC 14764 a ISO/IEC 12207Measurement Measurementm14MIS-PyME software measurement maturity model-supporting the definition of software measurement programs[31]GQ(1)MMedical Systemsm15CMCM - Configuration Management Capability Model[32]CMMI and ANSI/AAMI SWSoftware quality assurance standardsm17Concepts for a network rativity model[34]CMM, ISO/IEC ISO4 (SPICE)Open Source Softwarem18Process Maturity Model for Open Source Software[35]CMMI-DEV, ISO/IEC 15504 (SPICE)Performance Engineeringm19PEMM - Performance Engineering Maturity Model[36]CMMProduct Line Managementm21Product Process Reference Models for Product Line Development[38]ISO 15504, ISO S0128, 50129Perdurt Quality Managementm21Product Process Reference Models for Product Line Development[40]CMMI SE-SW, CENELEC 5012 S0128, 50129Requirements Maagementm23Formal Specifications Strategies Maturity Model[41]CMMMaintenance Managementm23Formal Specifications <b< td=""><td></td><td></td><td>, i j</td><td></td><td></td></b<>			, i j		
services and acquisition.Image: constraint of the service of the se					Capability, Malcolm
acquisition.Image: CMM, ISO/IEC TR 15504, ISO/IEC 12207, ISO/IEC 12207, ISO/IEC 12207, ISO/IEC 12207, ISO/IEC 12207Knowledge Managementm12Knowledge Management Maturity Model[29]CMMMaintenance Measurementm13Software Maintenance Maturity Model[30]ISO/IEC 14764 a ISO/IEC 12207Measurementm14MIS-PyME software measurement maturity model-supporting the definition of software measurement programs[31]GQ(I)MMedical Systemsm15CMCM - Configuration Management Capability Model[32]CMMI and ANSI/AAMI SWSoftware quality assurancem16Framework for assessing the use of third-party software quality assurance standards[33]ISO 9000-3 and CMMNetworkm17Concepts for a network maturity model[34]CMM, ISO/IEC 15504 (SPICE)Open Source Softwarem18Process Maturity Model for Product Line Product Line[36]CMMProduct Line mangementm20Evolving Standard Process (SPICE)[37]ISO/IEC 12207 (SO/IEC 15504, ISO (SPICE)Product Quality mangementm21Product Process mased on CENELEC railway standard[38]ISO 15504, ISO (SD 15504, ISO (SD 15504, ISO (SD 128, 50129)Requirements mangementm23Formal Specifications strategies Maturity Model[41]CMMMailway/Safety Engineeringm23Formal Specifications strategies Maturity Model[41]CMMSol128, 50129m24Requirements					Baldrige National
NormalImage: mail of the second s					
Knowledge Managementm12Knowledge Management Maturity ModelISO/IEC 12207, ISO/IEC CD 152Knowledge Maintenancem13Software Maintenance Maturity Model[29]CMMMeasurementm14MIS-PyME software measurement maturity model-supporting the definition of software measurement programs[31]GQ(I)MMedical Systemsm15CMCM - Configuration Management Capability Model[32]CMMI and ANSI/AAMI SW ModelSoftware qualitym16Framework for assessing the use of third-party software quality assurance standards[33]ISO 9000-3 and CMMNetworkm17Concepts for a network maturity model[34]CMM, ISO/IEC 15504 (SPICE)Open Source Softwarem18Process Maturity Model for Depen Source Software[35]ISO/IEC 12207Performance Engineeringm19PEMM - Performance Engineering Maturity Model[36]CMMProduct Line Dependencies[37]ISO/IEC 12207Managementm21Product Process Dependencies[38]ISO 15504, ISO 1504 (SPICE)Product Quality Managementm21Product Process Dependencies[38]ISO 15504, ISO 1501 (SDI 25012, S0129)Railway/Safety Requirementsm23Formal Specifications Strategies Maturity Model[41]CMM 43]Security Engineering/m23Formal Specifications Strategies Maturity Model[41]SW CMM 43]	equisition.				
Image 1Image 1 <thimage 1<="" th="">Image 1Image 1<th< td=""><td></td><td></td><td></td><td></td><td> ,</td></th<></thimage>					,
ManagementMaturity ModelImagementMaturity ModelImagementMaintenancem13Software Maintenance[30]ISO/IEC 14764 and ISO/IEC 12207MeasurementM14MIS-PyME software[31]GQ(I)MMeasurementm14MIS-PyME software[31]GQ(I)Mmeasurement maturitymodel-supporting thedefinition of software[31]GQ(I)MMedicalm15CMCM - Configuration[32]CMMI andSystemsm16Framework for assessing the[33]ISO 9000-3 andQualitywas of third-party software[34]CMM, ISO/IECNetworkm17Concepts for a network[34]CMM, ISO/IECNetworkm17Concepts for a network[35]CMMI-DEV,Softwarem18Process Maturity Model for[35]CMMI-DEV,Softwarem19PEMM - Performance[36]CMMEngineeringm20Evolving Standard Process[37]ISO/IEC 12207Managementm21Product Line Development[38]ISO 15504, ISOPerdouct Qualitym21Product Process[38]ISO 15504, ISODependencies[39]9126, BootstrapRailway/Safetym22Formal Specifications[41]CMMMaturity Modelm23Formal Specifications[41]CMMManagementsm23Formal Specifications[41]ISO/IEC 15408, SSE-CMMSecuritym23A CC-based Security[44]ISO/IEC 154					ISO/IEC CD 15288
Maintenancem13Software Maintenance Maturity Model[30]ISO/TEC 14764 a ISO/TEC 12207Measurementm14MIS-PyME software measurement maturity model-supporting the definition of software measurement programs[31]GQ(I)MMedicalm15CMCM - Configuration Management Capability Model[32]CMMI and ANSI/AAMI SWSoftwarem16Framework for assessing the use of third-party software quality assurance standards[33]ISO 9000-3 and CMMNetworkm17Concepts for a network maturity model[34]CMM, ISO/IEC 15504 (SPICE)Open Source Softwarem18Process Maturity Model for Open Source Software[35]CMMI-DEV, ISO/IEC 15504 (SPICE)Performance Engineeringm19PEMM - Performance Product Line[36]CMMProduct Quality Managementm21Product Process Dependencies[37]ISO/IEC 12207Management Product Qualitym21Product Process Dependencies[38]ISO 15504, ISO 150/ISO/IEC 12207Railway/Safety Reference Models for Product Line Development[40]CMMI SE-SW, Softased on CENELEC railway standard[41]Requirements Requirementsm23Formal Specifications Strategies Maturity Model[41]SW CMM [43]Security Engineering/m25A CC-based Security Engineering Process[44]ISO/IEC 15408, SSE-CMM		m12	0 0	[29]	CMM
Maturity ModelISO/IEC 12207Measurementm14MIS-PyME software measurement maturity model-supporting the definition of software measurement programs[31]GQ(I)MMedicalm15CMCM - Configuration Management Capability Model[32]CMMI and ANSI/AAMI SW ModelSoftwarem16Framework for assessing the use of third-party software quality assurance standards[33]ISO 9000-3 and CMMNetworkm17Concepts for a network maturity model[34]CMM, ISO/IEC 15504 (SPICE)Open Source Softwarem18Process Maturity Model for Open Source Software[35]CMMPerformance Engineeringm19PEMM - Performance Engineering Maturity Model[36]CMMProduct Line Managementm20Evolving Standard Process (SPICE)[37]ISO/IEC 12207Product Line Managementm21Product Process Dependencies[38]ISO 15504, ISO S012S 15504, ISO S012S 1528, 50129Product Quality m21m22CMMI RAMS extension based on CENELEC railway standard[40]CMM SE-SW, CENELEC 5012 S0128, 50129Requirements m23Formal Specifications Strategies Maturity Model[41]CMM SW CMM [43]Security Engineering/m25A CC-based Security Engineering Process[44]ISO/IEC 15408, SSE-CMM		m12		[30]	ISO/IEC 14764 and
Medical Systemsm15CMCM - Configuration Management Capability Model[32] ModelCMMI and ANSI/AAMI SW ANSI/AAMI SW ModelSoftware Qualitym16Framework for assessing the use of third-party software quality assurance standards[33]ISO 9000-3 and CMMNetworkm17Concepts for a network maturity model[34]CMM, ISO/IEC 15504 (SPICE)Open Sourcem18Process Maturity Model for Open Source Software[35]CMMOpen Sourcem19PEMM - Performance Engineering Maturity Model[36]CMMProduct Line Managementm20Evolving Standard Process (SPICE)[37]ISO/IEC 12207Management engineeringm21Product Process Dependencies[38]ISO 15504, ISO (SPICE)Product Quality managementm21Product Process Dependencies[38]ISO 15504, ISO (SPICE)Refurence managementm23Formal Specifications Strategies Maturity Model[41]CMM CMM EASW, CENELEC 5012 50128, 50128, 50129Requirements m23Formal Specifications Strategies Maturity Model[41]SW CMM [43]Security Engineering/m25A CC-based Security Engineering Process[44]ISO/IEC 15408, SSE-CMM	viantenance	mis		[50]	
Medical Medicalmodel-supporting the definition of software measurement programs[32]CMMI and ANSI/AAMI SWMedical Systemsm15CMCM - Configuration Management Capability Model[33]ISO 9000-3 and CMMSoftware Qualitym16Framework for assessing the use of third-party software quality assurance standards[34]ISO 9000-3 and CMMNetworkm17Concepts for a network maturity model[34]CMM, ISO/IEC 15504 (SPICE)Open Source Softwarem18Process Maturity Model for Open Source Software[35]CMMI-DEV, ISO/IEC 15504 (SPICE)Performance Engineeringm19PEMM - Performance Engineering Maturity Model[36]CMMProduct Line Managementm20Evolving Standard Process Reference Models for Product Line Development[37]ISO/IEC 12207 SoftwareProduct Quality m21m21Product Process Based on CENELEC railway standard[38]ISO 15504, ISO S0128, 50129Requirements m23Formal Specifications Strategies Maturity Model[41]CMMMalway/Safety m23m23Formal Specifications Strategies Maturity Model[41]Security Engineering/m25A CC-based Security Engineering Process[44]ISO/IEC 15408, SSE-CMM	Measurement	m14	MIS-PyME software	[31]	GQ(I)M
Medical systemsm15CMCM - Configuration Management Capability Model[32] ANSI/AAMI SW ANSI/AAMI SWSoftware Qualitym16Framework for assessing the use of third-party software quality assurance standards[33]ISO 9000-3 and CMMNetworkm16Framework for assessing the use of third-party software quality assurance standards[34]CMM, ISO/IEC ISO/IEC)Open Sourcem17Concepts for a network maturity model[34]CMM.ISO/IEC ISO/IEC 15504 (SPICE)Open Source Softwarem18Process Maturity Model for Open Source Software[35]CMMI-DEV, ISO/IEC 15504 (SPICE)Performance Engineeringm19PEMM - Performance Engineering Maturity Model[36]CMMProduct Line Managementm20Evolving Standard Process Dependencies[37]ISO/IEC 12207Pailway/Safety Railway/Safetym21Product Process Dased on CENELEC railway standard[40]CMMI SE-SWL SOI128, 50129Requirements m23Formal Specifications Strategies Maturity Model[41]CMMM24Requirements CMM Requirements CMM[42]Security Engineering/m25A CC-based Security Engineering Process[44]ISO/IEC 15408, SSE-CMM					
Medical Systemsm15CMCM - Configuration Management Capability Model[32]CMMI and ANSI/AAMI SW ANSI/AAMI SW ModelSoftware Qualitym16Framework for assessing the use of third-party software quality assurance standards[33]ISO 9000-3 and CMMNetworkm17Concepts for a network maturity model[34]CMM, ISO/IEC 15504 (SPICE)Open Source Softwarem18Process Maturity Model for Open Source Software[35]CMMI-DEV, (SPICE)Performance Engineeringm19PEMM - Performance Engineering Maturity Model[36]CMMProduct Line Managementm20Evolving Standard Process (SPICE)[37]ISO/IEC 12207Product Quality Managementm21Product Process Dependencies[38]ISO 15504, ISO (SPICE)Product Quality m21m21Product Process Dependencies[39]9126, Bootstrap S0128, 50129Requirements m23Formal Specifications Strategies Maturity Model[41]CMM CMM Strategies Maturity Modelm24Requirements CMM Lagi[42]SW CMM LagiSecurity Engineering/m25A CC-based Security Engineering Process[44]ISO/IEC 15408, SSE-CMM					
Medical Systems m15 CMCM - Configuration Management Capability Model [32] CMMI and ANSI/AAMI SW Software Quality 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 m18 Process Maturity Model for Open Source Software [35] CMMI-DEV, ISO/IEC 15504 Performance m19 PEMM - Performance Engineering [36] CMM Product Line m20 Evolving Standard Process Reference Models for Product Line Development [37] ISO/IEC 12207 Management m21 Product Process Dependencies [39] 9126, Bootstrap Railway/Safety m23 Formal Specifications Strategies Maturity Model [41] CMM m23 Formal Specifications Strategies Maturity Model [41] SW CMM M24 Requirements CMM [42] SW CMM Kerategies Maturity Model [43] SSE-CMM					
SystemsManagement Capability ModelANSI/AAMI SWSoftwarem16Framework for assessing the use of third-party software quality assurance standards[33]ISO 9000-3 and CMMNetworkm17Concepts for a network maturity model[34]CMM, ISO/IEC 15504 (SPICE)Open Sourcem18Process Maturity Model for Open Source Software[35]CMM1-DEV, ISO/IEC 15504Performance Engineeringm19PEMM - Performance Engineering Maturity Model[36]CMMProduct Line Managementm20Evolving Standard Process Reference Models for Product Line Development[37]ISO/IEC 12207Railway/Safety standardm21Product Process Dependencies[38]ISO 15504, ISO S0128, 50129SW CMMRequirementsm23Formal Specifications Strategies Maturity Model[41]CMMm24Requirements CMM[42]SW CMMManagementm25A CC-based Security Engineering Process[44]ISO/IEC 15408, SSE-CMM	Medical	m15		[32]	CMMI and
NodelModelSoftware Qualitym16Framework for assessing the use of third-party software quality assurance standards[33]ISO 9000-3 and CMMNetworkm17Concepts for a network maturity model[34]CMM, ISO/IEC 15504 (SPICE)Open Source Softwarem18Process Maturity Model for Open Source Software[35]CMMI-DEV, ISO/IEC 15504 (SPICE)Performance Engineeringm19PEMM - Performance Engineering Maturity Model[36]CMMProduct Line Managementm20Evolving Standard Process Reference Models for Product Line Development[37]ISO/IEC 12207Product Quality m21m21Product Process Dependencies[38]ISO 15504, ISO J9126, BootstrapRailway/Safety m22m22CMMI RAMS extension based on CENELEC railway standard[40]CMM CENELEC 5012 50128, 50129Requirements m23Formal Specifications Strategies Maturity Model[41]CMM (EMI Strategies Maturity ModelSecurity Engineering/m25A CC-based Security Engineering Process[44]ISO/IEC 15408, SSE-CMM				[02]	ANSI/AAMI SW68
Quality Assuranceuse of third-party software quality assurance standardsCMMNetworkm17Concepts for a network maturity model[34]CMM, ISO/IEC 15504 (SPICE)Open Source Softwarem18Process Maturity Model for Open Source Software[35]CMMI-DEV (SPICE)Performance Engineeringm19PEMM - Performance Engineering Maturity Model[36]CMMProduct Line Managementm20Evolving Standard Process (SPICE)[37]ISO/IEC 12207Product Quality m21m21Product Process Dependencies[38]ISO 15504, ISO (SPICE)Railway/Safety standardm22CMMI RAMS extension based on CENELEC railway standard[40]CMMI SE-SW, CENELEC S012Requirementsm23Formal Specifications Strategies Maturity Model[41]CMM (Mature)Security Engineering/m25A CC-based Security Engineering Process[44]ISO/IEC 15408, SSE-CMM					
Assurance quality assurance standards Concepts for a network maturity model [34] CMM, ISO/IEC 15504 (SPICE) Network m17 Concepts for a network maturity model [35] CMM, ISO/IEC 15504 (SPICE) Open Source m18 Process Maturity Model for Open Source Software [36] CMM - Performance (SPICE) Performance m19 PEMM - Performance [36] CMM Product Line m20 Evolving Standard Process Reference Models for Product Line Development [37] ISO/IEC 12207 Product Quality m21 Product Process [38] ISO 15504, ISO Dependencies Railway/Safety m22 CMMI RAMS extension based on CENELEC railway standard 50128, 50129 Requirements m23 Formal Specifications Strategies Maturity Model [41] CMM m24 Requirements CMM [42] SW CMM [43] SSE-CMM		m16		[33]	
Network m17 Concepts for a network maturity model [34] CMM, ISO/IEC 15504 (SPICE) Open Source m18 Process Maturity Model for Open Source Software [35] CMMI-DEV, ISO/IEC 15504 (SPICE) Performance m19 PEMM - Performance [36] CMM Engineering m20 Evolving Standard Process Reference Models for Product Line [37] ISO/IEC 12207 Product Quality m21 Product Process Dependencies [38] ISO 15504, ISO 9126, Bootstrap Railway/Safety m22 CMMI RAMS extension based on CENELEC railway standard [40] CMMI SE-SW, CENELEC 5012 50128, 50129 Requirements m23 Formal Specifications Strategies Maturity Model [41] CMM m24 Requirements CMM [42] SW CMM [43] SO/IEC 15408, SD/IEC 15408, Security m25 A CC-based Security Engineering Process [44] ISO/IEC 15408, SSE-CMM SSE-CMM	- ·				CMM
maturity model 15504 (SPICE) Open Source Software m18 Process Maturity Model for Open Source Software [35] CMMI-DEV, ISO/IEC 15504 (SPICE) Performance Engineering Maturity Model [36] CMM Product Line m20 Evolving Standard Process Reference Models for Product Line Development [37] ISO/IEC 12207 Product Quality m21 Product Process Dependencies [39] 9126, Bootstrap Railway/Safety m22 CMMI RAMS extension based on CENELEC railway standard [40] CMMI SE-SW, CENELEC 5012 Requirements m23 Formal Specifications Strategies Maturity Model [41] CMM m24 Requirements CMM [42] SW CMM m25 A CC-based Security Engineering Process [44] ISO/IEC 15408, SSE-CMM		m17		[24]	CMM ISO/IEC
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 [39] 9126, Bootsrap Railway/Safety m22 CMMI RAMS extension based on CENELEC railway standard [40] CMMI SE-SW, CENELEC 5012 Requirements m23 Formal Specifications Strategies Maturity Model [41] CMM M24 Requirements CMM [42] SW CMM [43] Security m25 A CC-based Security Engineering Process [44] ISO/IEC 15408, SSE-CMM	Network	11117		[34]	
Performance Engineering m19 PEMM - Performance Engineering Maturity Model (SPICE) Product Line Management m20 Evolving Standard Process Reference Models for Product Line Development [37] ISO/IEC 12207 Product Quality m21 Product Process Dependencies [38] ISO 15504, ISO Railway/Safety m22 CMMI RAMS extension based on CENELEC railway standard [40] CMMI SE-SW, CENELEC 5012 Requirements m23 Formal Specifications Strategies Maturity Model [41] CMM m24 Requirements CMM [42] SW CMM [43] SO/IEC 15408, SSE-CMM	Open Source	m18		[35]	
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] ISO 15504, ISO Railway/Safety m22 CMMI RAMS extension based on CENELEC railway standard [40] CMMI SE-SW, CENELEC 5012 50128, 50129 Requirements m23 Formal Specifications Strategies Maturity Model [41] CMM M24 Requirements CMM [42] SW CMM [43] SSE-CMM	Software		Open Source Software		
Engineering Engineering Maturity Model Product Line Management m20 Product Line Devolopment [37] ISO/IEC 12207 Product Quality m21 Product Process [37] ISO/IEC 12207 Product Quality m21 Product Process [38] ISO 15504, ISO 9126, Bootstrap Railway/Safety m22 CMMI RAMS extension based on CENELEC railway standard [40] CMMI SE-SW, CENELEC 5012 50128, 50129 Requirements m23 Formal Specifications Strategies Maturity Model [41] CMM Security m25 A CC-based Security Engineering Process [44] ISO/IEC 15408, SSE-CMM					
Product Line Management m20 Reference Models for Product Line Development [37] ISO/IEC 12207 Product Quality m21 Product Process [38] ISO 15504, ISO 9126, Bootstrap Railway/Safety m22 Requirements CMMI RAMS extension based on CENELEC railway standard [40] CMMI SE-SW, CENELEC 5012 50128, 50129 Requirements m23 Requirements Formal Specifications Strategies Maturity Model [41] CMM Security m25 A CC-based Security Engineering/ [44] ISO/IEC 15408, SSE-CMM		m19		[36]	CMM
Management Reference Models for Product Line Development Image: Constraint of the system Product Quality m21 Product Process Dependencies [38] ISO 15504, ISO Railway/Safety m22 CMMI RAMS extension based on CENELEC railway standard [40] CMMI SE-SW, CENELEC 5012 CENELEC 5012 Requirements m23 Formal Specifications Strategies Maturity Model [41] CMM Security m25 A CC-based Security Engineering [44] ISO/IEC 15408, SSE-CMM		m20		[27]	ISO/IEC 12207
Product Line Development Product Line Development Product Quality m21 Product Process Dependencies [38] ISO 15504, ISO 9126, Bootstrap Railway/Safety m22 CMMI RAMS extension based on CENELEC railway standard [40] CMMI SexSw, CENELEC 5012 50128, 50129 Requirements m23 Formal Specifications Strategies Maturity Model [41] CMM m24 Requirements CMM [42] SW CMM m25 A CC-based Security [44] ISO/IEC 15408, SSE-CMM		11120		[37]	130/IEC 1220/
Image: Constraint of the sector of					
Railway/Safety m22 CMMI RAMS extension based on CENELEC railway standard [40] CMMI SE-SW, CENELEC 5012 50128, 50129 Requirements m23 Formal Specifications Strategies Maturity Model [41] CMM m24 Requirements CMM [42] SW CMM security m25 A CC-based Security [44] ISO/IEC 15408, SSE-CMM	Product Quality	m21	Product Process	[38]	ISO 15504, ISO
based on CENELEC railway standard CENELEC 5012 50128, 50129 Requirements m23 Formal Specifications Strategies Maturity Model [41] CMM m24 Requirements CMM [42] SW CMM [43] Formal Specifications process [44] ISO/IEC 15408, SSE-CMM				[39]	
standard 50128, 50129 Requirements m23 Formal Specifications Strategies Maturity Model [41] CMM m24 Requirements CMM [42] SW CMM [43] [43] [44] SO/IEC 15408, SECurity Engineering/ m25 A CC-based Security Engineering Process [44] ISO/IEC 15408, SSE-CMM	kailway/Safety	m22		[40]	
Requirements m23 Strategies Maturity Model [41] CMM m24 Requirements CMM [42] SW CMM [43] [43] [44] ISO/IEC 15408, SECurity Engineering/ Engineering Process SSE-CMM					
Strategies Maturity Model Strategies Maturity Model m24 Requirements CMM [42] SW CMM [43] [43] [43] [44] ISO/IEC 15408, Security m25 A CC-based Security [44] ISO/IEC 15408, Engineering/ Engineering Process SSE-CMM	Requirements	m23		[41]	
m24 Requirements CMM [42] [43] SW CMM Security m25 A CC-based Security [44] ISO/IEC 15408, SSE-CMM	equitemento			[-1]	C.mm
Security m25 A CC-based Security [44] ISO/IEC 15408, Engineering/ Engineering Process SSE-CMM		m24			SW CMM
Engineering/ Engineering Process SSE-CMM					100 100 10100
		m25		[44]	
Service Evaluation Model	Engineering/ Service		Engineering Process Evaluation Model		SSE-CIVIIVI
Oriented m26 Development system [45] ISO/IEC 15504,		m26		[45]	ISO/IEC 15504.
security process of ISO/IEC ISO/IEC ISO/IEC 15408			security process of ISO/IEC	L 14 J	
TR 15504 and security			TR 15504 and security		
considerations for software					
m27 Lessons learned with the [46] CMM		m 27		[46]	CMM
m27 Lessons learned with the [46] CMM systems security engineering		m27		[46]	CMM
capability maturity model					
m28 Representation of [47] SW CMM		m28		[47]	SW CMM
knowledge in Information			knowledge in Information	-	
Technology Service					
Capability Maturity Model (IT Service CMM)			Capability Maturity Model		
	l		(11 SCIVICE CIVILVI)	I	1

	m29	Research on third party logistics service capability	[48]	СММ
SME (Small	m30	maturity model MARES Process	[49]	ISO/IEC 15504
and Medium		Assessment Model	[50]	
Enterprises)	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]	СММ
	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 2167 ^a , 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 Implementatio n	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

Proceedings of International Conference on Software Process. Improvement And Capability dEtermination (SPICE). Pisa, Italy, May 2010

	m45	SAMM - Modern software assurance and a five-level model of software assurance maturity	[67]	СММ
	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]	ХР
	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.

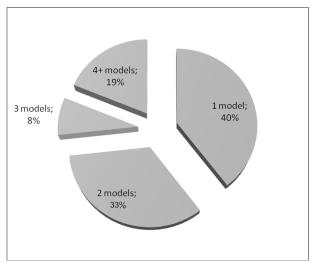
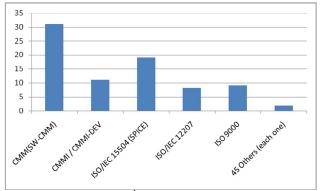
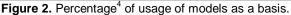


Figure 1. Percentage of number of source models used

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.





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 domainspecific adaptation of such models.

Acknowledgements

The authors would like to thank Alessandra Zoucas for her participation in the systematic literature review.

This work was supported by the CNPq (*Conselho Nacional de Desenvolvimento Científico e Tecnológico*) (including support by the Program on National Research and Technology Institutes) and CAPES (*Coordenação de Aperfeiçoamento de Pessoal de Nível Superior*), entities of the Brazilian government focused on scientific and technological development.

References

[1] Salviano, C. F. and Figueiredo, A. M. C. M., "Unified Basic Concepts for Process Capability Models", 20th Int Conf on Sw. Eng. and Knowledge Eng. SEKE, 2008, pp. 173-178.

[2] CMMI Product Team, "CMMI for Development, Version 1.2", Technical Report CMU/SEI-2006-TR-008, Carnegie Mellon University/Software Engineering Institute, 2006.

[3] ISO/IEC 15504: Information Technology Process Assessment - Part 1 to 5", ISO/IEC International Standard, 2005.

[4] ISO - International Organization for Standardization, "ISO9001:2008 Quality management systems – Requirements", 2008.

[5] Sheard S. A., "The Frameworks Quagmire", Crosstalk: The Journal of Defense Software Engineering, vol. 10, no. 9, September 1997.

[6] Sheard S. A., "Evolution of the Frameworks Quagmire", IEEE Computer, vol. 34, no. 7, July 2001, pp. 96-98.

[7] ISO/IEC - International Organization for Standardization (ISO) / International Electrotechnical Commission (IEC), "ISO/IEC 12207: Standard for Information Technology", 1998.

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%.

[8] Magee S. and Thiele D., "Engineering Process Standards: State of the Art and Challenges". IEEE IT Pro September/October 2004.

[9] Software Engineering Institute (SEI), "Class A Appraisal Results". Available at: http://www.sei.cmu.edu/cmmi/casestudies/profiles/cmmi. cfm.

[10] Paulk M. C., "Surviving the Quagmire of Process Models, Integrated Models, and Standards", Proceedings of the ASQ Annual Quality Congress, 2004.

[11] Cass et al., "SPICE for SPACE trials, risk analysis, and process improvement". Software Process: Improvement and Practice, vol.9, no.1, pp.13-21, 2004.

[12] SIG A., "Automotive SPICE - Process Assessment Model", The Procurement Forum, 2007.

[13] Rout T. and Dorling A., "ISO/IEC 15504 (SPICE) A Status Report". SPICE Conference, 2005.

[14] Moore J. W., "An Integrated Collection of SoftwareEngineeringStandards,"IEEESoftware,November/December 1999, pp. 51-57.

[15] Salviano, C. F., Zoucas, A. C., Silva, J. V. L., Alves, A. M., Wangenheim, C. G., and Thiry, M., "A Method Framework for Engineering Process Capability Models".16th European Systems and Software Process Improvement and Innovation, pp. 6.25-6.36, 2009, Madrid, Spain.

[16] Kitchenham B.A., "Procedures for Performing Systematic Reviews". Tech. Report TR/SE-0401, Keele University, 2004.

[17] Fabbrini F. et al., "Integrating joint reviews with automotive SPICE assessments results". Lecture Notes in Computer Science, vol.5007, 2008.

[18] J. Lee et al., "An Overview of the Business Process Maturity Model (BPMM)". Lecture Notes in Computer Science, Volume 4537/2010, Springer, 2007.

[19] Ratneshwer G., "A maturity model for CBSE". 2nd India Software Engineering Conference, pp. 127-128, 2009.

[20] Torgersson J. and Dorling A., "Assessing CBD -What's the Difference?" pp.332, 28th Euromicro Conference, 2002. [21] Sen A. et al., "Data Warehousing Process Maturity: An Exploratory Study of Factors Influencing User Perceptions". IEEE Transactions on Engineering Management, vol. 53, no. 3, pp.440–455, 2006.

[22] Visconti M. and Cook C., "Software system documentation process maturity model". ACM Conference on Computer Science, pp. 352-357, 1993.

[23] Mengxing H. et al., "E-government maturity model and its evaluation". Journal of Southeast University Vol. 24, No. 3, pp. 389-392, 2008.

[24] Marshall S. and Mitchell G., "Applying SPICE to e-Learning: An e-Learning Maturity Model". Conferences in Research and Practice in Information Technology, Vol. 30, pp.185-191, 2004.

[25] Marshall, S. and Mitchell, G., "Benchmarking International E-learning Capability with the E-Learning Maturity Model". EDUCAUSE, 2007.

[26] Cass A. et al., "SPiCE in Action - Experiences in Tailoring and Extension," 28th Euromicro Conference, pp.352, 2002.

[27] Pušnik M. et al., "Extending Information System Integrability Index with CMM Model. A Preliminary Proposal". 29th Int. Conference on Information Technology Interfaces. pp. 145-150, 2007.

[28] Ibrahim L. and Pyster A., "A Single Model for Process Improvement," IT Professional, vol. 6, no. 3, pp. 43-49, 2004.

[29] Feng J., "A Knowledge Management Maturity Model and Application". Technology Management for the Global Future, 2006. Vol. 3, pp. 1251-1255, 2006

[30] April A. et al., "SMCMM Model to Evaluate and Improve the Quality of the Software Maintenance Process," 8th Euromicro Working Conference on Software Maintenance and Reengineering, pp.243, 2004.

[31] Díaz-Ley M. et al., "MIS-PyME Software Measurement Maturity Model-Supporting the Definition of Software Measurement Programs", Lecture Notes in Computer Science. vol. 5089, 2009.

[32] Mccaffery F. and Coleman G., "Developing a configuration management capability model for the medical device industry". Int. Journal of Information

Systems and Change Management vol.2, no.2, pp.139-154, 2007.

[33] Bovee M. et al.," A framework for assessing the use of third-party software quality assurance standards to meet FDA medical device software process control guidelines". IEEE Transactions on Engineering Management,

vol.48, no. 4, pp.465-478, 2001.

[34] Capone J. et al., "Concepts for a network maturity model". IEEE Workshop on Application - Specific Software Engineering and Technology, 1998.

[35] Ciolkowski M. and Soto M., "Towards a Process Maturity Model for Open Source Software". 32nd Annual IEEE Int. Computer Software and Applications Conference, pp.1213-1214, 2008.

[36] Scholz A. and Schmietendorf A., "A risk-driven Performance Engineering Process Approach and its Evaluation with a Performance Engineering Maturity Model". 15th UK Performance Engineering Workshop, 1999

[37] Hoyer C. and Chroust G., "Evolving Standard Process Reference Models for Product Line Development". Software Engineering and Advanced Applications, pp.320-327, 2006.

[38] Taramaa J. et al., "Product-Based Software Process Improvement for Embedded Systems," Euromicro, vol. 2, pp.20905, 1998.

[39] Hamann D. et al., "Dependency Definition Method". Workshop on Software Process and Product Improvement, 1998.

[40] Fonseca J. and Almeida J., "CMMI RAMS Extension Based on CENELEC Railway Standard". Lecture Notes in Computer Science, Springer, Vol.3688, 2005.

[41] Fraser M. and Vaqishnavi V., "A formal specifications maturity model". Communications of the ACM, Vol.40, no.12, pp.95-103, 1997.

[42] Beecham S. et al., "Using an expert panel to validate a requirements process improvement model". Journal of Systems and Software, Vol.76, no. 3, pp.251-275, 2005.

[43] Beecham, S. et al., "Building a requirements process improvement model". Software Process: Improvement and Practice, 2003. [44] Le J. et al., "A CC-based Security Engineering Process Evaluation Model" 27th COMPSAC, pp.130, 2003.

[45] Lee E. and Lee M., "Development System Security Process of ISO/IECTR15504 and Security Considerations for Software Process Improvement". Lecture Notes in Computer Science, Springer, vol.3481, pp. 363-372, 2005.

[46] Hefner R., "Lessons learned with the systems security engineering capability maturity model", 19th Int. Conference on Software Engineering, p.566-567, 1997.

[47] Daneshgar F. et al., "Representation of knowledge in information technology Service Capability Maturity Model (IT Service CMM)". Research Challenges in Information Science, pp.215-226, 2008.

[48] Qiao H. and Zhao Q., "Research on Third Party Logistics Service Capability Maturity Model". IEEE International Conference on Service Operations and Logistics, and Informatics, vol.2, pp.2858-2861, 2008.

[49] Wangenheim C. et al., "Standard based software process assessments in small companies". Software Process Improvement and Practice, vol.11, no. 3, pp.329-335, 2006.

[50] Wangenheim C. et al., "Helping small companies assess software processes". IEEE Software, vol.23, no.1, pp.91-98, 2006.

[51] Varkoi T. et al., "Process improvement priorities in small software companies". Portland Int. Conference on Management of Engineering and Technology, pp.555, 1999.

[52] Laporte C. Y.et al., "Developing International Standards for Very Small Enterprises". IEEE Computer, Vol.41, Iss.3, pp.98-101, 2008.

[53] Pino F. J.et al., "Adaptation of the standards ISO/IEC 12207:2002 and ISO/IEC 15504:2003 for the assessment of the software processes in developing countries", IEEE Latin America Transactions, vol.4, no.2, pp.85-92, 2006.

[54] Zeineddine R. and Mansour N., "Software Quality Improvement Model for Small Organizations". Lecture Notes in Computer Science, Springer, vol.2869, 2003.

[55] Laryd A. and Orci T., "Dynamic CMM for Small Organizations". 1. Argentine Symposium on Software Engineering, pp.133-149, 2000.

[56] Oktaba H. et al., ""Software Process Improvement: The Competisoft Project". IEE Computer, vol.40, no.10, pp.21-28, 2007.

[57] Laporte C. et al., "Initiating Software Process Improvement in Small Enterprises: Experiment with Micro-Evaluation Framework". Int. Conference on Software Development, pp.153-163, 2005.

[58] Rocha A. R. et al., "Process Reference Model and Assessment Method". Lecture Notes in Computer Science, Springer, vol.3733, 2005.

[59] Weber K. et al., "Brazilian Software Process Reference Model and Assessment Method". Lecture Notes in Computer Science, Springer, vol.3733, 2005.

[60] Paulk M. C. et al., "Capability Maturity Model, Version 1.1", IEEE Software, vol.10 n.4, p.18-27, 1993.

[61] Kuvaja P., "BOOTSTRAP: A software process assessment and improvement methodology". Lecture Notes in Computer Science, Springer, vol.926, pp.31-48, 1995.

[62] Cass et al., "SPICE for SPACE: A Process Assessment and Improvement Method for Space Software Development", European Space Agency Bulletin 107, 2001.

[63] Mahmood N. et al, "A maturity model for the implementation of software process improvement: an empirical study", Journal of Systems and Software, Vol.74, n.2, pp.155-172, 2005.

[64] April A. and Coallier F., "Trillium: a model for the assessment of telecom software system development and maintenance capability", 2nd IEEE Software Engineering Standards Symposium, pp.175, 1995.

[65] Rana K. and Ahmad S., "Bringing maturity to test". Electronics Systems and Software, vol.3, no.2, 2005.

[66] Burnstein I. et al., "Developing a Testing Maturity Model, Part II", Crosstalk, September, 1996.

[67] Bush M., "Modern Software Assurance and a Five-Level Model of Software Assurance Maturity", Journal of High Integrity Systems, 1.2, pp.157-169, 1994.

[68] Jacobs J and Trienekens J., "Towards a Metrics Based Verification and Validation Maturity Model", 10th Int. Workshop on Software Technology and Engineering Practice, pp.123, 2002.

[69] Ericson T. et al., "TIM - a test improvement model". Software Testing, Verification and Reliability, Vol.7, Iss.4, pp.229-246, 1996.

[70] Kyung-A Y. et al., "A Framework for the V&V Capability Assessment Focused on the Safety-Criticality".13th IEEE Int. Workshop on Software Technology and Engineering Practice, pp.17-24, 2005

[71] Ramachandran M., "A Process Improvement Framework for XP Based SMEs". Lecture Notes in Computer Science, Springer, vol.3556, pp.202-205, 2005.

[72] Nawrocki J. et al., "Toward maturity model for extreme programming", 27th Euromicro Conference, pp.233-239, 2001.

[73] McCafferry F. et al., "Ahaa - Agile, Hybrid Assessment Method for Automotive, Safety Critical SMEs". 30th Int. Conference on Software Engineering, pp.551-560, 2008.