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Re-defining the Requirements Engineering Process Improvement Model

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***Abstract*—A specialized Requirements Capability Maturity Model (R-CMM) was created by a group of researchers from UK as an attempt to support the requirements engineering phase of software development. The validation performed to this model shows that it has some potentials to be a useful tool for both practitioners and researchers in the field of process improvement and requirements engineering. However, the R-CMM focuses on the requirements engineering process defined within the retired Software Engineering Institute's (SEI's) Software Capability Maturity Model (SW_CMM) process improvement framework. To continue its relevance and usefulness, we re-define the whole R-CMM within the characteristics of the latest Capability Maturity Model for Integration (CMMI) for Development (CMMI-DEV) v1.2. This paper describes how the CMMI-DEV characteristics are used to re-define the R-CMM, and rationale for re-building the requirements engineering model based on the latest process improvement framework. Also, this paper explains how the re-defined R-CMM adapts to the goals and practices set by the CMMI-DEV.**

Keywords-requirements engineering (RE); RE process improvement; model

I. INTRODUCTION

Requirement Engineering (RE) is a very important part of software development yet getting requirements right continues to be a universal problem [1]. A study in 12 UK companies described in [1],[2] shows that of all the development problems, 48% stem from requirements. This finding is supported by a similar study conducted in 11 Australian companies in [3] and by another study in [4]. Requirements errors can be costly in term of lost time, lost revenue, loss of reputation and even survival. It is estimated that correcting the requirements errors late (e.g., during maintenance) can cost up to 200 times as much as correcting the errors during the requirements phase [5].

A RE process is a structured set of activities which are followed to derive, validate and maintain a systems requirements document [6]. There are RE standards available such as the IEEE Recommended Practice for Software Requirements Specifications [7], and the IEEE Guide for Developing System Requirements Specifications [8] that set out general principles or give detailed guidance for particular activities or documents. However, these standards offer no aid for selecting appropriate methods or for designing a RE process optimized for a particular organization [9]. This problem and other problems related to the RE process have motivated RE process assessment and improvement works by several researchers such described in [6],[9],[10],[11],[12],[13],[14].

Surveys such as that reported in [15] clearly demonstrate that RE process improvement is an important issue. Companies interested in RE process improvement now have a choice of at least three Requirements Engineering improvement models reviewed in [16]: the Requirements Engineering Good Practice Guide (REGPG) [6], the Requirements Engineering Process Maturity Model (REPM)[17], and Requirements Capability Maturity Model (R-CMM)[10],[18]. All the three models were built based on the Software Engineering Institute's (SEI's) Software Capability Maturity Model (SW_CMM). The REGPG is the most widely known and has been validated across a range of application domains but is a complex model [13]. The REPM is applicable only for project evaluation and not evaluation of an organization's process maturity [17]. Of all the three RE process improvement models, the R-CMM has the potential to offer substantial benefits to organizations if future development can complete it [9]. Hence, we decided to enhance the R-CMM and explain why and how we do it in this paper.

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A. Motivation for Re-building the R-CMM

Beecham et al. in their papers [10],[18],[19] introduce the R-CMM model as an attempt to help practitioners reduce their RE problems. The R-CMM was validated by a group of software process improvement (SPI) and RE experts [20]. The validation results show that the R-CMM is able to help RE practitioners to identify their priorities and guidance needed toward solving their RE problems within a software development context [20]. However, parts of the R-CMM are only exist in draft form and also the model was built based on an assumption that the SW_CMM will continue to be supported by the SEI as an integral component of the CMMI [18],[20]. Hence, when SW_CMM was totally retired and no longer supported by the Software Engineering Institute (SEI) since December 31, 2007 [21], we consider that the existence of the R-CMM is also no longer valid just like the SW_CMM. We are primarily motivated by this reason to continue the R-CMM's relevance and usefulness to the practitioners by re-building the model.

We re-build the R-CMM mainly by changing the model to be based upon the latest version of the CMMI framework and name the new model as R-CMMi. The additional letter 'i' to the original model name means 'improved' version of the R-CMM which represent the aim we hope to achieve from this work.

B. Rationale for Re-building the R-CMM based on the CMMI

Basing the R-CMMi on the latest version of a known software process improvement framework offers the user several advantages. The recent CMMI framework supports multiple constellations called CMMI for Development (CMMI-DEV), CMMI for Services (CMMI-SVC) and CMMI for Acquisition (CMMI-ACQ) [22]. The R-CMMi is re-built based on the CMMI-DEV version 1.2 which was released in August 2006. Amongst the rationale for basing our model on this CMMI-DEV is that:

- The CMMI-DEV is being adopted worldwide and remains a de facto standard for "software-intensive system development" [22]. Any company already using the CMMI-DEV should find the R-CMMi easy to apply and use.
- It contains additional guidelines for RE practices on top of the existing RE practices included in the previous versions of the framework. The additional practices are grouped under the Key Process Area (KPA) named Requirements Development (RD)[22]. These RE practices are integrated with the software development.
- Like the SW_CMM, the CMMI-DEV is designed to be tailored and adapted to focus on specific needs as it is a normative model [23]. As discussed by Philips in [22], community that is interested in focusing at specific area of process improvement may need to "provide interpretive guidance or expanded coverage of specific practices and goals" for the area.

The R-CMMi generally taps into the strength of the CMMI-DEV and reflect the update made to the framework to re-built the RE specialized model. Like the R-CMM, this model take practitioners from a high level view of the RE practices, through to a detailed descriptions and to a process assessment method to guide companies towards satisfying their specific RE process improvement and general company goals.

This paper is organized as follows: In section two we provide an overview of the R-CMM. In section three we introduce R-CMMi and in section four we present the detailed of Level 2 of the R-CMMi. Section five describes possible future work, and section six summarizes and concludes this paper.

II. THE REQUIREMENTS-CAPABILITY MATURITY MODEL: AN OVERVIEW

The R-CMM is also known as the University of Hertfordshire Model [9]. The R-CMM is a direct adaptation of the SW_CMM framework for Requirements Engineering processes (shown in Fig.1). The rationale given is to enable practitioners to use the model in conjunction with on-going SPI activities. Yet, it can still be used independently of the SW_CMM to assess Requirements Engineering capability in organizations. This model was built based upon the SW_CMM, thus it uses a staged architecture but process assessment is continuous.

The R-CMM uses the five SW_CMM maturity levels to classify RE processes. This model uses a Goal Question Metric (GQM) approach to guide companies to look at their current practices and set realistic goals when planning for requirements engineering process improvement. The R-CMM levels, goal and focus for each level are [18]:

- R-CMM Level 1: The goal is to raise awareness of the requirements process.

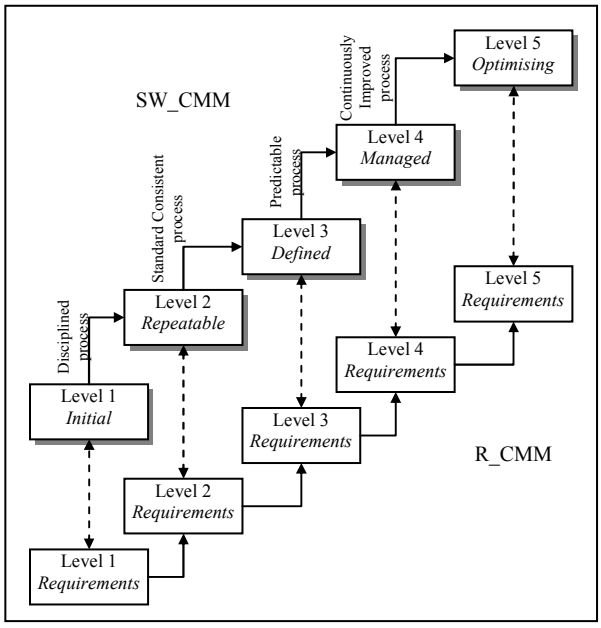

Figure 1. The R-CMM 5 level framework [18]

- R-CMM Level 2: The goal is to implement a repeatable requirements process and company at this level should focus on project level standards.
- R-CMM Level 3: The goal is to implement a defined requirements process and company at this level should focus on organization wide communication and standards.
- R-CMM Level 4: The goal is to implement a managed requirements process. A company at this level should focus on measurement.
- R-CMM Level 5: The goal of this level is to implement an optimizing requirements process. A level 5 company should focus on continuous improvement.

The goal in each maturity level is then decomposed into five requirements related questions that are used to recognized requirements engineering process stages (called phases). The phases are requirements management, elicitation, analysis and negotiation, documentation, and verification and validation. Each phase in the R-CMM defines a set of processes (called key processes) at each maturity level. This model recognizes a total of 68 processes from three main sources: the SW_CMM, empirical research (including [1]), and literature. To aid interpretation and correct implementation, a more detailed guideline (in terms of sub-processes) for each process was planned. However, only detailed guideline of level 2 was found in the literature. The set of processes and process description of levels 3 to 5 currently exist in draft form.

Process assessment of the R-CMM is carried out by allocating a score (outstanding=10, qualified=8, originally qualified=6, fair=4, weak=2, and poor=0) to each process against three assessment criteria (approach, deployment, and results). The average of the score for approach, deployment and results are recorded for each process. Then the scores are summed for each phase and the sum of all five phases yields an overall/ capability score (0→2: Level 1, 3→4: Level 2, 5→6: Level 3, 7→8: Level 4, 9→10: Level 5) that highlights where their requirements process weakness lie [24].

III. THE R-CMMi FRAMEWORK

Fig. 2 depicts the R-CMMi framework and places it in context with the CMMI-DEV. This high-level view of the model shows how the RE process matures from an initial RE process to an optimizing RE process level. The main difference between the R-CMM and the R-CMMi, in terms of RE maturity level, is at level 2 and level 4 which can be seen by comparing Fig 1 and Fig. 2. These RE maturity levels describe an evolutionary path for an organization that wants to improve its RE process. RE maturity levels may be determined by performing an assessment to the RE practices. Like the CMMI-DEV, the assessment can be performed for organizations that comprise entire companies (usually for small companies), or group of projects within a company. However, unlike the CMMI-DEV that has two representations for you to approach process improvement and appraisal [22], the R-CMMi only uses a staged improvement path. In this paper, we use the term "RE maturity level" or "RE level" interchangeably.

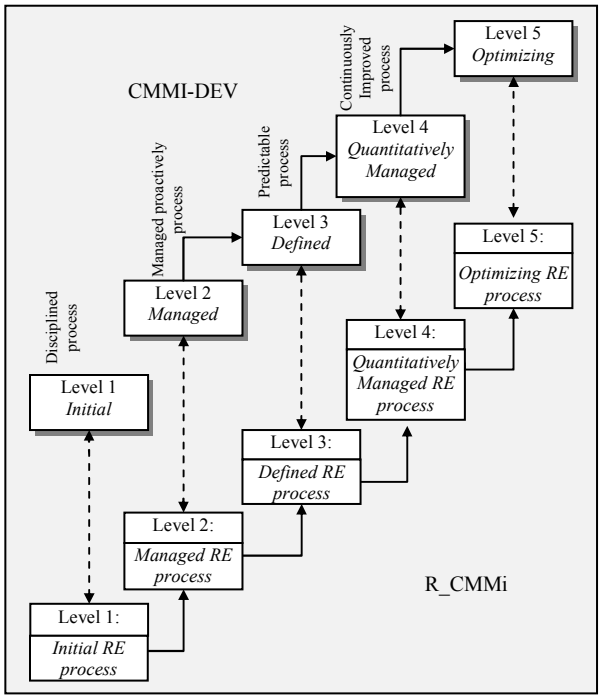

Figure 2. The R-CMMi framework

For an organization to reach a particular RE maturity level, it must satisfy all of the set of RE practices that are targeted for improvement. This process assessment method is adapted from the Standard CMMI Appraisal Method for Process Improvement (SCAMPI) Version 1.2 developed by the SEI as described in [25]. The term assessment implies that an organization can perform appraisal to and for itself and assessments are intended to motivate organizations to initiate or continue software process and RE process improvement programs.

A. RE Maturity Level 1: Initial

At maturity level 1, RE process is usually ad hoc and chaotic. Usually the maturity level 1 organization does not defined its RE process and practices and does not provide a stable environment to support the RE process. As described in [22], success at this RE level depends on "the competence and heroics of the people in the organization and not on the use of proven processes". Also, RE maturity level 1 organizations often produce products that work but they "frequently exceed their budgets and do not meet their schedules" [22].

Based on the survey discussed in [2], the common problems found in level 1 organization relates to "vague requirements, lack of traceability, undefined RE process, insufficient RE resource, lack of training and poor levels of skills" [18]. Thus, a general improvement goal for maturity level 1 organization with ad hoc RE process is to mature to level 2 where their RE process become managed.

B. RE Maturity Level 2: Managed

Requirements Management (REQM) is a level 2 key process area in the CMMI-DEV. The R-CMMi reflects this by creating a detailed model (described in section 4) with focus given to the practices of the requirements management phase. Apart from relying on the R-CMM and CMMI-DEV for maturity characteristics, we also refer to the RE literature for complimentary RE practices. Hence, at maturity level 2, RE process is planned and executed in accordance with policy; requirements changes are managed, requirements traceability is maintained; requirements status tracking is established; involve relevant stakeholders; RE process plan is in place; adequate resources are allocated; RE process is monitored, controlled and reviewed; and RE process adherence is evaluated.

In the spirit of continuous improvement, a level 2 organization should be working towards achieving level 3 maturity.

C. RE Maturity Level 3: Defined

At maturity level 3, RE process is established in organizational standard, procedures, and methods and improved over time. The standard RE process is used to establish consistency across the organization. Also, at this level, RE process is described more rigorously than at maturity level 2. A defined RE process clearly states the practices to elicit needs, analyze, negotiate, document, and verify and validate requirements. At maturity level 3, "the organization must further mature the maturity level 2" [18] practices and RE process is managed proactively.

In general, the R-CMMi adapts the generic and specific practices of the Requirements Development (RD) key process area (in level 3 of the CMMI-DEV) and adds complimentary RE practices from the literature in model.

D. RE Maturity Level 4: Quantitatively Managed

At maturity level 4, the organization and project establish quantitative objectives for product quality and RE process performance and use them in managing the RE process. Quantitative objectives are "based on the needs of the customer, end users, organization, and process implementers" [22] and RE process performance is "understood in statistical terms and is managed throughout the life of the process" [26]. Focus is also given to the planning and performing of quantitative requirements management process. At maturity level 4, the RE process performance and requirements management process, particularly, are controlled using quantitative techniques and are quantitatively predictable. At this maturity level, the R-CMMi is guided primarily by the R-CMM and we also rely on the CMMI-DEV to specify the RE practices.

E. RE Maturity Level 5: Optimizing

At maturity level 5, an organization continually improves its RE process through quantitative understanding of the common causes of the RE problems. Unlike the level 5 of the R-CMM that only focuses at the "requirements defect prevention activities" [19], the R-CMMi maturity level 5 also focuses on continually improving the RE process performance through "incremental and innovative" [22] process improvements. At maturity level 5, quantitative RE process improvement objectives for the organization are established, continually monitored, controlled and revised to continually reflect changing business objectives, and used as criteria in managing the RE process improvement.

In other words, at maturity level 5, not only organization is concerned with addressing the common causes of RE problems but also with changing the RE process to improve process performance and to achieve the established quantitative RE process performance objectives.

IV. R-CMMI LEVEL 2: AN EXAMPLE

This section gives example of the RE maturity level 2 R-CMMi. Unlike the R-CMM that is built using the GQM approach, the R-CMMi structure adapts the structure of the staged representation of CMMI-DEV. Fig. 3 illustrates the structure of this model. At each maturity level, organization need to implement several RE practices to achieve the RE goal for the specific level. For each RE practice, we provide a list of sub-practices, typical work product and practice elaboration to guide assessment and identification of an organization's strengths and weaknesses. Practices describe what an organization must implement to achieve a RE goal. Sub practices, typical work product and practice elaboration are, however, optional components which provide details to help organization approach a RE practice.

The R-CMMi level 2 has 20 RE practices needed to achieve managed RE goal explained in section 3.2. Table 1 lists the 20 RE practices and the mapping of the practices with the R-CMM processes and the CMMI-DEV's specific goal (SG), specific practice (SP), generic goal (GG), and generic practices (GP). A practice with empty cell for the mapping column indicates that it is a recommended complimentary practice which we adapt from the literature. At this maturity level, requirements management practices are put in place so that RE process is performed and managed according the its documented plan.

Each RE practice listed in Table 1 has its practice guideline which consists of sub practices, typical work products and practice elaboration similar to the example given in Fig. 4.

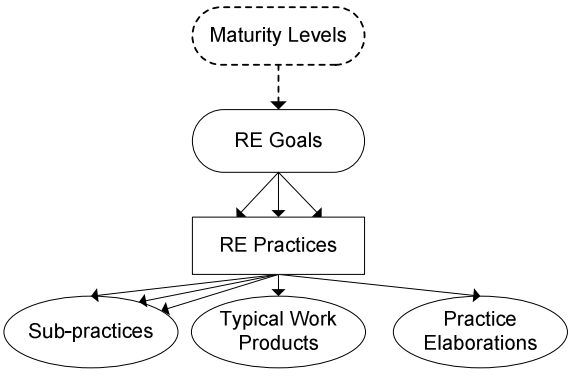

Figure 3. The R-CMMi structure

TABLE I. LEVEL 2 R-CMMI

Practices		CMMI SP, SG, GP; R-CMM processes (P)[a]
P1	Establish an Organizational Policy for Planning and Performing Requirements Engineering Process	P1 (indirectly) GP 2.1
P2	Plan the Requirements Engineering Process	GP 2.2 PP SP 2.4 - 2.6
P3	Provide Resources for Performing Requirements Engineering Process	P5 (indirectly) B5 GP 2.3
P4	Assign Responsibility for Performing Requirements Engineering Process	P2, B2 (indirectly) GP 2.4
P5	Train People for Performing Requirements Engineering Process	P3 (indirectly) P6 (indirectly) B3 B6 (indirectly) GP 2.5 OT SG 2
P6	Establish Process to Assess Feasibility and External Environment of the Project	P12 B11
P7	Identify and Involve Relevant Stakeholders of the Requirements Engineering Process	P4 B4 P10 GP 2.7
P8	Explore Alternative Solutions, Techniques and Tools Support for the Requirements Engineering Process	P8
P9	Monitor and Control the Requirements Engineering Process	P18 GP 2.8
P10	Objectively Evaluate Adherence of the Requirements Engineering Process	GP 2.9 P18 (indirectly)
P11	Review Requirements Engineering Status with Higher Level Management	P20 GP 2.10
P12	Obtain an Understanding of Requirements	P9 (indirectly) P15 (indirectly) P17 (indirectly) REQM SP 1.1
P13	Obtain Commitment to Requirements	P19 (indirectly) REQM SP 1.2
P14	Establish a Requirements Change Management Process	GP 3.1
P15	Manage Requirements Changes	P16 REQM SP 1.3
P16	Maintain Bi-directional Traceability of Requirements	P13 REQM SP 1.4
P17	Manage Configurations of the Requirements Engineering Process	REQM GP 2.6
P18	Perform Requirements Status Tracking	
P19	Identify Inconsistencies Between Project Work & Requirements	REQM SP 1.5
P20	Institute Process to Maintain Stability within Project	P7 B7 (indirectly)

a. PP – Project Planning
REQM – Requirements Management
OT – Organizational Training
SP – Specific Practice
GP – Generic Practice

P2. Plan the Requirements Engineering Process

Description
Establish and maintain the plan for performing the requirements engineering process.

Practice Elaboration
1. *Uniquely identify requirements.*
2. *Identify stable and volatile requirements.*
3. *Identify reusable requirements.*
4. *Identify the real (actual) requirements.*

Subpractices
1. *Plan for requirements identification, elicitation, and storage.*
2. *Plan for necessary resources needed to perform the project.*
3. *Plan the involvement for identified stakeholders.*
4. *Establish and maintain the overall requirements engineering plan content.*

Typical Work Product
1. *Requirements engineering plan*

Figure 4. Example of a RE practice guideline

The R-CMM assessment method, as explained in section 2, was developed based on an internal assessment procedure implemented by Motorola as mentioned in [18], [27]. However, we prefer to apply a different assessment method to the practices in this model. The SCAMPI version 1.2 is considered more appropriate as it was designed to provide "benchmark-quality rating" relative to CMMI and is "applicable to a wide range of appraisal usage modes, including both internal process improvement and external capability determinations" [25]. Similar to the SCAMPI version 1.2, a RE practice of a RE maturity level in the R-CMMi assessment process is rated either "fully implemented (FI)", or "largely implemented (LI)", or "partially implemented (P)" or "not implemented (NI)" or "not yet (NY)". For an organization to mature at a RE maturity level, all of the defined set of RE practices for the RE level must be rated either FI or LI.

V. FUTURE WORK

The work to create the R-CMMi is nearly completed. Next stage is validation of the model. However, before we could validate it, we need to consider how best to present the model in a way that is "clear, appropriate for the users and easy to use" [19]. Currently, we are in this stage and we are preparing a tool that can help organization performs its internal process appraisal, finds its strengths and weaknesses, and be presented with an improvement suggestion which could be adapted by the RE practitioners in the organization.

The R-CMM was validated by a group of 20 software process improvement and RE experts panel invited to examine the RE model components and to complete a detailed questionnaire. Apart from the detailed explanation in [20], the uses of expert panel for various purposes including to validate a model are discussed also in [28],[29],[30]. Our plan is to invite several RE expert panels to participate in the validation process of the R-CMMi. However, validation to the R-CMMi will mainly involve RE experts in Malaysian software companies. We have yet to determine the number

of participants but we hope to get as many as possible. Also, we foresee a possibility of conducting a few cycles of pre-validation and model's correction before a final validation could be performed to the model.

VI. CONCLUSION

In this paper, we describe why and how we have created the R-CMMi from the R-CMM by adapting the CMMI-DEV software process improvement framework. The R-CMMi inherits and retains the characteristics of the CMMI-DEV and the R-CMM in order to build on proven, continually supported methods and promote a "smooth transition for practitioners familiar with CMM techniques" [18]. The RE maturity level 2 details and process assessment description also included in the paper show how practitioners are guided towards recognizing their own RE process strengths and weaknesses.

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