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Best practice fusion of CMMI-DEV v1.2 (PP, PMC, SAM) and PMBOK 2008

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ABSTRACT

Context: The establishment of effective and efficient project management practices still remains a challenge to software organizations. In striving to address these needs, "best practice" models, such as, CMMI or PMBOK, are being developed to assist organizations interested in improving project management. And, although, those models share overlapping content, there are still differences and, therefore, each of the models offers different advantages.
Objective: This paper proposes a set of unified project management best practices by integrating and harmonizing on a high-level perspective PMBOK (4th ed.) processes and CMMI-DEV v1.2 specific practices of the basic project management process areas PP, PMC and SAM.
Method: Based on the analysis of both models, a unified set of best practices has been defined by a group of researchers with theoretical and practical expertise on the CMMI framework and software process improvement as well as project management and the PMBOK. The proposed set has been revised by different researchers from different institutions in several review rounds until consensus was achieved.
Results: As a result, a set of unified best practices is defined and explicitly mapped to the correspondent PMBOK processes and CMMI specific practices of the current versions of both models.
Conclusion: We can conclude that an integration and harmonization of both models is possible and may help to implement and assess project management processes more effectively and efficiently, optimizing software process improvement investments.

1. Introduction

Despite many improvement efforts, many software projects still have problems to deliver on time late, within budget, with all the required features and functions [1]. Among the reasons for those problems is a lack of project management [2,3]. This indicates that the establishment of effective and efficient project management practices still remains a challenge to software organizations. In striving to address these needs, "best practice" models are being developed to assist organizations with an interest in improving project management. This includes, software process capability/maturity models, such as CMMI – Capability Maturity Model Integration (http://www.sei.cmu.edu/cmmi), which guides the assessment and improvement of organizational maturity and process capability for the development of products and services, mainly, in the software sector. On the other hand, there exists several best practice models specifically related to project management, such as, the Guide to the Project Management Body of Knowledge (PMBOK) [4], which provides guidelines for managing individual projects and describes the project management lifecycle and the related processes. PMBOK also represents the reference model of the Organizational Project Management Maturity Model (OPM3) [5], a project management maturity model for the assessment and improvement of organizational project management processes.

In this respect, PMBOK and the definition of project management process areas of CMMI both represent collections of best practices for project management. Both models share overlapping content with regard to project management, but as there are still differences, each of the models offers different advantages. In this context, an organization intending to improve its project management practices may be confused by deciding on which model to adopt or, when considering several, resulting in an ineffective implementation with overlaps duplicating efforts. Or, the assessment of the organizational process in alignment with both models

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may lead to the repeated collection of the same evidence and, thus, may increase unnecessarily assessment costs and duration.

Yet, there have been only sparse efforts on the integration of both models with respect to project management processes. Harmonizing and integrating both models may complement each other and, in practice, enhance the project management efficiency and effectiveness in an organization driving more coherent and complete project management efforts [6]. A single unified set of best practices can provide an efficient and effective mechanism for assessing and improving processes [7].

Using such a set of integrated best practices allows, for example, an assessment based on various models simultaneously, where only a single set of evidence needs to be collected addressing both models in parallel, preventing redundancy. The explicit tracking of the unified best practices to the source models allows generating separate results for each of the underlying models based on a single set of collected evidence. And, consequently, reduce assessment time and cost and, thus, optimize SPI investments.

In this article, we explore the similarities and differences of two prominent best practice models (CMMI and PMBOK) with respect to basic project management best practices and propose a set of unified best practices. Initiating this work, we focus in this paper on basic software project management best practices (covering PP – Project Planning, PMC – Project Monitoring and Control and SAM – Supplier Agreement Management). In this context, we also limit our work on considering the process area definitions themselves, not taking into consideration the process capability dimension.

To contextualize this article, we first present a brief overview on the CMMI framework in Section 2 and PMBOK in Section 3. Then, we analyze both models with respect to project management processes and propose a unified set of best practices for project management in Section 4. In Section 5, we discuss the results also in respect with related work.

2. CMMI framework

Capability Maturity Model Integration (CMMI) (http://www.sei.cmu.edu/cmmi) is a process improvement maturity model for the development of products and services. It consists of best practices that address development and maintenance activities that cover the product lifecycle from conception through delivery and maintenance. The purpose of the CMMI is to provide guidance for improving an organization's processes and its ability to manage the development, acquisition, and maintenance of products or services. The CMMI framework is developed in cooperation between the Software Engineering Institute (SEI) and organizations from US industry and government sponsored by the US Department of Defense (DoD) and the National Defense Industrial Association (NDIA)/USA.

The CMMI framework is the basic structure that organizes CMMI components, including common elements of the current CMMI models, as well, as rules and methods for generating models, their appraisal methods (including associated artifacts), and training materials. CMMI constellations have being generated supporting specific areas of interest. Currently three constellations of the CMMI framework are available: CMMI for Development (CMMI-DEV) [8], CMMI for Services (CMMI-SVC) [9] and CMMI for Acquisition (CMM-ACQ) [10]. Here, due to our focus on software development, we focus on *CMMI-DEV*. Its purpose is to help organizations improve their development and maintenance processes for both products and services, considering that project management PAs are shared between two of the three current CMMI constellations (DEV and SVC). Both constellations contain practices that cover project management, process management, systems engineering, hardware engineering, software engineering, and other supporting processes used in development and maintenance.

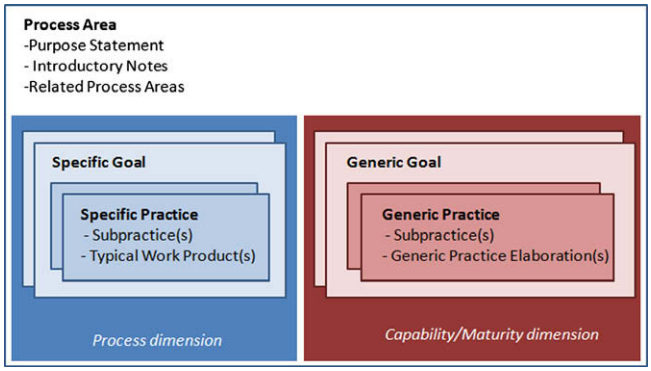

Fig. 1. CMMI model components.

Within the CMMI Product Suite, a project is defined as a managed set of interrelated resources which delivers one or more products to a customer or end user. A project has a definite beginning and typically operates according to a plan. Such a plan is frequently documented and specifies what is to be delivered or implemented, the resources and funds to be used, the work to be done, and a schedule for doing the work. A project can be composed of projects.

CMMI models are basically composed of a process area dimension and a capability/maturity dimension (as shown in Fig. 1).

In the CMMI models, a *process area* is a cluster of related practices in an area that, when implemented collectively, satisfy a set of goals considered important for making improvement in that area. CMMI-DEV v1.2 encompasses 22 process areas (PA) grouped in 4 categories: Process Management, Project Management, Engineering, and Support. Focusing on project management, the project management process areas in CMMI-DEV include the following process areas:

- *Project Planning:* The purpose of Project Planning (PP) is to establish and maintain plans that define project activities.
- *Project Monitoring and Control:* The purpose of Project Monitoring and Control (PMC) is to provide an understanding of the project's progress so that appropriate corrective actions can be taken when the project's performance deviates significantly from the plan.
- *Supplier Agreement Management:* The purpose of Supplier Agreement Management (SAM) is to manage the acquisition of products from suppliers.
- *Integrated Project Management + IPPD*[1]: The purpose of Integrated Project Management (IPM) is to establish and manage the project and the involvement of the relevant stakeholders according to an integrated and defined process that is tailored from the organization's set of standard processes. For IPPD, Integrated Project Management + IPPD also covers the establishment of a shared vision for the project and the establishment of integrated teams that will carry out objectives of the project.
- *Risk Management:* The purpose of Risk Management (RSKM) is to identify potential problems before they occur so that risk-handling activities can be planned and invoked as needed across the life of the product or project to mitigate adverse impacts on achieving objectives.
- *Quantitative Project Management:* The purpose of Quantitative Project Management (QPM) is to quantitatively manage the

[1] Integrated Project Management (IPM) includes one goal that applies only when using CMMI with the IPPD group of additions.

project's defined process to achieve the project's established quality and process-performance objectives.

These project management process areas are divided in basic and advanced process areas. The *basic project management* process areas address activities related to establishing and maintaining the project plan, establishing and maintaining commitments, monitoring progress against the plan, taking corrective action, and managing supplier agreements. PP includes developing the project plan, involving stakeholders appropriately, obtaining commitment to the plan, and maintaining the plan. When using IPPD, stakeholders represent not just the technical expertise for product and process development, but also the business implications of product and process development.

Planning begins with requirements that define the product and project. The project plan covers the various project management and development activities performed by the project. The project reviews other plans that affect the project from various relevant stakeholders and establish commitments with those stakeholders for their contributions to the project. For example, these plans cover configuration management, verification, and measurement and analysis.

PMC includes monitoring activities and taking corrective action. The project plan specifies the appropriate level of project monitoring, the frequency of progress reviews, and the measures used to monitor progress. Progress is determined primarily by comparing project status to the plan. When the actual status deviates significantly from the expected values, corrective actions are taken as appropriate. These actions may include re-planning.

SAM addresses the need of the project to acquire those portions of work that are produced by suppliers. Sources of products that may be used to satisfy project requirements are proactively identified. The supplier is selected, and a supplier agreement is established to manage the supplier. The supplier's progress and performance are tracked by monitoring selected work products and processes, and the supplier agreement is revised as appropriate. Acceptance reviews and tests are conducted on the supplier-produced product component.

Those basic project management process areas are associated with Maturity Level 2 (ML2) in the staged representation.

In the CMMI framework, each process area includes a set of related practices that collectively are required in order to achieve *specific goals* (*SG*). A specific goal is mapped to *specific practices* (*SP*), which describe the activities expected to result in achievement of specific goal of a process area. In addition, sub-practices, typical work products, amplifications, notes, and references can be associated to practices representing informative model components that help model users understand the goals and practices and how they can be achieved. *Typical work products* provide example outputs from a specific or generic practice. *Sub-practices* are descriptions that provide guidance for interpreting specific or generic practices, and may include examples. *Amplifications* provide guidance for interpreting model information for specific disciplines (e.g., software engineering). In addition, for each process area a *purpose* and *introductory notes* are given and *related process areas* can be identified as informative items.

On the other hand, the capability/maturity dimension of CMMI defines process area capability in the continuous representation and organizational maturity in the staged representation. This dimension of CMMI is used for benchmarking and appraisal activities as well as guiding an organization's improvement efforts. Here, due to our focus on basic project management best practices considering only Capability Level 1 for basic project management process areas, we do not further discuss capability/maturity aspects of CMMI.

3. PMBOK

The Guide to the Project Management Body of Knowledge (PMBOK) [4] is a recognized standard for project management. It provides guidelines for managing individual projects and defined project management and related concepts and describes the project management lifecycle and the related processes. PMBOK has been developed through a voluntary consensus standards development process coordinated by the Project Management Institute (PMI). Its current version (4th ed.) has been published in late 2008.

Following PMBOK, a project is understood as "*a temporary endeavour undertaken to create a unique product, service, or result*" [4]. In comparison to the CMMI framework, PMBOK makes a clear distinction between projects (which are temporary and end) and operational work, which is ongoing and sustains the organizations over time. In contrast to projects, operations work does not terminate when its current objectives are met but instead follow new directions to support the organization's strategic plans.

Following PMBOK, project management is understood as the application of knowledge, skills, tools and techniques to project activities to meet the project requirements. Project management is accomplished through the appropriate application and integration of 42 logically grouped project management processes comprising five process groups.

These process groups are (Fig. 2):

- *Initiating Process Group:* Processes performed to define a new project or a new phase of an existing project by obtaining authorization to start the project or phase.
- *Planning Process Group:* Processes required to establish the scope of the project, refine the objectives, and define the course of action required to attain the objectives that the project was undertaken to achieve.
- *Executing Process Group:* Processes performed to complete the work defined in the project management plan to satisfy the project specifications.
- *Monitoring and Controlling Process Group:* Processes required to track, review and regulate the progress and performance of the project; identify any areas in which changes to the plan are required; and initiate the corresponding changes.
- *Closing Process Group:* Processes performed to finalize all activities across all Process Groups to formally close the project or phase.

A process is a set of interrelated actions and activities performed to achieve a pre-specified product, result or service. Each process in PMBOK is characterized by its inputs, the tools and techniques that can be applied, and the resulting outputs (Fig. 3).

In this context, project management processes ensure the effective flow of the project throughout its existence. These processes encompass the tools and techniques involved in applying the skills and capabilities described in the nine Knowledge Areas, including:

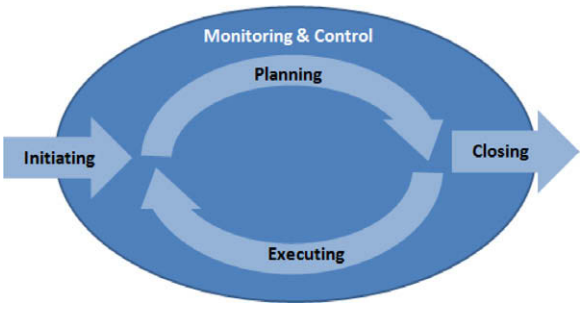

Fig. 2. Project management process groups [4].

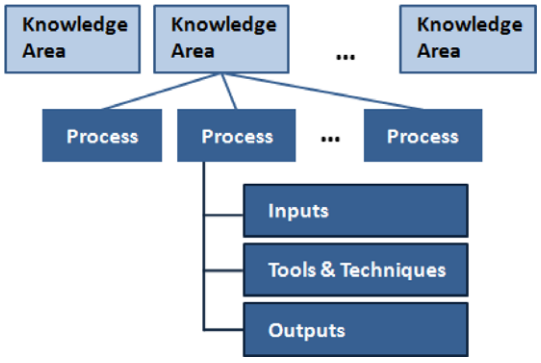

Fig. 3. PMBOK model components.

- Project Integration Management.
- Project Scope Management.
- Project Time Management.
- Project Cost Management.
- Project Quality Management.
- Project Human Resource Management.
- Project Communication Management.
- Project Risk Management.
- Project Procurement Management.

Based on PMBOK, PMI also developed OPM3 – the Organisational Project Management Maturity Model [3]. OPM3 provides a route by which organizations can advance their strategic goals through the application of Project Management principles and practices, and can be applied in any type or size of organization. OPM3 is a framework made up of three interrelated components: best practices, capabilities and outcomes all within the portfolio, program and project management domains. Yet, due to our focus here, we concentrate on PMBOK as a collection of best practices.

4. Integrating and harmonizing the project management best practices

With the intention to integrate and harmonize the best practices complementing each of the models, we propose a unified set of best practices (UBP) and map them to respective PMBOK processes and CMMI-DEV specific practices of basic project management process areas PP, PMC and SAM. The purpose of this integration is on one hand to complement each of the models and on the other hand to facilitate a simultaneous implementation and assessment of project management processes in conformance with both models.

The integration has been done by a group of senior and junior researchers at the LQPS (Laboratory for Software Quality and Productivity at UNIVALI/Brazil) and the Quality Group of the National Institute of Science and Technology for Digital Convergence at UFSC/Brazil, who have theoretical and practical expertise on the CMMI framework and software process improvement as well as project management and PMBOK. In a first step, the source models have been selected and analyzed, comparing their structure and identifying relevant elements within the scope of the present research. In several workshop meetings, the researchers defined a first set of UBPs interpreting and discussing both models. This has been done by discussing opinions on each of the practices/processes and deriving UBPs until consensus among the researchers was obtained. This set of UBP has been revised using a group decision making process, where the developed set of UBPs has been presented to two senior researchers with knowledge and experience on CMMI and PMBOK from different institutions, who expressed their opinions. Each of the comments has been analyzed by a moderator (one of the authors) and either accepted or, otherwise, in a new review round discussed with the external experts until consensus was reached. Fig. 4 illustrates the adopted research process based on [11,12].

The CMMI and PMBOK are both collections of best practices that have a project management focus. Yet, CMMI addresses project management of engineering endeavours and encompasses a broader scope while PMBOK addresses specifically project management on any kind of project or organization. And, although, both models have a project management focus, the structure of these models is different. While CMMI is composed of Process Areas (and capability/maturity dimensions) described by goals and practices, PMBOK is defined by Knowledge Areas (KA), Process Groups and Processes, where each of the processes is described in terms of inputs, tools and techniques and outputs [6]. In addition, PMBOK does not include a capability/maturity dimension, which is outside of the scope of PMBOK, covered by OPM3 as the corresponding organizational project management maturity model. Those structural differences also complicate the identification of equivalent components for a mapping of both models. As our objective is to propose a set of unified best practices, we analyze CMMI with respect to specific practices and PMBOK with respect to processes.

Based on a high-level comparison, we can observe that CMMI – as intended – addresses project management among other process area categories, whereas PMBOK addresses exclusively project management and, thus, most of CMMI-DEV process areas outside the project management category are not covered by PMBOK. Yet, in general on a high level view all project management Knowledge Areas of the PMBOK seem to be also covered by CMMI-DEV, although, not necessarily within project management process areas. For example, the PMBOK process Collect Requirements corresponds to practices of the CMMI Engineering process areas RD – Requirements Development and REQM – Requirements Management. Yet, due to our specific focus on basic project management practices in this paper, we limit our work here to the consideration of specific practices of the basic project management process areas of CMMI-DEV v1.2 (including PP, PMC and SAM) and Project Management Processes of the PMBOK 2008. In case, where correspond-

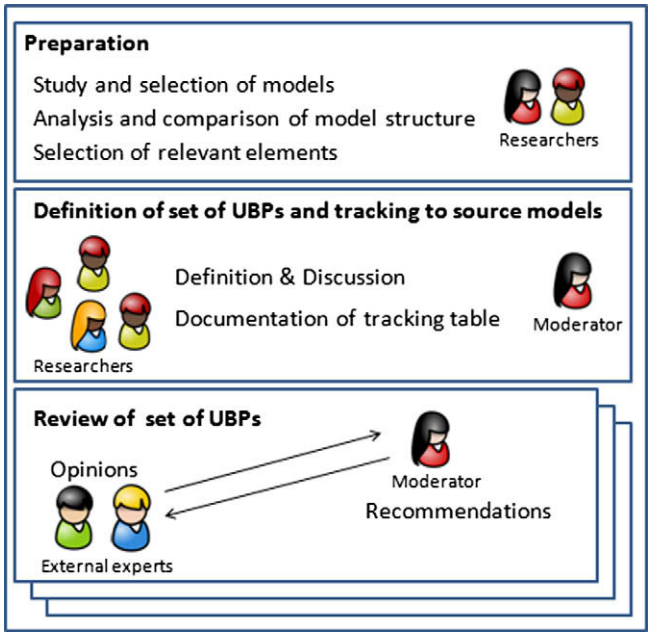

Fig. 4. Research process.

Table 1
Unified best practices (UBP) and their correspondence to the source models.

Unified best practice (UBP)	Description of UBP	CMMI-DEV v1.2:2006 (process area/specific practice)	Degree of coverage (*T*, *P*, –)	PMBOK 4th ed:2008 (project management process)	Degree of coverage (*T*, *P*, –)
Initiating Process Group					
I1. Develop Project Charter	Develop a document that formally authorizes a project or a phase and document initial requirements that satisfy the stakeholder's needs and expectations	–	–	4.1 Develop Project Charter	*T*
I2. Identify Stakeholders	Identify all people or organizations impacted by the project and document relevant information regarding their interest, involvement, and impact on project success	PP/SP 2.6 Plan Stakeholder Involvement	*T*	10.1 Identify Stakeholders	*T*
Planning Process Group					
P1. Define Project Lifecycle	Define the project lifecycle phases to be adopted in the project	PP/SP 1.3 Define Project Lifecycle	*T*	–	–
P2. Collect Requirements	Define and document stakeholders' needs to meet the project objectives	[RD and REQM]	Not considered here	5.1 Collect Requirements	*T*
P3. Define Scope	Develop a detailed description of the project and product	PP/SP 1.1 Estimate the Scope of the Project	*P*	5.2 Define Scope	*T*
P4. Create WBS	Subdivide project deliverables and project work into smaller, more manageable components	PP/SP 1.1 Estimate the Scope of the Project	*P*	5.3 Create WBS	*T*
P5. Define Activities	Identify the specific actions to be performed to produce the project deliverables	PP/SP 1.1 Estimate the Scope of the Project	*P*	6.1 Define Activities	*T*
P6. Establish Estimates of Work Product and Task Attributes	Establish and maintain estimates of the attributes of the work products and tasks	PP/SP 1.2 Establish Estimates of Work Product and Task Attributes	*T*	–	–
P7. Sequence Activities	Identify and document relationships among the project activities	PP/SP 2.1 Establish the Budget and Schedule	*P*	6.2 Sequence Activities	*T*
P8. Develop Human Resource Plan	Identify and document project roles, responsibilities, reporting relationships, and creating a staffing management plan	PP/SP 2.4 Plan for Project Resources	*P*	9.1 Develop Human Resource Plan	*P*
P9. Plan for Needed Knowledge and Skills	Plan for knowledge and skills needed to perform the project	PP/SP 2.5 Plan for Needed Knowledge and Skills	*T*	9.1 Develop Human Resource Plan	*P*
P10. Plan for Project Resources	Plan for necessary resources (labor, machinery/equipment, material and methods) to perform the project	PP/SP 2.4 Plan for Project Resources	*P*	6.3 Estimate Activity Resources	*T*
P11. Estimate Activity Durations	Approximate the number of work periods needed to complete individual activities with estimated resources	PP/SP 2.1 Establish the Budget and Schedule	*P*	6.4 Estimate Activity Durations	*T*
P12. Develop Schedule	Establish and maintain the project schedule, analyzing activity sequences, durations, resource requirements and schedule constraints to create the project schedule	PP/SP 2.1 Establish the Budget and Schedule	*P*	6.5 Develop Schedule	*T*
P13. Estimate Effort	Estimate the effort for completing the work products and tasks based on estimation rationale	PP/SP 1.4 Determine Estimates of Effort and Cost	*P*	–	–
P14. Estimate Costs	Estimate the monetary resources needed to complete the work products and tasks based on estimation rationale	PP/SP 1.4 Determine Estimates of Effort and Cost	*P*	7.1 Estimate Costs	*T*
P15. Determine Budget	Establish and maintain the project budget aggregating the estimated cost of individual activities or work packages.	PP/SP 2.1 Establish the Budget and Schedule	*P*	7.2 Determine Budget	*T*
P16. Plan Quality	Identify quality requirements and/or standards for the project and product, and document how the project will demonstrate compliance	[QPM]	Not considered here	8.1 Plan Quality	*T*
P17. Plan Communications	Determine project stakeholder information needs and define a communication approach	–	–	10.2 Plan Communications	*T*

(*continued on next page*)

Table 1 (*continued*)

Unified best practice (UBP)	Description of UBP	CMMI-DEV v1.2:2006 (process area/specific practice)	Degree of coverage (*T*, *P*, –)	PMBOK 4th ed:2008 (project management process)	Degree of coverage (*T*, *P*, –)
P18. Plan Risk Management	Define how to conduct risk management activities for a project	–	–	11.1 Plan Risk Management	*T*
P19. Identify Risks	Identify and document which risks may affect the project	PP/SP 2.2 Identify Project Risks	*P*	11.2 Identify Risks	*T*
P20. Perform Qualitative Risk Analysis	Prioritize risks for further analysis or action by assessing and combining their probability of occurrence and impact	PP/SP 2.2 Identify Project Risks	*P*	11.3 Perform Qualitative Risk Analysis	*T*
P21. Perform Quantitative Risk Analysis	Analyze quantitatively the effect of identified risks on overall project objectives	[RSKM]	Not considered here	11.4 Perform Quantitative Risk Analysis	*T*
P22. Plan Risk Responses	Develop options and actions to enhance opportunities and to reduce threats to project objectives	[RSKM]	Not considered here	11.5 Plan Risk Responses	*T*
P23. Determine Acquisition Type	Determine the type of acquisition for each product or product component to be acquired	SAM/ SP 1.1 Determine Acquisition Type	*T*	12.1 Plan Procurements	*T*
P24. Plan for Data Management	Plan for the management of project data	PP/SP 2.3 Plan for Data Management	*T*	–	–
P25. Establish the Project Plan	Establish and maintain a project plan as the basis for managing the project	PP/SP 2.7 Establish the Project Plan	*T*	4.2 Develop Project Management Plan	*T*
P26. Review Plans That Affect the Project	Review all plans that affect the project to understand project commitments	PP/SP 3.1 Review Plans That Affect the Project	*T*	–	–
P27. Reconcile Work and Resource Levels	Reconcile the project plan to reflect available and estimated resources	PP/SP 3.2 Reconcile Work and Resource Levels	*T*	–	–
P28. Obtain Plan Commitment	Obtain commitment from relevant stakeholders responsible for performing and supporting plan execution	PP/SP 3.3 Obtain Plan Commitment	*T*	–	–
Executing Process Group					
E1. Direct and Manage Project Execution	Perform the work defined in the project management plan to achieve the project's objectives	–	–	4.3 Direct and Manage Project Execution	*T*
E2. Perform Quality Assurance	Audit the quality requirements and the results from quality control measurements to ensure appropriate quality standards and operation definitions are used	–	–	8.2 Perform Quality Assurance	*T*
E3. Acquire Project Team	Confirm human resource availability and obtain the team necessary to complete project assignments.	–	–	9.2 Acquire Project Team	*T*
E4. Develop Project Team	Improve the competencies, team interaction and the overall team environment to enhance project performance	–	–	9.3 Develop Project Team	*T*
E5. Manage Project Team	Track team member performance, providing feedback, resolving issues, and managing changes to optimize project performance	–	–	9.4 Manage Project Team	*T*
E6. Distribute Information	Make relevant information available to project stakeholders as planned	–	–	10.3 Distribute Information	*T*
E7. Manage Stakeholders Expectations	Communicate and work with stakeholders to meet their needs and addressing issues as they occur	–	–	10.4 Manage Stakeholders Expectations	*T*
E8. Select Suppliers	Obtain seller responses and select suppliers based on an evaluation of their ability to meet the specified requirements and established criteria	SAM/SP 1.2 Select Suppliers	*T*	12.2 Conduct Procurements	*P*
E9. Establish Supplier Agreements	Establish and maintain formal agreements with the supplier	SAM/SP1.3 Establish Supplier Agreements	*T*	12.2 Conduct Procurements	P
E10. Execute the Supplier Agreement	Perform activities with the supplier as specified in the supplier agreement	SAM/SP 2.1 Execute the Supplier Agreement	*T*	–	–
Monitoring and Controlling Process Group					
M1. Monitor and Control Project	Monitor and control the progress with respect to	PMC/ SP 1.1 Monitor Project	*P*	4.4 Monitor and Control Project	*P*

Work	Project Planning parameters to meet the performance objectives defined in the project management plan	Planning Parameters		Work	
M2. Perform Integrated Change Control	Review all change requests, approving changes and managing changes to the deliverables, organizational process assets, project documents and the project plan	[REQM]	Not considered here	4.5 Perform Integrated Change Control	*T*
M3. Verify Scope	Formalize the acceptance of the completed project deliverables	–	–	5.4 Verify Scope	*T*
M4. Monitor and Control Scope	Monitor the status of the project and product scope and manage changes to the scope baseline	PMC/ SP 1.1 Monitor Project Planning Parameters	*P*	5.5 Control Scope	*T*
M5. Monitor and Control Schedule	Monitor the status of the project to update project progress and to manage changes to the schedule baseline	PMC/ SP 1.1 Monitor Project Planning Parameters	*P*	6.6 Control Schedule	*T*
M6. Monitor and Control Costs	Monitor the status of the project to update the project budget and to manage changes to the cost baseline	PMC/ SP 1.1 Monitor Project Planning Parameters	*P*	7.3 Control Costs	*T*
M7. Monitor and Control Quality	Monitor and record results of executing the quality activities to assess performance and recommend necessary changes	–	–	8.3 Perform Quality Control	*T*
M8. Conduct Progress Reviews	Periodically review the project's progress, performance and issues by collecting and distributing performance information, including status reports, progress measurements, and forecasts	PMC/SP 1.6 Conduct Progress Reviews	*T*	10.5 Report Performance	*T*
M9. Conduct Milestone Reviews	Review the accomplishments and results of the project at selected project milestones	PMC/SP 1.7 Conduct Milestone Reviews	*T*	–	–
M10. Monitor and Control Risks	Monitor risks against those identified in the project plan, implement risk response plans, track identified risks, monitor residual risks and identify new risks	PMC/SP 1.3 Monitor Project Risks	*T*	11.6 Monitor and Control Risks	*T*
M12. Administer Procurements	Manage procurement relationships, monitor contract performance, select and evaluate work products from the supplier, and make changes and corrections as needed	SAM/ SP2.3 Evaluate Selected Supplier Work Products	*T*	12.3 Administer Procurements	*T*
M13. Monitor Selected Supplier Processes	Select, monitor, and analyze processes used by the supplier	SAM/SP 2.2 Monitor Selected Supplier Processes	*T*	12.3 Administer Procurements	*P*
M14. Monitor Commitments	Monitor commitments against those identified in the project plan	PMC/SP 1.2 Monitor Commitments	*T*	–	–
M15. Monitor Data Management	Monitor the management of project data against the project plan	PMC/SP 1.4 Monitor Data Management	*T*	–	–
M16. Monitor Stakeholder Involvement	Monitor stakeholder involvement against the project plan	PMC/SP 1.5 Monitor Stakeholder Involvement	*T*	10.4 Manage Stakeholder Expectation	*P*
M17. Analyze Issues	Collect and analyze the issues and determine the corrective actions necessary to address the issues	PMC/SP 2.1 Analyze Issues [CAR]	*T*	4.4 Monitor and Control Project Work	*P*
M18. Take Corrective Action	Take corrective action on identified issues	PMC/ SP 2.2 Take Corrective Action	*T*	4.5 Perform Integrated Change Control	*P*
M19. Manage Corrective Action	Manage corrective actions to closure	PMC/ SP 2.3 Manage Corrective Action	*T*	4.5 Perform Integrated Change Control	*P*
Closing Process Group					
C1. Close Project or Phase	Finalize all activities across all of the management process groups to formally complete the project or phase	–	–	4.6 Close Project or Phase	*T*
C2. Close Procurements	Ensure that the supplier agreement is satisfied before accepting the acquired product	SAM/SP2.4 Accept the Acquired Product	*T*	12.4 Close Procurements	*T*
C3. Transition the Acquired Product	Transition the acquired products from the supplier to the project	SAM/SP 2.5 Transition Products	*T*	12.4 Close Procurements	*P*

ing practices to PMBOK processes exist in CMMI, but are outside of the set of basic project management process areas, we indicate the respective process area, but without further details. Our intention here is to define a unified set of practices within the defined scope, instead of providing a complete mapping of both models.

In some cases, the content of PMBOK Knowledge Areas also appears to be divided among several CMMI-DEV process areas. For example, CMMI's PP-SP 1.1 (Estimate the Scope of the Project) covers aspects of several PMBOK processes, including §5.2 Define Scope, §5.3 Create WBS and §6.1 Define Activities. Considering such overlaps of practices and processes between both models, the unified set of practices is defined on a fine-grained level. The degree of correspondence of each unified practices with respect to an element of the source models is documented, differentiating between a (*T*) total correspondence, (*P*) partial correspondence or (–) no correspondence. In case of a partial correspondence, more than one unified practice is defined, which all together provide a total correspondence to the respective element of a source model. In case where CMMI offers correspondent content (but, beyond any of the basic project management process areas PP, PMC, SAM), we indicate the respective process area, yet, without any more details, as it is outside the scope of our current research.

In accordance to PMBOK, we group the unified best practices into five process groups: Initiation, Planning, Monitoring and Controlling, Execution, and Closing. No further ordering or sequence of practices is specified.

The resulting set of unified best practices and their correspondence to both source models is shown in Table 1.

Based on the detailed analysis of project management best practices of both models, we can observe that in general there is a large overlapping. Yet, concerning the project management process groups as identified by PMBOK, we can observe that CMMI with respect to basic project management practices does not demonstrate a strong focus on project initiation, execution and closing practices. Practices of CMMI directed to the execution and closing of projects are basically focused on the acquisition process. Among PMBOK Knowledge Areas only partly covered by the CMMI-DEV is also Human Resource Management. In addition, CMMI does not focus as part of project management process areas on the quality management, but this is covered in CMMI through the process area on Product and Process Quality Assurance (PPQA).

On the other hand, PMBOK does not focus in such an explicit way on data management as well as it does not have practices explicitly directed to the integration of plans and the obtainment of commitment to the project plan.

5. Discussion

Although, there exists a series of mappings of the CMMI framework to other models such as ISO 9001 or ISO/IEC 15504 (http://www.sei.cmu.edu/cmmi/casestudies/mappings/comparisons.cfm), only few efforts are directed to the mapping or comparison of the CMMI framework and the PMBOK. The principal research in this area has been done by Sherer and Trasher [6], who compare the Capability Maturity Model® Integration (CMMI[SM]), version 1.1 CMMI-SE/SW/IPPD/SS to the Project Management Body of Knowledge (PMBOK®) Guide Third Edition, and the PMBOK Guide to CMMI-SE/SW/IPPD/SS. In this work, a high-level comparison on processes addressed by both models is done, advantages of each of the models structures are discussed as well as how much both models supplement each other. The authors also have done a detailed mapping between PMBOK and CMMI, comparing goals and practice of the CMMI of all process areas and maturity levels to PMBOK Knowledge Areas (including, processes, inputs, tools and techniques and outputs) and vice versa (https://bscw.sei.cmu.edu/pub/bscw.cgi/0/417678). In this respect, the work presents a complete and detailed mapping of both models. Other work in this area includes an analysis of the degree of relationship between the Knowledge Areas of the 2000 version of PMBOK with process areas of CMMI-SE/SW [13]. Yet, no detailed mapping between both models is presented. Another example is the mapping on the 2000 version of the PMBOK and CMMI-SW/SE presented by [14], analyzing on how PMBOK processes can support specific practices of the Project Planning process area and generic practices related to Maturity Level 2 of the CMMI.

These research works provide comparisons and mappings on different levels of refinement and scope, yet, in general, they refer to outdated versions of both models. And, although, there may be only small differences in these versions of the CMMI (when focusing on project management), several changes have been made in the last version of the PMBOK (including, the addition and exclusion of processes). In addition, existing work in this area focuses on the mapping of these models. Yet, the intention of our work is to define a set of unified best practices harmonizing both models in difference to the related work focusing on the mapping and/or comparison of the models. In this context, a similar objective is pursued by the harmonization effort coordinated by the FAA – Federal Aviation Agency, which based on the iCMM [15] presents a model unifying diverse models and standards, including, ISO 9001:2000, EIA/IS 731, *Malcolm Baldrige National Quality Award* e *President's Quality Award*, CMMI-SE/SW/IPPD e CMMI-A, ISO/IEC TR 15504, ISO/IEC 12207, e ISO/IEC CD 15288. This work is also currently being evolved and updated as part of the ENTERPRISE SPICE initiative (http://www.enterprisespice.com). In fact, the comparison and unification presented in this article served as a basis for the development of the project management process of this model.

6. Conclusions and future work

In this paper, we propose a set of unified project management best practices integrating and harmonizing on a high-level perspective PMBOK (4th ed.) processes and CMMI-DEV v1.2 specific practices of the basic project management process areas PP, PMC and SAM. The set of UBPs is also explicitly mapped to the correspondent PMBOK processes and CMMI specific practices in order to enable the tracking to respective elements of the source models. We can conclude that the development of such a set of UBPs is possible, despite their differences with respect to structure and content.

The resulting set of UBPs is expected to help to implement and assess project management processes more effectively and efficiently by allowing the simultaneous consideration of both models and, thus, optimizing software process improvement investments.

As next steps, we plan to enhance this mapping covering also advanced project management practices of the CMMI framework as well as the comparison and integration of further best practice models including software project management aspects, such as, the standard ISO/IEC 15504/12207. And, as such a mapping of best practice models is just a first step in using reference models in practice, we also plan to provide further support for the matching of such unified sets of best practices within the specific processes in an organization based on earlier work in a possible combination of different maturity models [16].

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