# Dependency Analysis between CMMI Process Areas

Paula Monteiro[1], Ricardo J. Machado[1], Rick Kazman[2], and Cristina Henriques[3]

[1] Universidade do Minho
{pmonteiro,rmac}@dsi.uminho.pt
[2] Software Engineering Institute
kazman@sei.cmu.edu
[3] I2S, Informática Sistemas e Serviços, SA
cristina.henriques@i2s.pt

**Abstract.** SPI and in particular CMMI is being widely use by several organizations to improve their product quality. However, the SMEs are reluctant in adopting it and in particular maturity level 2 of CMMI, because they think that achieving this level is too expensive and do not see a clear benefit on it. Our solution to captivate the interest of SMEs in CMMI is the anticipation of some process areas of maturity level 3 considered as a benefit by the organization and implement those process areas at the same time of maturity level 2 of CMMI. In this paper, we identify the dependencies among all the process areas of CMMI and between all the process areas of each maturity level. Our study was conducted to identify the impact on the dependencies of maturity level 2 when we introduce some process areas of maturity level 3 in the implementation effort.

**Keywords:** dependency analysis, CMMI, process areas, maturity levels.

## 1 Introduction

CMMI-DEV (Capability Maturity Model Integration for Development) [1], [2] is a well-known Software Process Improvement (SPI) model developed by the Software Engineering Institute (SEI). It is concerned in helping organizations to improve their processes. This SPI model has been implemented by several organizations [3], [4] that report a great improvement in reducing costs, improving the productivity, and the performance. According to [5] the most frequent reasons given by organizations for adopting a CMM[1]-based SPI model, like CMMI, were the improvement of their software quality, development time, development costs and productivity. However, customer satisfaction and staff motivation were referred in some SMEs [5].

Coleman and Connor performed a study [6] of how SPI models are applied in the software industry and they concluded that the software managers reject the implementation of SPI models because of the implementation costs. In what concerns why

[1] The Capability Maturity Model (CMM), originally developed as a tool for objectively assessing the ability of government contractors' processes to perform a contracted software project, has been superseded by CMMI, though the CMM continues to be a general theoretical process capability model used in the public domain.

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organizations do not adopt the maturity level 2 of CMMI, according to [7] the most frequent reasons given were: small organization, too costly, no time, using other SPI and no clear benefit in this CMMI level. Wilkie *et al.* [8] have concluded that small organizations are mainly focused on the product quality assurance instead of the process quality assurance and medium organizations consider process quality important but not so important as CMMI suggests. Organizations do not consider the maturity level 2 a high-value improvement since the process areas of this maturity level are mainly concerned on the process quality and the organizations are concerned with the product quality. To make CMMI widely used in small organizations, Wilkie *et al.* [8] suggest that CMMI should be recasted to cover the needs of this type of organizations. Other studies [9], [10], [11], [12] have become aware that to persuade SMEs in the adoption of an SPI model it is important to show to the organizations the benefits of its adoption, lower their costs and make the benefits perceptible in a short time. The SEI has had several research projects dedicated to this issue; SEI called them "Improving Processes in Small Settings". The original URL is no longer available, but the results of those projects could be found in [13]. However, no solution for the dependency analysis and cross-ML|CL improvement roadmaps in SMEs have been tackled.

Taking into account that the problem of software is a management problem and not a technical one [14], we can state that organizations do not see that when they implement maturity level 2 they are solving the historical problems of software projects like: understand and break the project scope, frequent requirements changes, deadline and cost issues. All these issues are addressed in this CMMI maturity level.

Our solution to make CMMI widely used in SMEs does not consist in recasting the CMMI, but to propose to the organizations the implementation of the process areas of the maturity level 2 and, at same time, to implement some process areas of the maturity level 3. These process areas could be chosen by the organization according to their needs of improvement or chosen according the higher benefit to the organization.

To analyze the impact of this approach, we decided to study the dependencies between the process areas, to better understand which other process areas than those chosen for implementation must be at least taken into account because of the dependencies between them.

SPI models and, in particular, CMM model have a long history of evolution [15]. The CMM model was initially published in 1987 and has evolved into the currently CMMI-DEV v1.2. We should not consider that the CMMI-DEV v1.2 is a silver bullet; CMMI will keep its evolution. This means that need to conducted studies about this framework. Namely, the study of dependencies between the process areas remains relevant to build assessment schemes tailored to the organizations' needs.

There are some studies focusing on the analysis of the dependencies between the process areas and the specific practices of maturity level 2 [16], [17] in order to discover an implementation sequence of the process areas. They do not conceive a global view of the dependencies, unlike the ISO 9001:2000 [18] (or the newer 9001:2008 [19]) already do. One of the mandatory requirements from ISO 9001 is the clause 4.1b): "the organization shall [...] determine the sequence and interaction of these processes".

This paper is organized as follows. Section 2 presents a brief description of CMMI, section 3 describes the dependencies between the maturity levels 2 and 3 of CMMI, section 4 describes the dependencies between the maturity levels 2 and the validation and verification process areas, and, finally, in section 5, some conclusion are presented.

## 2 CMMI for Development Model

CMMI-DEV is composed by a set of 22 process areas divided by categories and by maturity levels. In Table 1, we present the list of the 22 process areas grouped by maturity levels. To help the discussion, we add {PAn} to the CMMI acronym defined in [1], [2]. *PA* stands for *process area*, and *n* corresponds to the number of the process area.

**Table 1.** Table of all CMMI process areas

| | Category | PA | Acronym |
|---|---|---|---|
| MATURITY LEVEL 2 | Engineering | Requirements Management | {PA 1} REQM |
| | Project Management | Project Monitoring and Control | {PA 2} PMC |
| | Project Management | Project Planning | {PA 3} PP |
| | Project Management | Supplier Agreement Management | {PA 4} SAM |
| | Support | Measurement and Analysis | {PA 5} MA |
| | Support | Configuration Management | {PA 6} CM |
| | Support | Process and Product Quality Assurance | {PA 7} PPQA |
| MATURITY LEVEL 3 | Engineering | Product Integration | {PA 8} PI |
| | Engineering | Requirements Development | {PA 9} RD |
| | Engineering | Technical Solution | {PA 10} TS |
| | Engineering | Validation | {PA 11} VAL |
| | Engineering | Verification | {PA 12} VER |
| | Process Management | Organizational Process Definition | {PA 13} OPD |
| | Process Management | Organizational Process Focus | {PA 14} OPF |
| | Process Management | Organizational Training | {PA 15} OT |
| | Project Management | Integrated Project Management | {PA 16} IPM |
| | Project Management | Risk Management | {PA 17} RSKM |
| | Support | Decision Analysis and Resolution | {PA 18} DAR |
| MATURITY LEVEL 4 | Process Management | Organizational Process Performance | {PA 19} OPP |
| | Project Management | Quantitative Project Management | {PA 20} QPM |
| MATURITY LEVEL 5 | Process Management | Organizational Innovation and Deployment | {PA 21} OID |
| | Support | Causal Analysis and Resolution | {PA 22} CAR |

All the CMMI process areas have established specific goals (SG). These specific goals are unique characteristics that must be performed in order to satisfy each process area. In Table 2, we have an example of the specific goals of two process areas: the validation (VAL) and the verification (VER) process areas. We do not present all the specific goals, since they are listed in the official CMMI documentation. In our study, we are not considering the integrated product and process development (IPPD) "addition". Table 2 shows that each specific goal can be divided into specific practices (SP). The specific practices describe all the activities that must be performed to accomplish the specific goals.

Beside the specific goals and specific practices, CMMI model defines a set of generic goals (GG) and generic practices (GP). The generic goals, as the name says, are generic to all process areas. They are characteristics that must be performed to institutionalize the processes of each process area. The generic practices describe all the activities that must be performed to accomplish the generic goals. Table 3 lists all the generic goals and generic practices of CMMI.

**Table 2.** CMMI specific goals example

| | PA | Specific Goals |
|---|---|---|
| ML3 | {PA 11} VAL | **SG 1 Prepare for Validation**<br>SP 1.1 Select Products for Validation<br>SP 1.2 Establish the Validation Environment<br>SP 1.3 Establish Validation Procedures and Criteria<br>**SG 2 Validate Product or Product Components**<br>SP 2.1 Perform Validation<br>SP 2.2 Analyze Validation Results |
| | {PA 12} VER | **SG 1 Prepare for Verification**<br>SP 1.1 Select Work Products for Verification<br>SP 1.2 Establish the Verification Environment<br>SP 1.3 Establish Verification Procedures and Criteria<br>**SG 2 Perform Peer Reviews**<br>SP 2.1 Prepare for Peer Reviews<br>SP 2.2 Conduct Peer Reviews<br>SP 2.3 Analyze Peer Review Data<br>**SG 3 Verify Selected Work Products**<br>SP 3.1 Perform Verification<br>SP 3.2 Analyze Verification Results |

**Table 3.** CMMI generic goals for the continuous and staged representations

| Generic Goal | Continuous | Staged |
|---|---|---|
| **GG 1 Achieve Specific Goals**<br>GP 1.1 Perform Specific Practices | CL1 | |
| **GG 2 Institutionalize a Managed Process**<br>GP 2.1 Establish an Organizational Policy<br>GP 2.2 Plan the Process<br>GP 2.3 Provide Resources<br>GP 2.4 Assign Responsibility<br>GP 2.5 Train People<br>GP 2.6 Manage Configurations<br>GP 2.7 Identify and Involve Relevant Stakeholders<br>GP 2.8 Monitor and Control the Process<br>GP 2.9 Objectively Evaluate Adherence<br>GP 2.10 Review Status with Higher Level Management | CL2 | ML2 |
| **GG 3 Institutionalize a Defined Process**<br>GP 3.1 Establish a Defined Process<br>GP 3.2 Collect Improvement Information | CL3 | ML3, ML4, ML5 |
| **GG 4 Institutionalize a Quantitatively Managed Process**<br>GP 4.1 Establish Quantitative Objectives for the Process<br>GP 4.2 Stabilize Subprocess Performance | CL4 | |
| **GG 5 Institutionalize an Optimizing Process**<br>GP 5.1 Ensure Continuous Process Improvement<br>GP 5.2 Correct Root Causes of Problems | CL4 | |

## 2.1 Staged vs. Continuous Representations

CMMI has two representations that can be followed by an organization to become a CMMI assessed company. These representations are: the staged and the continuous representation. In the continuous representation, the organization can choose the order of the improvements to meet the organization objectives by choosing one or more process areas. This kind of representation uses the term Capability Level (CL) to characterize the improvement. Capability levels are a means for incrementally improving the processes corresponding to a given process areas. In the staged representation, the organization uses a set of pre-defined process areas, imposed by the CMMI model. In this case, the term used to characterize the improvement is Maturity Level (ML).

Levels are used in CMMI to describe an evolutionary path recommended for an organization that wants to improve the processes it uses to develop and maintain its products and services. To achieve a capability level the organization must satisfy all the specific goals and generic goals for the process areas selected to be improved.

To achieve a maturity level the organization must satisfy all the specific and generic goals for the pre-defined set of process areas imposed by the maturity level under implementation. It is important to notice that in the continuous representation GG1 to GG5 are applied, but in the staged representation only the GG2 and GG3 are applied.

To illustrate the concepts of continuous and staged representation we will explain how to achieve CL1 to CL3 for the {PA11} and how to achieve ML2 and ML3. To support our approach, these capability and maturity levels are analyzed in this manuscript to establish cross-ML|CL improvement roadmaps, as stated by the formula (6).

### 2.2 Introduction to Notation

Achieving CL1.{PA11} implies to execute all the specific goals for {PA11} and the GG1.

$$\begin{gathered}\mathrm{CL1.\{PA11\}} = \mathrm{GG1.\{PA11\}} = \sum_{i=1}^{2} \mathrm{SGi.\{PA11\}} = \mathrm{SG1.\{PA11\}} \wedge \\ \mathrm{SG2.\{PA11\}} = \sum_{i=1}^{3} \mathrm{SP1.i.\{PA11\}} \wedge \sum_{i=1}^{2} \mathrm{SP2.i.\{PA11\}}\,.\end{gathered} \tag{1}$$

The previous equation expresses this effort. Executing all the specific goals for {PA11} is the same of executing the entire specific practices for {PA11}.

To achieve CL2 to {PA11} we have to perform all the specific goals for {PA11} and the GG2. In the next equation we see that to achieve CL2.{PA11} we have to achieve CL1.{PA11} and, at the same time, to execute all the specific goals for GG2.

$$\begin{gathered}\mathrm{CL2.\{PA11\}} = \mathrm{CL1.\{PA11\}} \wedge \mathrm{GG2.\{PA11\}} = \\ \mathrm{CL1.\{PA11\}} \wedge \sum_{i=1}^{10} \mathrm{GP2.i.\{PA11\}}\,.\end{gathered} \tag{2}$$

The equation

$$\begin{gathered}\mathrm{CL3.\{PA11\}} = \mathrm{CL2.\{PA11\}} \wedge \mathrm{GG3.\ \{PA11\}} = \\ \mathrm{CL1.\{PA11\}} \wedge \sum_{i=1}^{10} \mathrm{GP2.i.\{PA11\}} \wedge \sum_{i=1}^{2} \mathrm{GP3.i.\{PA11\}}\end{gathered} \tag{3}$$

represents the effort to achieve CL3 for {PA11}. This effort includes all the work to achieve CL2 for {PA11} and, at the same time, the effort to accomplish the GG3.

In what concerns to the maturity levels, we represent the improvement from ML1 to ML2 by ML1→ML2. This improvement corresponds to the execution of the activities illustrated by the following equation:

$$\begin{gathered}\mathrm{ML1{\rightarrow}ML2} = \sum_{i=1}^{7} (\mathrm{SGj.\{PAi\}} \wedge \mathrm{GG2.\{PAi\}}) = \\ (\sum_{j=1}^{1} \mathrm{SGj.\{PA1\}} \wedge \sum_{k=1}^{10} \mathrm{GP2.k.\{PA1\}}) \wedge (\sum_{j=1}^{2} \mathrm{SGj.\{PA2\}} \wedge \sum_{k=1}^{10} \mathrm{GP2.k.\{PA2\}}) \wedge \\ (\sum_{j=1}^{3} \mathrm{SGj.\{PA3\}} \wedge \sum_{k=1}^{10} \mathrm{GP2.k.\{PA3\}}) \wedge (\sum_{j=1}^{2} \mathrm{SGj.\{PA4\}} \wedge \sum_{k=1}^{10} \mathrm{GP2.k.\{PA4\}}) \wedge \\ (\sum_{j=1}^{2} \mathrm{SGj.\{PA5\}} \wedge \sum_{k=1}^{10} \mathrm{GP2.k.\{PA5\}}) \wedge (\sum_{j=1}^{3} \mathrm{SGj.\{PA6\}} \wedge \sum_{k=1}^{10} \mathrm{GP2.k.\{PA6\}}) \wedge \\ (\sum_{j=1}^{2} \mathrm{SGj.\{PA7\}} \wedge \sum_{k=1}^{10} \mathrm{GP2.k.\{PA7\}})\,.\end{gathered} \tag{4}$$

This equation says that attaining ML2 implies to perform all the specific goals from {PA1} to {PA7} and, at the same time, to perform the GG2 once again from {PA1} to {PA7}.

To achieve the ML3 we have to perform the following:

$$\begin{gathered} \text{ML2}\rightarrow\text{ML3} = \\ \text{ML1}\rightarrow\text{ML2} \wedge \sum_{i=1}^{18} \text{GG3}.\{\text{PAi}\} \wedge \sum_{i=8}^{18} \text{SGj}.\{\text{PAi}\} \wedge \sum_{i=8}^{18} \text{GG2}.\{\text{PAi}\} \end{gathered} \tag{5}$$

which means that we have to achieve ML2 and perform, at the same time, the specific goals from {PA8} to {PA18}, the GG3 from {PA1} to {PA18} and the GG2 from {PA8} to {PA18}.

## 3 Discovering the Process Areas Dependencies

By looking into the official CMMI documentation [1], [2] we cannot have a global view of the dependencies between the all the process areas. By reading the "related process areas" section of each process area, we can only understand what are the dependencies of each process area independently.

To obtain the complete list and a graph representation of all the dependencies between all the process areas we started to analyze the "related process areas" section for all the process areas. Then, we decided to create a matrix (that contains the information of all the dependencies) and a set of graphs (that graphically represents the information stored in the matrix). The matrix rows represent the source process areas and the columns represent the destination process areas, in the dependency analysis perspective.

### 3.1 Elementary Dependency Analysis

Next, we describe our efforts to characterize the elementary dependency analysis of a particular process area; we also call this analysis the *PAn-centric dependency analysis* (*n* is the number of the process area; see Table 1). PPQA process area is next illustrated as an example.

In the "related process areas" section of the PPQA, we can read "*refer to the **Project Planning process area** for more information about identifying processes and associated work products that will be objectively evaluated*" and "*refer to the **Verification process area** for more information about satisfying specified requirements*". This means that the PPQA is related to the PP and VER process areas. This information is represented in the matrix by marking with an X the cell that corresponds to the PPQA row and to the PP column and also the cell that corresponds to the PPQA row and to the VER column (see Table 4). The matrix is capable of representing the dependency information about all the process areas. We also represent this information in graphs, for better understanding. The graph for this elementary dependency analysis example is presented in Fig. 1.

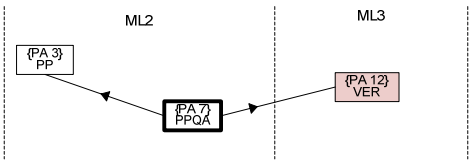


**Fig. 1.** Elementary Dependency Analysis Graph

**Table 4.** PPQA matrix line

| | depended PA / PA depends | ML 2 | | | | | | | ML 3 | | | | | | | | | | | ML 4 | | ML 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | {PA 1} REQM | {PA 2} PMC | {PA 3} PP | {PA 4} SAM | {PA 5} MA | {PA 6} CM | {PA 7} PPQA | {PA 8} PI | {PA 9} RD | {PA 10} TS | {PA 11} VAL | {PA 12} VER | {PA 13} OPD | {PA 14} OPF | {PA 15} OT | {PA 16} IPM | {PA 17} RSKM | {PA 18} DAR | {PA 19} OPP | {PA 20} QPM | {PA 21} OID | {PA 22} CAR |
| ML 2 | {PA 7} PPQA | | | X | | | | | | | | | X | | | | | | | | | | |

## 3.2 Dependencies of CMMI Process Areas

To create the complete matrix and graphs of the CMMI process areas we executed the elementary dependency analysis for all the process areas. The resulting matrix is presented in Table 5. To easily understand the impact of the dependencies between all the process areas, we organized the matrix by maturity level.

It is also possible to obtain a graph representation of the global matrix of Table 5. To ease the visualization of the dependencies of each CMMI maturity level, we decided to create 4 graphs, one for each maturity level. The explanation about how to create those graphs appears in the next section.

Each of those 4 graphs is denominated as *ML-n Centric Dependency Analysis Graph* (where n is the maturity level under study). In Fig. 2 and 3, we can see the ML-2 and the ML-3 centric dependency analysis graphs. The main idea behind the creation of these ML-n centric graphs is to allow us to see only the dependencies that

**Table 5.** Dependencies between all the CMMI process areas

| | depended PA / PA depends | ML 2 | | | | | | | ML 3 | | | | | | | | | | | ML 4 | | ML 5 | | Number of Dependencies |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | {PA 1} REQM | {PA 2} PMC | {PA 3} PP | {PA 4} SAM | {PA 5} MA | {PA 6} CM | {PA 7} PPQA | {PA 8} PI | {PA 9} RD | {PA 10} TS | {PA 11} VAL | {PA 12} VER | {PA 13} OPD | {PA 14} OPF | {PA 15} OT | {PA 16} IPM | {PA 17} RSKM | {PA 18} DAR | {PA 19} OPP | {PA 20} QPM | {PA 21} OID | {PA 22} CAR | |
| ML 2 | {PA 1} REQM | | x | x | | | x | | | x | x | | | | | | | x | | | | | | 6 |
| | {PA 2} PMC | | | x | | x | | | | | | | | | | | | | | | | | | 2 |
| | {PA 3} PP | x | | | | | | | | x | x | | | | | | | x | | | | | | 4 |
| | {PA 4} SAM | x | x | | | | | | | x | x | | | | | | | | | | | | | 4 |
| | {PA 5} MA | x | x | x | | | x | | | x | | | | x | | | | | | | x | | | 7 |
| | {PA 6} CM | | x | x | x | | | | | | | | | | | | | | | | | | | 3 |
| | {PA 7} PPQA | | | x | | | | | | | | | x | | | | | | | | | | | 2 |
| ML 3 | {PA 8} PI | | | | x | | x | | | x | x | x | x | | | | | x | x | | | | | 8 |
| | {PA 9} RD | x | | | | | x | | x | | x | x | x | | | | | x | | | | | | 7 |
| | {PA 10} TS | x | | | | | | | | x | | | x | | | | | | x | | | x | | 5 |
| | {PA 11} VAL | | | | | | | | | x | x | | x | | | | | | | | | | | 3 |
| | {PA 12} VER | x | | | | | | | | x | | x | | | | | | | | | | | | 3 |
| | {PA 13} OPD | | | | | | | | | | | | | x | | | | | | | | | | 1 |
| | {PA 14} OPF | | | | | | | | | | | | x | | | | | | | | | | | 1 |
| | {PA 15} OT | | | x | | | | | | | | | x | | | | | | x | | | | | 3 |
| | {PA 16} IPM | | x | x | | x | | | | | | | x | x | | | | | | | | | | 5 |
| | {PA 17} RSKM | | x | x | | | | | | | | | | | | | | | x | | | | | 3 |
| | {PA 18} DAR | | | x | | | | | | | | | | | | x | x | | | | | | | 3 |
| ML 4 | {PA 19} OPP | | | | | x | | | | | | | | x | | x | | | | x | x | | | 2 |
| | {PA 20} QPM | | x | | | x | | | | | | | | x | | | | | | x | | x | x | 7 |
| ML 5 | {PA 21} OID | | | | | x | | | | | | | | x | x | x | x | | x | x | | | | 7 |
| | {PA 22} CAR | | | | | x | | | | | | | | | | | | | | | x | x | | 3 |
| | Number of Dependencies | 6 | 7 | 9 | 2 | 6 | 4 | 0 | 1 | 8 | 6 | 3 | 6 | 6 | 2 | 1 | 3 | 5 | 5 | 2 | 3 | 3 | 1 | |

are concerned to the maturity level under study, by eliminating from the graph a huge number of dependencies that we do not want to take into account when we are studying a particular maturity level. However, we have also constructed the global graph with all the CMMI dependencies (also called *CMMI Dependency Analysis Graph*) to show the global view of the dependencies between the CMMI process areas and to verify what are the bi-directional dependencies between the process areas of different maturity levels (Fig. 4).

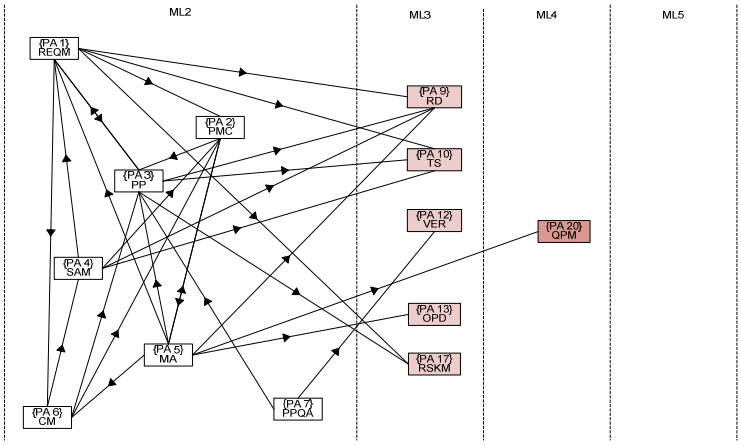


**Fig. 2.** ML-2 centric dependency analysis graph

### 3.3 ML-2 Centric Dependency Analysis

To study, discover and analyze the dependencies of the process areas of maturity level 2, we have to perform the ML-2 centric dependency analysis. Since we already have the matrix with all the dependencies between CMMI process areas (Table 5), we can use this information to analyze the dependencies of maturity level 2. We start by creating the ML-2 centric dependency analysis graph. To create this graph we select the rows from the matrix that corresponds to the maturity level 2 (the first 7 rows).

To better explain the creation of this graph, we will comment {PA3} Project Planning as an example. To represent in the graph the dependencies that {PA3} possesses from the others CMMI process areas, we parse the matrix row that corresponds to {PA3} as shown in Table 6. We can see that {PA3} has 4 dependencies from other process areas: {PA1} REQM, {PA9} RD, {PA10} TS and {PA17} RSKM.

In Table 6 we replaced the X from the original matrix with the symbol ►, in order to express that this connection starts in {PA3} and ends in {PA1}, for instance. We have also made some changes in the column {PA3}. In this column, we replaced the X by the symbol ◄, in order to express that this connection ends in {PA3} and starts in {PA2}, for instance. To construct the graph we only need to parse the rows.

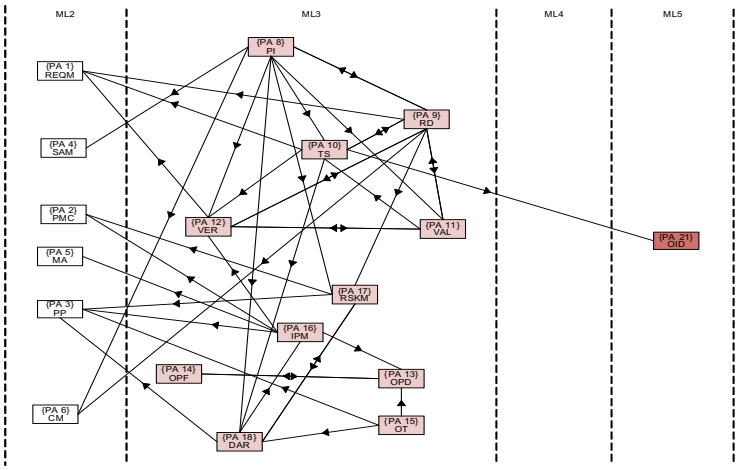


**Fig. 3.** Dependencies of process areas of the CMMI maturity level 3

**Table 6.** ML-2 centric dependency analysis for {PA3}PP

| | depended PA / PA depends | ML 2 | | | | | | | ML 3 | | | | | | | | | | ML 4 | | ML 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | {PA 1} REQM | {PA 2} PMC | {PA 3} PP | {PA 4} SAM | {PA 5} MA | {PA 6} CM | {PA 7} PPQA | {PA 8} PI | {PA 9} RD | {PA 10} TS | {PA 11} VAL | {PA 12} VER | {PA 13} OPD | {PA 14} OPF | {PA 15} OT | {PA 16} IPM | {PA 17} RSKM | {PA 18} DAR | {PA 19} OPP | {PA 20} QPM | {PA 21} OID | {PA 22} CAR |
| ML 2 | {PA 1} REQM | | | ◄ | | | | | | | | | | | | | | | | | | | |
| | {PA 2} PMC | | | ◄ | | | | | | | | | | | | | | | | | | | |
| | {PA 3} PP | ► | | | | | | | | ► | ► | | | | | | | ► | | | | | |
| | {PA 4} SAM | | | | | | | | | | | | | | | | | | | | | | |
| | {PA 5} MA | | | ◄ | | | | | | | | | | | | | | | | | | | |
| | {PA 6} CM | | | ◄ | | | | | | | | | | | | | | | | | | | |
| | {PA 7} PPQA | | | ◄ | | | | | | | | | | | | | | | | | | | |

In Fig. 2 we can observe the existence of a bi-directional dependency between {PA3} and {PA1}. To express this bi-directional dependency, in Table 7 we replaced the X by the symbol ◄►. Since the process areas are ordered in the same way both in rows and in columns, to easily identify the bi-directional dependencies we just need to check if the row n and column n are marked with an X.

**Table 7.** {PA3}PP bi-directional dependencies of ML-2 Centric Dependency Analysis

| | depended PA / PA depends | ML 2 | | | | | | | ML 3 | | | | | | | | | | ML 4 | | ML 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | {PA 1} REQM | {PA 2} PMC | {PA 3} PP | {PA 4} SAM | {PA 5} MA | {PA 6} CM | {PA 7} PPQA | {PA 8} PI | {PA 9} RD | {PA 10} TS | {PA 11} VAL | {PA 12} VER | {PA 13} OPD | {PA 14} OPF | {PA 15} OT | {PA 16} IPM | {PA 17} RSKM | {PA 18} DAR | {PA 19} OPP | {PA 20} QPM | {PA 21} OID | {PA 22} CAR |
| ML 2 | {PA 1} REQM | | X | ◄► | | | X | | | X | X | | | | | | | X | | | | | |
| | {PA 2} PMC | | | | | | | | | | | | | | | | | | | | | | |
| | {PA 3} PP | ◄► | | | | | | | | | | | | | | | | | | | | | |
| | {PA 4} SAM | X | | | | | | | | | | | | | | | | | | | | | |
| | {PA 5} MA | X | | | | | | | | | | | | | | | | | | | | | |
| | {PA 6} CM | | | | | | | | | | | | | | | | | | | | | | |
| | {PA 7} PPQA | | | | | | | | | | | | | | | | | | | | | | |

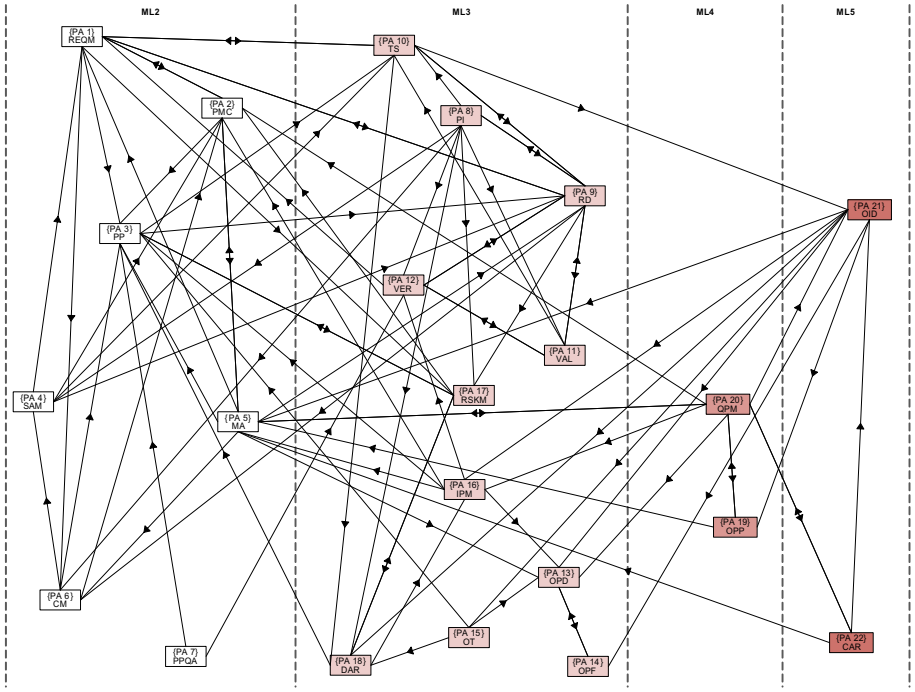


**Fig. 4.** Global dependencies between CMMI process areas

## 4 ML-2 Centric Dependency Analysis with Elementary Dependency Analysis for Validation and Verification Process Areas

As a motivation to convince SMEs that CMMI maturity level 2 brings real benefits, we decided study what are the theoretical dependencies we should expect when performing ML1→ML2 and, at the same time, prepare for one CL3 assessment for some process areas, namely CL3.{PA11} and CL3.{PA12}. The choice of {PA11} and {PA12} is based on the particular needs of I2S (the company where we will perform the complete dependency analysis with real data). The type of assessment we are considering is a combination of staged and continuous representations. The combination of maturity level 2 assessment and CL3.{PA11} and CL3.{PA12} is given by the following expression:

$$\mathrm{ML1} \rightarrow \mathrm{ML2} \parallel (\mathrm{CL3}.\{\mathrm{PA11}\} \wedge \mathrm{CL3}.\{\mathrm{PA12}\}) \ldots \tag{6}$$

To analyze the dependencies we must expect from this case, we need to study the *{PA11} centric dependency analysis* and the *{PA12} centric dependency analysis*. To generate the {PA11} centric dependency analysis graph (Fig. 5a) we need to parse the row of {PA11} in the matrix of Table 5. Analogous exercise must be performed to generate the {PA12} centric dependency graph (Fig. 5b).

The global view of the dependencies when performing ML1→ML2 with the simultaneous assessment of CL3 for both {PA11} and {PA12} is depicted Fig.6. The information that represents the ML-2 centric dependency analysis graph is depicted in black. The information relative to the {PA11} centric dependency analysis graph and to the {PA12} centric dependency analysis graph is represented in red.

The graph represented in Fig.6 permits to conclude that the effort to perform ML1→ML2 and to achieve, simultaneously, CL3 for {PA11} and {PA12} should not be an obstacle to assume the maturity level 2 as the main organizational goal, in this considered case. All the existing dependencies are relative to process areas already imposed by the maturity level 2. The only extra effort that must be considered consists in implementing {PA11} and {PA12}.

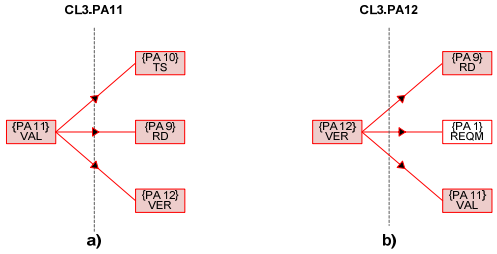


**Fig. 5.** a) Elementary Dependency Analysis for {PA11} and b) Elementary Dependency Analysis for {PA12}

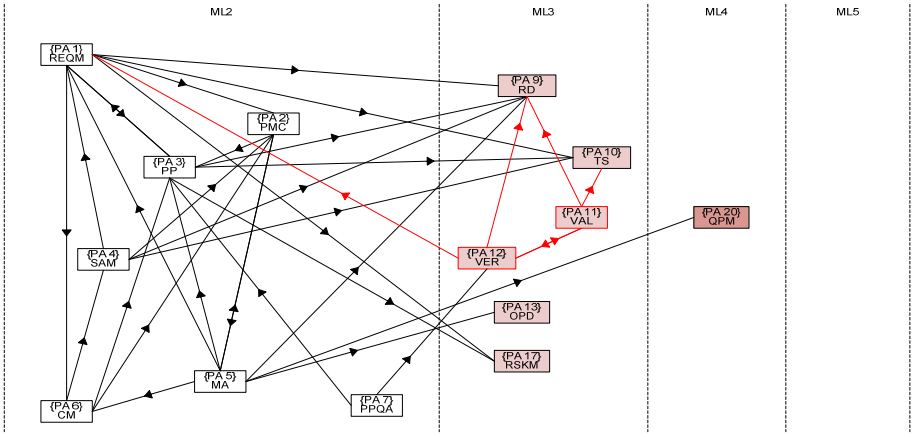


**Fig. 6.** Dependencies between CMMI ML2 and V&V ({PA11} and {PA12}) Process Areas

## 5 Conclusions

CMMI official documentation does not explicitly describe the existing dependencies among the process areas. To find out the global theoretical dependencies, we need to complement the reading of the documentation with special care and analysis capabilities,

but, even after that, it is hard to obtain the global view of the dependencies. Our final goal is not to reach the global theoretical dependencies, but rather to use this view as a characterization of the framework limitations to be next confronted with the dependencies we can observe in the implementation of real SPI projects (by adopting SCAMPI appraisals whether for ML or CL assessments). This means that this paper will be considered as a baseline for future comparisons with empirical results.

In this paper we describe a set of techniques to identify the dependencies between all the process areas and to create a global view of those dependencies by means of some matrix and a set of graphs. We have also developed a notation that translates the meaning of achieving a particular capability and maturity level. This notation allows to understand which specific practices and specific goals have to be implemented to achieve a given capability and maturity level.

Our motivation to explicit the global dependencies between CMMI process areas arose when we tried to understand the impact of implementing the maturity level 2 simultaneously with some process areas from maturity level 3 as a way to make CMMI more widely used in Portuguese SMEs. As an example, we analyzed the dependencies between the process areas of maturity level 2 and two particular process areas of maturity level 3.

As future work, we will also complement our current dependency analysis study with the interactions between the process areas of each category in order to analyze if those interactions are already identified as a dependency between the process areas. For this study we will use the information described with the bird's-eye view presented in [1]. Another source of information that will be used to complement this dependency study is the SG descriptions of each PA. For instance, PP should be dependent also from OPD (SP1.4 for the Measurement Repository), having cross links in PP SP1.4 sub-practice 1.

This complementary study may lead us to a new set of dependencies that, again, are not well described in the CMMI official documentation.

## References

1. CMMI Product Team: Capability Maturity Model Integration, version 1.2, CMMI for Development, CMU/SEI-2006-TR-008, ESC-TR-2006-008 (2006), http://www.sei.cmu.edu/publications/documents/06.reports/06tr008.html
2. Chrissis, M.B., Konrad, M., Shrum, S.: CMMI(R): Guidelines for Process Integration and Product Improvement. The SEI Series in Software Engineering, 2nd edn. Addison-Wesley Professional, Reading (2006)
3. Gibson, D.L., Goldenson, D.R., Kost, K.: Performance Results of CMMI®-Based Process Improvement. Software Engineering Institute, CMU (2006), http://www.sei.cmu.edu/library/abstracts/reports/06tr004.cfm
4. Goldenson, D.R., Gibson, D.L.: Demonstrating the Impact and Benefits of CMMI®: An Update and Preliminary Results. Software Engineering Institute, CMU (2003), http://www.sei.cmu.edu/library/abstracts/reports/03sr009.cfm
5. Staples, M., Niazi, M.: Systematic review of organizational motivations for adopting CMM-based SPI. Information and Software Technology 50, 605–620 (2008)

6. Coleman, G., O'Connor, R.: Investigating software process in practice: A grounded theory perspective. Journal of Systems and Software 81, 772–784 (2008)
7. Staples, M., Niazi, M., Jeffery, R., Abrahams, A., Byatt, P., Murphy, R.: An exploratory study of why organizations do not adopt CMMI. Journal of Systems and Software 80, 883–895 (2007)
8. Wilkie, F.G., McFall, D., McCaffery, F.: An evaluation of CMMI process areas for small-To medium-sized software development organisations. Software Process Improvement and Practice 10, 189–201 (2005)
9. Cater-Steel, A., Toleman, M., Rout, T.: Process improvement for small firms: An evaluation of the RAPID assessment-based method. Information and Software Technology 48, 323–334 (2006)
10. Wangenheim, C.G.v., Varkoi, T., Salviano, C.F.: Standard based software process assessments in small companies. Software Process: Improvement and Practice 11, 329–335 (2006)
11. Quality Management for Small Enterprises Project, http://www8.cs.umu.se/~jubo/Projects/QMSE/
12. Software Process Improvement in Regions of Europe Project, http://www.cse.dcu.ie/spire/spire.html
13. Improving Processes in Small Settings, http://www.sei.cmu.edu/iprc/ipss.html
14. Humphrey, W.S.: Introduction to the team software process. Addison-Wesley, Reading (2000), ISBN 0-201-47719-X
15. Paulk, M.C.: A History of the Capability Maturity Model for Software. ASQ Software Quality Professional 12, 5–19 (2009)
16. Villalón, J.A.C.-M., Agustín, G.C., Mejía, J., Gilabert, T.S.F., Sánchez, A.: CMMI-ACQ: A Formal Implementation Sequences of the Processes Areas at Maturity Level 2. In: Robotics and Automotive Mechanics Conference on Electronics, pp. 212–217 (2008)
17. Chen, X., Staples, M., Bannerman, P.L.: Analysis of Dependencies between Specific Practices in CMMI Maturity Level 2. In: O'Connor, R., Baddoo, N., Smolander, K., Messnarz, R. (eds.) EuroSPI, vol. 16, pp. 94–105. Springer, Heidelberg (2008)
18. International Organization for Standardization: ISO 9001:2000 - Quality management systems - Requirements. Geneva (2000)
19. International Organization for Standardization: ISO 9001:2008 - Quality management systems - Requirements. Geneva (2008)