



Technische Universiteit
Eindhoven
University of Technology



UNIVERSITAT POLITÈCNICA
DE CATALUNYA

Process Mining Opportunities for CMMI Assessments

Jordi Riera Cruañas
July 2011

Supervisors:

Dr. Ir. J.J.M. Trienekens, TU/e, TM/IS
Prof. Ir. R.J. Kusters, TU/e, TM/IS
Ir. J. Samalikova, TU/e, TM/IS

Technische Universiteit Eindhoven
Department of Technology Management
Division of Information Systems

Overview

The present document represents the Master Thesis that will complete my studies of Industrial Engineering in management specialization by the Universitat Politècnica de Catalunya.

The objective of this Master Thesis is to investigate literature on tool support of CMMIs key process areas to find if it is possible the usage of the tool Process Mining for improve the assessment of these key process areas and, for extension, the assessment of the model in general.

By realizing this research, I had the opportunity of increase my knowledge about the world of Software Engineering by discovering and studying the software improving model CMMI and the way for assessing it and, also, the tool of Process Mining, a really useful tool for supporting software product development.

I would like to thank especially to my supervisors Dr. Ir. J. M. Trienekens and Prof. Ir. R. J. Kusters for show me the contents of the present Master Thesis and help and support my work during this semester on TU/e Eindhoven and, also, to Ir. J. Samalikova for her support and cooperation during my Master Thesis.

Finally, I would like to thank also to my parents, my family and my friends, both from Spain and those that I met during my Erasmus, for their continued support. Without you, none of my work would be possible.

The author declares that the text and work presented in this thesis is original and that no sources other than those mentioned in the text and its references have been used in creating this thesis.

The copyright of this thesis lies with the owner. The author is responsible for its contents. TU/e cannot be held responsible for any claims with regard to implementing results of the thesis.

Table of contents

CHAPTER 1. INTRODUCTION TO THE RESEARCH	1
1. INTRODUCTION AT SOFTWARE ENGINEERING.....	1
1.1. <i>Software Nature and Qualities</i>	1
1.2. <i>Software Engineering Principles</i>	2
1.3. <i>Software Engineering Verification</i>	3
1.4. <i>Management of Software Engineering</i>	4
2. INTRODUCTION TO PROCESS IMPROVEMENT	5
3. SUMMARY OF THE CHAPTER	6
CHAPTER 2. RESEARCH DEFINITION	8
1. CONTEXT OF THE PROJECT.....	8
2. OBJECTIVE AND RESEARCH QUESTIONS.....	8
3. STRUCTURE OF THE PROJECT.....	9
CHAPTER 3. PROCESS MINING AND ANALYSIS	10
1. INTRODUCTION TO SOFTWARE CONFIGURATION MANAGEMENT AND PROCESS MINING.....	10
2. USAGE OF EVENT LOGS ON SOFTWARE PROCESS MINING.....	10
3. PROCESS MINING DIAGNOSTICS.....	11
3.1. LOG PREPARATION	11
3.2. LOG INSPECTION	11
3.3. PROCESS MINING ANALYSIS	12
4. PROCESS MINING PERSPECTIVES	12
4.1. CONTROL-FLOW PERSPECTIVE	12
4.1.1. <i>Process Model Discovery</i>	12
4.1.2. <i>Conformance Checking</i>	13
4.1.3. <i>LTL Checking</i>	14
4.2. PERFORMANCE PERSPECTIVE	14
4.2.1. <i>Throughput time calculation and Bottleneck analysis</i>	15
4.2.2. <i>Performance Sequence Analysis</i>	15
4.3. ORGANIZATIONAL PERSPECTIVE	15
4.3.1. <i>Social Network analysis</i>	16
4.4. CASE PERSPECTIVE	17
4.4.1. <i>Decision analysis</i>	17
5. SUMMARY OF THE CHAPTER	18

CHAPTER 4. CMMI DESCRIPTION	19
1. INTRODUCTION TO CMMI MODEL AND PROBLEMS	19
2. CMMI Maturity Levels.....	19
2.1. MATURITY LEVEL 1: INITIAL.....	20
2.2. MATURITY LEVEL 2: REPEATABLE.....	20
2.2.1. <i>Configuration Management and Requirements Management</i>	20
2.2.2. <i>Measurement and Analysis</i>	21
2.2.3. <i>Project Monitoring and Control</i>	21
2.2.4. <i>Project Planning</i>	21
2.2.5. <i>Process and Product Quality Assurance</i>	22
2.2.6. <i>Supplier Agreement Management</i>	22
2.3. MATURITY LEVEL 3: DEFINED	22
2.3.1. <i>Decision Analysis and Resolution</i>	23
2.3.2. <i>Integrated Project Management</i>	23
2.3.3. <i>Organizational Process Definition</i>	23
2.3.4. <i>Organizational Process Focus</i>	24
2.3.5. <i>Organizational Training</i>	24
2.3.6. <i>Product Integration</i>	24
2.3.7. <i>Requirements Development</i>	24
2.3.8. <i>Risk Management</i>	25
2.3.9. <i>Technical Solution</i>	25
2.3.10. <i>Verification and Validation</i>	25
2.4. MATURITY LEVEL 4: QUALITATIVELY MANAGED AND MATURITY LEVEL 5: OPTIMIZED.....	26
2.4.1. <i>Quantitative Project Management</i>	26
2.4.2. <i>Organizational Process Performance</i>	26
3. INCREASE CMMI LEVEL	27
4. SUMMARY OF THE CHAPTER	28
CHAPTER 5. CMMI ASSESSMENT	29
1. INTRODUCTION	29
2. PROCEDURE OF CMMI ASSESSMENTS	30
2.1. PLAN AND PREPARATION FOR THE ASSESSMENT	31
2.2. CONDUCT THE ASSESSMENT	32
2.3. REPORT THE RESULTS	32
3. STRENGTHS AND WEAKNESSES OF THE PROCEDURE.....	32
3.1. STRENGTHS AND WEAKNESSES OF PLAN AND PREPARATION	32
3.2. STRENGTHS AND WEAKNESSES OF CONDUCTION OF THE ASSESSMENT	33
4. PROCEDURE DEPENDING OF THE MATURITY LEVEL.....	34
5. DATA COLLECTION DEPENDING ON THE CLASS.....	34
5.1. DATA COLLECTION FOR CLASS C.....	34
5.2. DATA COLLECTION FOR CLASS B.....	35
5.3. DATA COLLECTION FOR CLASS A.....	36

6.	EVALUATION OF CMMI ASSESSMENT	37
7.	CATEGORIES OF PROBLEMS ONCE IMPLANTED CMMI.....	37
7.1.	ORGANIZATIONAL PROBLEMS	37
7.2.	TECHNICAL PROBLEMS.....	38
7.3.	HUMAN PROBLEMS	39
8.	RESULTS OF ASSESSMENT.....	40
9.	SUMMARY OF THE CHAPTER	40

CHAPTER 6. TOOLS OF PROCESS MINING FOR SUPPORTING CMMI ASSESSMENT 41

1.	INTRODUCTION	41
2.	METHODOLOGY FOR MATCHING PROCESS MINING AS A TOOL FOR CARRYING OUT CMMI ASSESSMENT	
	43	
2.1.	METHODOLOGY FOR MATCHING PROCESS MINING WITH 'PLAN AND PREPARATION FOR THE ASSESSMENT'	44
2.2.	METHODOLOGY FOR MATCHING PROCESS MINING WITH 'CONDUCT THE EVALUATION'	45
3.	MATCHES BETWEEN PROCESS MINING AND CMMI ASSESSMENT	47
4.	MISMATCHES BETWEEN PROCESS MINING AND CMMI ASSESSMENT	49
5.	MISMATCHES BETWEEN PROCESS MINING AND THE PRE-CONDITIONS OF CMMI ASSESSMENT	50
6.	SUMMARY OF THE CHAPTER	51

CHAPTER 7. TOOLS OF PROCESS MINING FOR SUPPORTING CMMI ASSESSMENT OF CONCRETE
PROCESS AREAS 52

1.	INTRODUCTION	52
2.	STANDARD METHODOLOGY FOR FINDING MATCHES BETWEEN CMMI PROCESS AREAS AND THE TOOL OF PROCESS MINING	52
3.	DEFINITIONS OF TERMS AS DEFINED IN CMMI AND SCAMPI DOCUMENTS	53
4.	DECISION ANALYSIS AND RESOLUTION	54
4.1.	SPECIFIC PROCESS INVOLVED	54
4.1.1.	<i>Establish evaluation criteria</i>	55
4.1.1.1.	Tools	55
4.1.2.	<i>Identify alternative solutions</i>	56
4.1.2.1.	Tools	56
4.1.3.	<i>Select Evaluation Methods</i>	56
4.1.3.1.	Tools	56
4.1.4.	<i>Evaluate the Alternatives and Select the Solution</i>	57
4.1.4.1.	Tools	57
4.2.	USERS' QUESTIONS AND RELATION WITH PROCESS MINING	58
4.2.1.	<i>Achieve Specific Goals</i>	59
4.2.1.1.	Perform Specific Practices	59
4.2.2.	<i>Institutionalize a Managed Process</i>	59
4.2.2.1.	Establish an Organizational Policy	59

4.2.2.2. Plan the Process	59
4.2.2.3. Provide Resources	59
4.2.2.4. Assign Responsibility	59
4.2.2.5. Train People.....	59
4.2.2.6. Manage Configurations	60
4.2.2.7. Identify and Involve Relevant Stakeholders	60
4.2.2.8. Monitor and Control the Process	60
4.2.2.9. Objectively Evaluate Adherence.....	61
4.2.2.10. Review Status with Higher Level Management	61
4.2.3. <i>Institutionalize a Defined Process</i>	61
4.2.3.1. Establish a Defined Process	61
4.2.3.2. Collect Improvement Information	62
4.2.4. <i>Institutionalize a Quantitatively Managed Process</i>	62
4.2.4.1. Establish Quantitative Objectives for the Process	62
4.2.4.2. Stabilize Sub process Performance.....	62
4.2.5. <i>Institutionalize an Optimized Process</i>	63
4.2.5.1. Ensure Continuous Process Improvement.....	63
4.2.5.2. Correct Root Causes of Problems	63
4.3. SUMMARY TABLE	63
5. ORGANIZATIONAL PROCESS FOCUS.....	64
5.1. SPECIFIC PROCESS INVOLVED	64
5.1.1. <i>Determine the opportunities for improve processes</i>	65
5.1.1.1.Tools	65
5.1.2. <i>Plan and implement improvements in the processes</i>	66
5.1.2.1. Tools	66
5.1.3. <i>Implement and Incorporate the Organizational Actives</i>	66
5.1.3.1. Tools	67
5.2. USERS' QUESTIONS AND RELATION WITH PROCESS MINING	67
5.2.1. <i>Achieve Specific Goals</i>	68
5.2.1.1. Perform Specific Practices	68
5.2.2. <i>Institutionalize a Managed Process</i>	68
5.2.2.1. Establish an Organizational Policy	68
5.2.2.2. Plan the Process	68
5.2.2.3. Provide Resources	68
5.2.2.4. Assign Responsibility	68
5.2.2.5. Train People.....	69
5.2.2.6. Manage Configurations	69
5.2.2.7. Identify and Involve Relevant Stakeholders	69
5.2.2.8. Monitor and Control the Process	69
5.2.2.9. Objectively Evaluate Adherence.....	70
5.2.2.10. Review Status with Higher Level Management	70
5.2.3. <i>Institutionalize a Defined Process</i>	71
5.2.3.1. Establish a Defined Process	71
5.2.3.2. Collect Improvement Information.....	71
5.2.4. <i>Institutionalize a Quantitatively Managed Process</i>	71
5.2.4.1. Establish Quantitative Objectives for the Process	71
5.2.4.2. Stabilize Sub process Performance.....	71
5.2.5. <i>Institutionalize an Optimized Process</i>	72
5.2.5.1. Ensure Continuous Process Improvement.....	72
5.2.5.2. Correct Root Causes of Problems	72
5.3. SUMMARY TABLE	72
6. SUMMARY OF THE CHAPTER	73

CHAPTER 8. CONCLUSIONS AND FUTURE RESEARCH	75
1. COMMENTS TO THE RESULTS	75
2. FUTURE RESEARCH	76

CHAPTER 9. REFERENCES	78
------------------------------	-----------

Chapter 1. Introduction to the Research

1. Introduction at Software Engineering

Before explaining the context of the thesis, there is needed an introduction to the world where the thesis frames. With this aim, firstly we will provide an introduction to the general concept of Software Engineering and later, to the world of Process Improvement.

In few words, Software Engineering is basically, the application of a systematic approach, disciplined and quantifiable for the development, operation and maintenance of software and their aim is essentially, improve the quality of the software products and try to increase the labor productivity. Also, Software Engineering tries to facilitate the control of the software development processes and define a discipline to ensure the production. For coming up with these concepts there is necessary the definition of several qualities, developed below.

1.1. Software Nature and Qualities

Out of technical concepts, Software Engineering (abbreviated SE) is an intellectual activity created for accomplishing with a functional aim to satisfy requirements. With this objective, differences between the concepts or internal qualities versus external qualities, depending if these qualities concern the developers or concern the qualities that the users perceive and, also, differences between categories product versus process based on ‘how do’ the development of the software products and processes. One concept that is important to take care about and, that will be also showed during all the Master Thesis, is that the quality of the process affects to the quality of the product. Consequently, Software Engineering pays attention on both categories.

Software Engineering bases their specification of the software quality on the called ‘Limit of Correctness’ based on the concept of the absolute ‘yes’ or ‘no’ in quality. When the assessment of a process is carried out, there is not a medium size. It exist a degree of correction but on the evaluations, the process quality needs to be answered by a totally correct implementation or not.

The concepts that Software Engineering Institute (SEI Webpage, 2011) identifies as more important for measure the quality are listed and explained following:

- Reliability: Is the mathematical probability of absence of failures during a period of time. If the specifications are correct, the correct software will be reliable.
- Robustness: This specification is based in the software comports “reasonably” even in unforeseen circumstances.
- The intelligent use of the resources: One of the ideas of the Software Engineering programs is to not waste the resources, use them as much as possible in an intelligent way.
- Friendliness: This concept is based about the topic that if the program that is used on the company is easy to use and also, easy to understand.
- Verifiability: For knowing if an implemented program is working correctly, it needs to be easy to verify it. The present attribute pays attention on this topic.

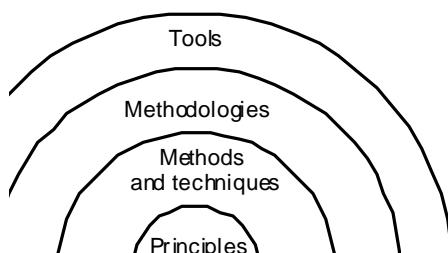
- Maintenance: Out from the easy verification of the Software, this needs to be also easy to maintain. This point is really important because normally, the maintenance cost around the 60 per cent of the total cost of implement a Software program.
- Reusability: Nowadays is important for the companies to not change often of programs. For this reason, the Software companies try to improve their standard programs with new versions based on the idea of this concept about trying to use existent products to develop new ones.
- Portability and Interoperability: Connecting with the previous idea, out for not changing program, the companies will want the Software programs can execute in different platforms and also those they have the ability to coexist with other operability systems.
- Punctuality: This concept is based on the product in time, without delays. The aim of Software Engineering programs is that help to improve the processes of a company and one of the most common objectives is to not have delays on the product delivery.
- Productivity: Also connecting with the previous concept, not only the company wants to not have delays but also that the software will be efficient.
- Visibility: The last one of the concepts that SEI identifies as important for measure the quality of their Software programs is that everything will be properly documented.

All these previous concepts will appear on the Software Program and process that are studied on the present thesis. The implementation of both systems that we will try to match will not be completed if all of the concepts developed above are not satisfied.

Out of these concepts, that assures the quality, Software Engineering applies several concepts that are needed for the correct implementation of their programs. This idea will be explained better on the next section.

1.2. Software Engineering Principles

For coming up with any process related with the Software Engineering, (Ghezzi et al., 2003, pp 41-66; Sommerville,2006, pp. 9-22) says that there are seven key principles to apply to processes and also, to the product. These principles are the base for implementing the tools and consequently, carry out with the process.



[Figure 1.1. Pyramid of Software Engineering](#)

Following, these key principles are the listed and developed:

- Rigor and formality: Both categories have to be a systematical practice. It is really important that the process will be controlled by software and evaluated by mathematical keys.

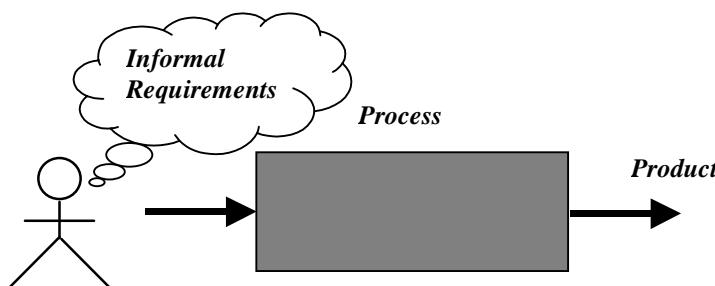
- Separation between worries: For carrying out with the process, the efforts done in every problem needs to be separated, work in parallel designing the correspondent responsibilities.
- Modularity: Following the previous concept, for coming up with the process, this will be harder if it is considered as a general. Software Engineering Institute recommends trying to divide the system in modules assigning roles and responsibilities in every one of it.
- Abstraction: This concept focuses on the identification of the aspects of a phenomenon ignoring the details. Try to know which is the concrete problem and later, all the consequences will be developed.
- Anticipation to the change: For coming up with the process and the products that will be used, the company needs also to anticipate the changes that will arrive in the future.
- Generality: This concept studies the fact about discover if the solution of a problem is part of the general procedure or will be in a specific section. This not means that the company needs to focus in that concrete section because also having the root of a problem in one concrete section; this problem can affect other ones.
- Incrementality: The last one of the principles of Software Engineering focuses on the topic of the increase the process. Not implement everything in one moment but doing step by step assuring that every one of these steps are correctly implemented.

As we will see later, all these processes are the ones that will be the basis for the studied programs and also, the basis for the verification and the assessment of the models.

1.3. Software Engineering Verification

All the previous concepts need to be verified for knowing if they are correctly implemented. This concept bases on the analysis of the product to see if it suitable or not and, to prove it, uses several tests divide in two big groups depending if the process is verified in general or in several steps: black box and white box (Thayer and Sommerville, 2002, pp. 35-76).

- Black Box: The criterion of division is based in the specification of the module. This way of verification supposes to verify the total of the process like a closed box knowing if there are accomplishing the requirements in the beginning and in the end of the implementation. The following image extracted from (Ghezzi et al., 2003), shows this concept.



This idea has problems because analyzes the process as a unique group. These problems are mainly the next ones: firstly is the idea that the requirements need to be comprised before the development and the second one is that the interaction between the company and the customer occurs only in the beginning and in the end of the project, not during the project itself.

- White Box: In contradiction from the previous, the 'White box' criterion bases in the internal code of the mode. It divides the process into modules that are able to interact between others. This concept is also showed on the next picture extracted from (Ghezzi et al, 2003).

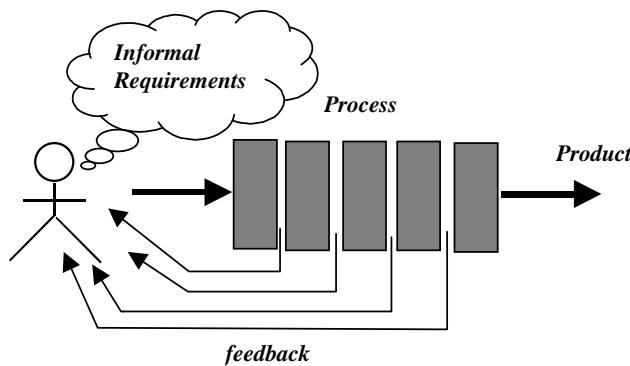


Figure 1.3. Concept of White Box Verification

This kind of criterion reduces the risks by means of improvements of the visibility and allows the modification of the project since these advances but on the other hand, is more complex than the verification by Black Box because needs to focus in everyone of the different models.

The White Box criterion and how it integrates activities, is the bases of the kind of models studied and developed on the present Master Thesis. On 'Chapter 3. CMMI Description', we will develop the concept of the integration of activities in a concrete process improvement model.

And, as a last step to this short introduction to the Software Engineering, we will introduce to the management of the processes. As it is said above, if the responsibilities of every process are not well defined, the implementation of a Software Engineering program will not evolve.

1.4. Management of Software Engineering

As stated in the beginning, Software Engineering is an intellectual activity that is able to realize for the people because it has a big variability in the productivity of the engineers and need predictive methods to estimate the complexity of the developed software, especially in the thematic of the costs.

According with (Ghezzi et al., 2003, pp. 457-500), this work needs several teams coordinated by a visible head. The aim of the form of work is to centralize the control of development by the

assignment of the adequate roles for make as easy as possible the process controlling every team an area and also, in this way, it makes easily to understand the solutions by the users. A common diagram that shows this way of work is attached on the following figure 1.4:

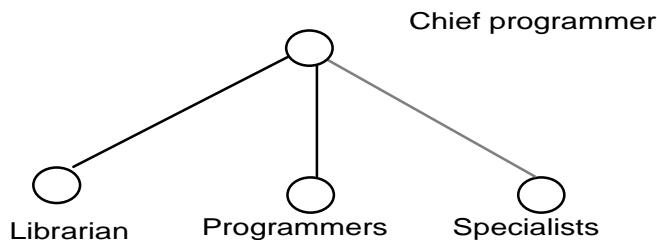


Figure 1.4. Responsibilities of common Software Engineering

Advancing concepts, this diagram is the base of the CMMI model because differences the organizations in two different types: mature and immature. If an organization is implementing the concept of teams for the different jobs is the first step for considered a mature organization because will center more in-depth in the quality of the products.

2. Introduction to Process Improvement

Software process improvement has become essential for satisfying the needs of customers and the requirements of markets regarding the quality of software products. All processes need to know about improvement for assuring every new change that the pass of the time will provide. For this reason, there is needed a defined sequence of stages to perform for obtain improvement.

Process Improvement is a cyclic activity characterized by the following stages: plan, do, check and act. The reason why this concept is considered a cycle is developed below.

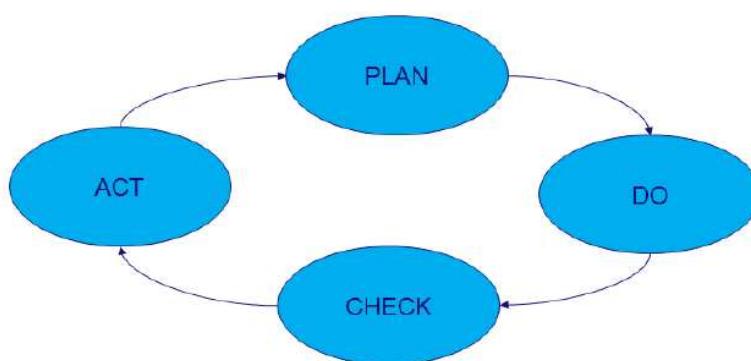


Figure 1.5. Process Improvement Cycle

These four stages developed consist about the following:

- Plan (change's implementation): this stage is characterized for the identification of the problem or opportunity for improvement, assembling a team and finally, developing an implementation plan.
- Do (making the change, pilot or small scale changes first): this stage includes carrying out a test, documenting procedures and observations and gathering data to track progress.
- Check (studying the results): this stage determines whether the improvement is made, based on an analysis of data and goal comparison, and provides the impact evaluation and the determination of improvement's occurrence. If results are not as expected, the Act stage can be skipped to return to the Plan stage.
- Act (adoption or abandon the change): this stage consists of deciding what changes will be made permanent, identifying the support structures to complete the change, implementing the change and developing a strategy for maintaining the improvement. If the change is not adopted, this stage returns to the 'Plan' stage.

Every one of the previous stages needs a big amount of time to perform it and for analyze the change effects. Consequently, process improvement is a long-term and also, a continuous activity for the organization (Bolognino, 2011).

But the problem of process improvement is that is not easy to come up with it, especially if we are talking about Software processes problems. These problems are related normally on the way that organization makes the data collection. Out from the different ways for collecting it, the tools required to collect these data requires also a full-time system administrator that will take care of the process (Sillitti et al., 2004). The normal ways for collect data on improvement processes in general and in the studied model in particular and, also, which tools are used, are concepts that will be developed on 'Chapter 5. CMMI Assessment'.

Anyway, the final goal of the system administrator and the organization in general is to understand the causes of every problem and repair costs of faults having in mind that on the long-term goal they will need to reduce their occurrence and probability. This is how an organization improves but, at the same time that the organization evolves, their environment evolves too complicating the system. On the other hand, during time passes, this environment provides also tools for support the own evolution. The most common evolution that the general environment has is the evolution of the programming languages, the evolution of development tools and their extensions and the metrics collection tools (Hochstein et al., 2008). One of those metric tools is the Process Mining that will be studied in-depth in the present master thesis before try to match it with the studied model for evolves software processes, CMMI and his assessment.

Concluding, the idea of this section is that if a company wants to continue being competitive, they need to adapt to the environmental changes and solve their problems improving and evolving constantly.

3. Summary of the Chapter

On the present 'Chapter 1. Introduction to the Research', we explained in few pages, what the world of the Software Engineering is and, the concept of the improvement of the processes.

Summarizing, on the section ‘1. Introduction to Software Engineering’, we saw that Software Engineering is the world related on how the organization applies their operations related on the development, operation and maintenance of software. On ‘section 1’, we develop the principles that this world has and, also, the different ways for verify it. These concepts are the bases of the present Maser Thesis because, on the present chapter, we developed the general area where both, Process Mining and the Software maturity models and their assessment, remains.

On the other hand, on section ‘2. Introduction to Process Improvement’, as it says that title, we introduce the process improvement and why the organization needs to improve them. This concept is related with the area of the Thesis because, when an organization decides to implement a maturity level like CMMI, is because they want to improve them. And, for show that they are improving, the organization needs to evaluate or assess them.

Once introduced the concepts where the present Master Thesis remains, explain which the function of the Software Engineering is and, also knowing a bit about the reasons for improving processes in a company, the research done in the Thesis can be presented.

Chapter 2. Research Definition

1. Context of the Project

Previously, on ‘Chapter 1. Introduction to the Research’, we defined the roots where this thesis will settle. In this section the previous steps will be addressed towards the objective of the thesis that will be also developed.

Nowadays, all the companies need to improve if they want to continue being competitive. For this reason, it exist several models that help the companies to improve, showing several steps that they need to accomplish for come up with the objective of evolve themselves. Examples of this kind of models are, for example, the ISO rules, the Six Sigma model or the Capability Maturity Model Integration (CMMI), among others.

The last one of these models, CMMI, will be the one that the present thesis will focus the attention. This model divides the improvement of every company in five different levels, which will be developed in chapter ‘Chapter 4. CMMI Description’, and accomplishing with every one of them, the improvement of the processes for the development of the company and the operation related with the software systems will evolve. For continuing evolving, the companies’ needs to assess every level when they think that are ready. If they don’t pass the corresponding evaluation, they will need to revise the processes involved and pass again for the assessment.

Nowadays, this assessment is done by the Software Engineering Institute (SEI) which is also the creator of the CMMI Model with the help of a program called SCAMPI, the initials of ‘Standard CMMI Appraisal Method for Process Improvement’. This kind of evaluations identifies the strengths and the weaknesses of the processes of the company and provides a qualification for the maturity level that the company is implementing.

On the other hand, Process Mining is a process management technique that allows the analysis of the processes of the company by using the registers of the events. With this aim, extract knowledge from the registers and uses information for discover how the organizations are really working, how they are controlling data and which is exactly the social structure of the company.

2. Objective and Research Questions

Software process improvement has become essential for satisfying the needs of customers and also, the requirements of the markets that, day by day, demands more level of quality on the software products.

For improve software processes in a systematic and structured way, there are developed several models that companies needs to follow for arriving to their objectives of improvement. One of these models is Capability Maturity Model Integration (CMMI) that, by their key process areas inside five different levels of maturity, helps the companies to improve.

For assess these key process areas in a quantitative way, data is collected from that process, preferably by using existing software engineering tools and is evaluated by an standard procedure.

On the other hand, previous research found that a particular configuration management can collect data from software processes. This concept is called Process Mining.

The objective of this Master Thesis is to investigate literature on tool support of CMMIs key process areas to find if it is possible the usage of the tool Process Mining for improve the assessment of these key process areas and, for extension, the assessment of the model in general.

3. Structure of the Project

For coming up with the previous objective, the present Master Thesis will advance by following the next contents in the order that will appear in the following description.

First of all, in 'Chapter3.Process Mining and Analysis' we will study literature about the tool of Process Mining. We will analyze the perspectives that this tool considers and how it works for obtain the knowledge from the registers. We will discover also which the possible questions that can be answered by using it are.

The following step will be the study of the other concept that we are considering on the present thesis: the CMMI Model. On 'Chapter 4.CMMI Description', we will describe it, paying attention to the differenced maturity models, which is the aim of every one of them and, which are the key process areas that the companies needs to accomplish for coming up properly with this model.

Once developed what is exactly CMMI Model and which is his function, on 'Chapter 5.CMMI Assessment' we will pay attention on the ways of data collection on CMMI Assessment and how the standard that Software Engineering Institute provides works. We will analyze which the problems of implanting this assessment are and, also, we will find the strengths and weaknesses of this standard.

When all the previous concepts will be developed, on 'Chapter 6.Tools of Process Mining for supporting CMMI Assessment', we will describe the methodology followed for trying to find if it is possible the usage of Process Mining for improve the weaknesses founded on the standard procedure for assess the implementation of the CMMI Model. The matches and mismatches between both concepts will be also showed on the present Chapter.

On the other hand, on 'Chapter 7.Tools of Process Mining for supporting CMMI Assessment of concrete Process Areas', we will develop in detail two process areas that every company needs to accomplish for coming up with the maturity levels of CMMI and, with the application of the methodology described on the previous Chapter with several modification for the concrete cases, we will try to find weak points of those CMMI key process areas where the tool of Process Mining can be implemented with the aim of improve the process area in particular and, consequently, the CMMI Model in general.

Finally, on 'Chapter 8.Conclusions' we will develop the conclusions extracted from the analysis and we will discuss if the implementation of Process Mining for improving CMMI Model and CMMI Assessment is possible and, if it's possible, in which points this application is recommended.

Chapter 3. Process Mining and Analysis

1. Introduction to Software Configuration Management and Process Mining

On ‘Chapter1.Introduction to the Research’, we described the concept of the process improvement, the reason why the companies have to improve and which is the cycle that they have to do for coming up with it. As we said also on that chapter, there is needed a collection of development tools with their correspondents extensions and metric collection tools. This concept is named Software Configuration Management and one of those metric tools is the Software Process Mining.

As it is said, Software Configuration Management is the task of tracking and controlling changes in the software including revision control and the establishment of baselines. In few words, this concept concerns itself the question: ‘Somebody did something, how can one reproduce it?’ (Cynosure Software Solutions, 2010).

But for coming up with Software Configuration Management, is necessary the usage of tools. One of those tools will be the one that we will develop in-depth on the present Master Thesis, the Software Process Mining.

On the tool of Software Process Mining, data from software development organization is logged into Event Logs and it is analyzed with the aim of extracting knowledge to discover process, how to control these data and which are the organizational and the social structures. Process Mining’s goal is to understand what is really going on into a process (Ramesh, 2005).

In fact, Process Mining is not a tool for designing processes but it provides a correct and realistic description of the current situation of the software process, understanding them and discovering which can be the realistic and detailed improvements that can be planned and executed on the actual and official process model.

2. Usage of Event Logs on Software Process Mining

The way of how Process Mining collects data is by catching it into the form of an Event Log. The idea of the concept Event Log is to perform steps during the operational process that are modelled by process models and that refers to specific moments in the process.

Event Log is structured in the following way: each record of the log refers to a document and document status, each record refers to a person and each record has its own timestamps (Kindler et al., 2005).

Event Log serves as a basis for process analysis because it can be compared against models to find differences and analyzed to check whether company policy was followed. One easy and typical Event Log is on the next Figure 3.1, extracted from (Samalikova et al., 2011).

case id	activity	event type
case 1	activity A	start
case 2	activity A	start
case 3	activity A	start

case id	activity	event type
case 3	activity B	start
case 1	activity B	start
case 1	activity C	start
case 2	activity C	start
case 4	activity A	start
case 2	activity B	start
case 2	activity D	start
case 5	activity A	start
case 4	activity C	start
case 1	activity D	start
case 3	activity C	start
case 3	activity D	start
case 4	activity B	start
case 5	activity E	start
case 5	activity E	complete
case 5	activity D	start
case 4	activity D	start

Figure 3.1. Example of Event Log

As a conclusion, Event Log is the basic tool for Process Mining being the base for extracting the process model and will be used for perform the different analysis that will be developed following.

3. Process Mining Diagnostics

An Event Log contains information about the activities that are performed in a real-life situation and, during the Process Mining analysis, will be used from different viewpoint for discovering the process structure and the involved knowledge.

But, Process Mining analysis is not the direct application of an event log for obtaining immediate solutions. (Bozkaya et al., 2009) described a general methodology based on three steps: Log preparation, Log inspection and finally, the own Process Mining analysis from four different perspectives. These steps and the commented perspectives are explained below.

3.1. Log Preparation

Every system of an organization provides information in its own way and it's necessary to define a standard for applying Process Mining. Log preparation transforms data recorded by a tool supporting a business process to an event log that has to meet several requirements to be useful. (Samalikova et al., 2011) notes that several requirements needed on this step of Process Mining Diagnostics are: that each audit trail entry should be an event that happened at a given point in time referring to only one activity and that each audit trail entry should refer to a specific process instance, also called 'case' ordered for example, in timestamps.

3.2. Log Inspection

On the second of the phases of the Process Mining Diagnostics, statistics about the log are gathered and give insights in the size of the process. Based on this process, size of the process is assessed and the appropriate mining algorithms can be chosen for example extracting the main behaviour from the event logs.

3.3. Process Mining Analysis

The final step of the Process Mining Diagnostics is also the own application of this model. It consists on the extraction of the process model from the event log and performs some analysis on it. This model has four different perspectives where the user can focus depending on his objectives. These four perspectives are: Control-Flow perspective, Performance perspective, Organizational perspective and Case perspective. These perspectives, at the same time, have relative sub-phases. The usage of every one of those perspectives, the kind of data that they need and the questions that can be answered by using it will be developed below by following the concepts demonstrated in (Bolognino, 2011; Samalikova et al., 2010; Samalikova et al., 2011; Van Der Aalst et al., 2005).

4. Process Mining Perspectives

For coming up with the analysis of Process Mining, it is possible to highlight different aspects of the process, everything depending on where the company wants to focus. These aspects are called perspectives and they try to concern the questions related with the ‘How’, ‘What’ and ‘Who’ of the process (Bolognino, 2011). These perspectives are: Control-Flow perspective, Performance perspective, Organizational perspective and Case perspective. On ‘Chapter 6. Tools of Process Mining for supporting CMMI Assessment’ and ‘Chapter 7. Tools of Process Mining for supporting CMMI Assessment of concrete process areas’, we will compare the models developed there with these perspectives trying to find matches between them and the CMMI Model and CMMI Assessment.

The four different perspectives of Process Mining are developed below.

4.1. Control-Flow Perspective

The first one of the perspectives of Process Mining that we will study shows how the actual process looks like in order to find the real sequence of tasks performed on cases, the difference between the official process and business rules defined by the company and the actual process and the data dependencies that affect the routing of a case.

But to extract the actual process model that has various control-flows, the event log has to satisfy the next requirement: it has to contain ordered sequences of events where each event refers to a case and each case refers to an activity.

This present perspective has three steps that focus on it, Process Model discovery, Conformance checking and LTL checking and, depending on the step that the organization wants to focus, data on this perspective will be collected in a heuristic way, on a genetic way or in a fuzzy mining way. Using the first one of the ways, the data is collected based on the frequencies, genetic mining collects data based on the evolutions of the system and finally, collecting data by fuzzy mining, data will be collected without a clear structure.

Below, these sub - phases of Control - Flow perspective will be developed.

4.1.1. Process Model Discovery

During this sub-phase, the model of the process extracted from software data is constructed. For coming up with it, different type of mining for applying the robustness or the noise of the process can be applied.

For this sub-phase, event log needs to contain the sequences ordered by event referring each event to a case and a task like is it shown on the Figure 3.2.

case id	activity	event type
case 1	activity A	start
case 2	activity A	start
case 3	activity A	start
case 3	activity B	start
case 1	activity B	start
case 1	activity C	start
case 2	activity C	start
case 4	activity A	start
case 2	activity B	start
case 2	activity D	start
case 5	activity A	start
case 4	activity C	start
case 1	activity D	start
case 3	activity C	start
case 3	activity D	start
case 4	activity B	start
case 5	activity E	start
case 5	activity E	complete
case 5	activity D	start
case 4	activity D	start

Figure 3.2. Event Log used on Control - Flow perspective

According to Samalikova et al. (2011), the usage of this sub-phase helps to answer questions like:

- Which is the real process that is really followed on the organization?
- How the process really looks like?
- How many cases are following a certain path?

4.1.2. Conformance Checking

In this sub - phase, the concept that is developed is if it is possible to replay a log in the process model and discover his behavior for conforming the process model.

On this sub-phase of the perspective, event log contains the sequences of events referring each one to a case and to a task or an activity. The form of the typical event log for coming up with this sub-phase of Control-Flow perspective is the same that Process model discovery needs and is it showed on Figure 3.2.

According to Samalikova et al. (2011), the usage of this sub-phase helps to answer questions like:

- Is the organization following the defined model?
- How much is deviating the real process from the defined one?
- Is the process skipping any tasks during the process execution?

4.1.3. LTL Checking

The last one of the sub-phases of the Control - Flow perspective is called Linear Temporal Logic checking and it is used in the case where is not a complete process model but just a set of constraints. For instance, there is needed to formulate the properties that the organization wants for the event log including how they want to order the sequences of events.

According to Samalikova et al. (2011), the usage of this sub-phase helps to answer questions like:

- Was task A executed by person P at the correct moment of time?
- Were tasks B, C and D executed by the same or by different people?
- Are the tasks following the expected order?

4.2. Performance Perspective

The second perspective that Process Mining Analysis contemplates, Performance Perspective focuses the analysis on the performance of the process, calculating the timeliness of cases and the limited capacity resources like the bottlenecks or the throughput time of the processes.

This perspective has two different sub-phases that are applied one for the calculation of the limited resources and the other one for the fact if the process or part of it is following a pattern or not. Both are focused on the weaknesses of the process and consequently, will be a useful perspective to take into account when the organization will want to know which the problems or defects of the process itself are.

Extracted from Samalikova et al. (2011), an example of the typical event log that this perspective uses is included following.

case id	activity	event type	time stamp
case 1	activity A	start	9-3-2004:15.01
case 2	activity A	start	9-3-2004:15.12
case 1	activity A	complete	9-3-2004:15.13
case 3	activity A	start	9-3-2004:16.03
case 3	activity B	start	9-3-2004:16.07
case 1	activity B	start	9-3-2004:18.25
case 2	activity A	complete	9-3-2004:18.30
case 3	activity A	complete	9-3-2004:18.33
case 1	activity C	start	10-3-2004:9.23
case 2	activity C	start	10-3-2004:10.34
case 3	activity B	complete	10-3-2004:10.34
case 4	activity A	start	10-3-2004:10.35
case 2	activity C	complete	10-3-2004:10.36
case 1	activity C	complete	10-3-2004:11.23
case 2	activity B	start	10-3-2004:12.34
case 2	activity D	start	10-3-2004:12.50
case 5	activity A	start	10-3-2004:13.05
case 4	activity C	start	11-3-2004:10.12
case 2	activity B	complete	11-3-2004:10.13
case 1	activity D	start	11-3-2004:10.14

case 3	activity C	start	11-3-2004:10.44
case 3	activity D	start	11-3-2004:11.03
case 2	activity D	complete	11-3-2004:11.04
case 4	activity B	start	11-3-2004:11.18
case 5	activity E	start	11-3-2004:12.22
case 5	activity E	complete	11-3-2004:13.17
case 5	activity D	start	11-3-2004:14.34
case 4	activity D	start	11-3-2004:15.56

Figure 3.3. Event Log used on Performance Perspective

Both sub -phases commented above are named and developed following.

4.2.1. Throughput time calculation and Bottleneck analysis

This sub - phase consists in the calculation of timeliness of cases and reveals the bottlenecks in a process by calculating waiting and execution times and the throughput time of the process if the timestamp of the end event is well recorded.

For coming up with this sub - phase Is necessary that the event log contains the ordered sequences of events referring each one to a case and an activity but also, as one can see in the Figure 3.3, is also needed the timestamps with the day and the hour of the start and the end event of the tasks. In this way, the timeliness of cases in the process can be calculated.

According to Samalikova et al. (2011), the usage of this sub-phase helps to answer the questions that puts name on the present sub - phase. These questions are:

- What is the throughput time of the process?
- Where are the bottlenecks of the process?

4.2.2. Performance Sequence Analysis

This part of Performance perspective wants to determine which sequence patterns are common and which patterns are less frequent. For this reason, the data requirements that the event log need to perform are the same used for the Throughput time calculation and Bottleneck analysis.

According to Samalikova et al. (2011), the usage of this sub-phase helps to answer questions like:

- What is the most common execution pattern and if there is a pattern, is this the expected one?
- Which pattern has the longest throughput time and is also this pattern expected?

4.3. Organizational Perspective

The third perspective of the Process Mining analysis focuses on the originator field, which performers are involved and how are they related. The goal is to show and understand which the structure of the organization is by classifying people in terms of roles and organizational units and to show relation between individual performers. This perspective is focused on answer 'Who?' is realizing every process.

Organizational perspective only has the aim of identify which the roles and the responsibilities of the involved personal are and, for this reason, only has one sub - phase that strictly dedicates to this objective, the called Social Network analysis. This analysis is developed below.

4.3.1. Social Network analysis

As the own name says, the sub - phase of the Organizational perspective bases their analysis on finding how is working the social network of the organization, who is working together, who has similar tasks or if there is any transfer of work between the employees, also called in a more scientific way, task originators.

Although focusing in similar concepts than Conformance checking and LTL checking of the Control - Flow perspective, social network analysis has a more specific objective, focusing in depth on who concretely are the task originators and which are the relations between them and, not as the analysis of Control-Flow perspective if, in general, a task is skipped or if is following the correct path. The information of who are concretely the task originators is not needed on the Control - Flow perspective but is useful if the organization can provide it.

Consequently, the data requirements that event log needs for coming up with this analysis is, out from the ordered sequences that are referring to an event or a case, the person that is performing the task, the task originator. This concept is showed on the Figure 3.5 that shows an example of an event log used for the Social Network Analysis

case id	activity	event type	originator
case 1	activity A	start	John
case 2	activity A	start	John
case 3	activity A	start	Sue
case 3	activity B	start	Carol
case 1	activity B	start	Mike
case 1	activity C	start	John
case 2	activity C	start	Mike
case 4	activity A	start	Sue
case 2	activity B	start	John
case 2	activity D	start	Pete
case 5	activity A	start	Sue
case 4	activity C	start	Carol
case 1	activity D	start	Pete
case 3	activity C	start	Sue
case 3	activity D	start	Pete
case 4	activity B	start	Sue
case 5	activity E	start	Clare
case 5	activity E	complete	Clare
case 5	activity D	start	Clare
case 4	activity D	start	Pete

Figure 3.4. Event Log used on Organizational perspective

As it is appreciated above, the questions that can be answered by implementing this kind of perspective are the following ones:

- Which task originators are working together?
- Which of them have similar tasks?
- Is there any transfer of work between the task originators?

4.4. Case perspective

The last perspective that Process Mining analysis has is Case perspective. This perspective focuses on the analysis of the process based on the properties of cases discovering the data dependencies that affect the routing of a case. This concept wants to answer 'What?' is happening with the data and how affects to the process itself. Similar as Organizational perspective, Case perspective has only a one sub-phase that is the attendant to provide this information. This sub-phase is called decision mining or, the name that we will use, Decision analysis.

4.4.1. Decision analysis

Completing the above, Decision analysis has the aim of analyze how data attributes influence the choices made in the process using the base on the past process executions. With this objective, the organization can see how data influences the routine of the process.

For implant the present perspective, event log needs to contain also the events that refer to a case and a task, and all the attributes that can be modified by the tasks to implement. In this way, the organization can see how this information is changing. One example of event log used on this perspective is attached following in Figure 3.5.

case id	activity	event type	originator	priority
case 1	activity A	start	John	medium
case 2	activity A	start	John	low
case 3	activity A	start	Sue	low
case 3	activity B	start	Carol	low
case 1	activity B	start	Mike	medium
case 1	activity C	start	John	medium
case 2	activity C	start	Mike	low
case 4	activity A	start	Sue	low
case 2	activity B	start	John	low
case 2	activity D	start	Pete	low
case 5	activity A	start	Sue	low
case 4	activity C	start	Carol	low
case 1	activity D	start	Pete	medium
case 3	activity C	start	Sue	low
case 3	activity D	start	Pete	low
case 4	activity B	start	Sue	low
case 5	activity E	start	Clare	low
case 5	activity E	complete	Clare	high
case 5	activity D	start	Clare	high
case 4	activity D	start	Pete	low

Figure 3.5. Event Log used on Case perspective

According to Samalikova et al. (2011) and to the concepts related above, the usage of this sub-phase helps to answer questions like:

-
- How data attributes influence the choices made in the process?
 - What type of cases follows a particular process path and is this the expected one?

5. Summary of the Chapter

On the present 'Chapter 3. Process Mining and Analysis', we studied and developed one of the main actors that affects the present Master Thesis, the tool of Software Process Mining.

In few words, Process Mining is a tool that provides a realistic description of the situation of the software processes and can be used for discover where the weaknesses of the process are.

Based on this concept, on the present chapter, we introduced the reader to the main concept of Process Mining. On the section '2. Usage of Event Logs On Software Process Mining', we developed the principal tool for coming up with the Process Mining, the Event Logs. Following, on section '3. Process Mining Diagnostics', we explained which the steps for implement Process Mining are and, finally, on section '4. Process Mining Perspectives', we elaborate the most important concept that we will use later on the Master Thesis, the perspectives where Process Mining focuses and what can the users do by using these perspectives.

Once developed the concepts of CMMI and CMMI Assessments, which will be developed on the next chapters, on 'Chapter 6. Tools of Process Mining for supporting CMMI Assessment' and 'Chapter 7. Tools of Process Mining for supporting CMMI Assessment of concrete Process Areas', we will try to find matches between the weak points of CMMI Assessment and these perspectives of Process Mining for discovering, consequently, if one can use Process Mining for improve the CMMI Assessments. Discover if there is an matches is the aim of the present Master Thesis.

Chapter 4. CMMI Description

1. Introduction to CMMI Model and Problems

The Capability Maturity Model Integration (CMMI) is the most recent successful model for improving and appraising the performance of development organizations. It is a powerful tool to guide process improvement initiatives, for software development and many related fields such as systems engineering, product acquisition, team management, research and development (Boras et al., 2009). Recently, CMMI is recognized as the most economic and powerful software process improvement methodology (SEI Webpage, 2011) provides guidance to use when developing processes and change the software development processes toward agility.

The way to use CMMI Model follows an easy perspective. The organization will improve them by passing through five different levels. Every level has different steps that they will need to accomplish for assuring the present level. When they think that are ready for grow to the following level, the Software Engineering Institute will evaluate them and if there is the consideration, the organization will grow to the next level.

By default, every early organization is at maturity level 1. To reach level 2, they should satisfy the goals of seven process areas - such as Requirements Management and Project Planning. To achieve the level 3, an organization should perform all the process areas of the level 2 plus the process areas defined for the level 3. Analogically, maturity levels 4 and 5 require the implementation of new process areas as well as those of the lower level process areas (Jokela and Lalli, 2003). All the levels and the corresponding process areas will be developed below.

But this concept is not as easy as it seems because several times, the organization don't know exactly where they are or they think that are implanting one system but this system is not working correctly. How this model helps to solve these questions and also, how the assessment measures it, will be developed in the present thesis.

First of all, in this present Chapter, we will introduce the five different maturity levels of the CMMI Model, the process areas inside every level that every company needs to rise and how the company can come up with them. This process areas will not be developed deeply because this is not the aim of the present Master Thesis but, for knowing that Process Mining can be a helpful tool for improve the way for asses every single process area, on 'Chapter7.Tools of Process Mining for supporting CMMI Assessment of concrete process areas', the process areas: Decision Analysis and Resolution' and 'Organizational Process Focus' will be explained in detail, their weaknesses will be found and we will try to find connections with the tool Process Mining, tool explained on 'Chapter 3. Process Mining and Analysis'.

But before, as it is said, in this present Chapter, all the maturity levels will be explained.

2. CMMI Maturity Levels

CMMI is divided in five different levels that will need to arise in order for obtain the success. Although is useful that the companies starts with maturity level 2 because the first one is also for the earlier and chaotic companies, on the following sections, all the maturity levels will be named and developed.

2.1. Maturity level 1: Initial

At maturity level 1, where are only the companies that have no order in their processes there are a lot of problems that they need to solve. This is the initial level of all the companies that are just starting their business (SEI Webpage, 2011).

The first step that a company needs to do for improve and arrive to level 2 is try to repeat the previous successes because the absence of consolidated knowledge and an organization wide culture create than successful projects can hardly be repeated and for this objective, one can prepare and analyze the log, the first step of the process mining (Ghezzi et al., 2003).

Differently from the other maturity levels that will be developed on the next section, on maturity level 1 there is not process areas to follow, the only aim that the companies needs to arise is to try to repeat their successes for arrive to maturity level 2, also called 'Repeatable'.

2.2. Maturity level 2: Repeatable

At level 2, requirements are managed and processes are planned, performed, measured, and controlled in individual development projects (CMMI Product Team, 2006, pp. 36-37). The aim of this maturity level is to assure that the organizations can repeat their successes and these successes cannot be repeated without the corresponding well planning.

In order to achieve this, CMMI identifies seven process areas that need to be implemented: configuration management, requirements management, measurement and analysis, project monitoring and control, project planning, process and product quality assurance and supplier agreement management. Every single area requires of several requirements for carrying it out with. Following, every process area will be described by an abstract of their functions.

The seven process areas defined on the last paragraph are developed following.

2.2.1. Configuration Management and Requirements Management

Although that CMMI Model considers this step as two different levels, for the present introduction, it is considered that both concepts can be explained together because they have several common points and they want to arise the same concept, the definition of the requirements and the identification between these requirements and the project planning and the work items.

Configuration Management has the purpose to identify the configuration of the work products that will compose the baselines of the process and control their changes by providing specifications (CMMI Product Team, 2006, pp. 114-131). On the other hand, Requirements Management wants to study the requirements of the process products for identify inconsistencies between those requirements and the process' plans and work products (CMMI Product Team, 2006, pp 408 – 420).

Is important that both concepts will be well defined because will be maintained during all the process improvement.

2.2.2. Measurement and Analysis

The purpose of Measurement and Analysis is to develop and sustain a measurement capability that will be used to support the management information needs (Software Quality Assurance, 2011). For come up with this concept, the company will need to specify the objectives of the measurement that they would like to perform, specifying in consequence the measures, the analysis techniques, the mechanism for data collection or how they will realize the feeling, among others.

The idea of this process area is also to perform with these concepts, storing, analyzing and reporting the feeling about data for obtaining objective results that can be used for making and taking the corrective actions.

For realizing Measurement and Analysis, Dalton (2011) identifies that the common tools are estimations of work product size, effort and cost (like the number of person hours needed for the process) or quality measures like the number of defects found in the process or the importance of the bottlenecks. All these data is collected in a database but the standard CMMI Model doesn't provide a standard tool for use in those cases.

2.2.3. Project Monitoring and Control

After the measurement and posterior analysis of data for knowing more or less where the problems are, the next process area is based on the understanding of the project's progress and takes the corrective actions if the performance is not according with the expected.

For obtaining progress, there is needed to control the actual process by periodical measurement of the actual effort, cost expended and the project performance for knowing if the company is going in the expected direction or there is any risk on the activities that are performed on the company (CMMI Product Team, 2006, pp. 313-326). For coming up with this process area, normally are used records of project performance or records of significant deviations, normally designed for every company in particular, not with the usage on an standard (Dalton, 2011).

When data is collected by the appropriate measurements, this can be analyzed and, if it is considered necessary, the corrective actions will be taken. If this fact happens, the process needs to be measured again for assure that the corrective actions have the expected results.

2.2.4. Project Planning

The aim of this process area is to establish and maintain the plans that define the activities of the project. Try to develop the initial plan of the project having a good relationship with the involved stakeholders is the first step.

For coming up with this process area, the organization has to take care of the elements of work and the resources, that are the bases of this process area because there is needed a commitment with the plan for all the involved personal and also because these plan needs to be maintained during all the improvement process (CMMI Product Team, 2006, pp. 327 – 352; Stark, 2002).

2.2.5. Process and Product Quality Assurance

The quality of the process, their reliability is one of the most important topics that one organization needs to take care about. On this process area of the maturity level 2, these topics are ensured (Software Quality Assurance, 2011).

For assuring quality, there is needed that all the performed processes, the work products and the different services were evaluated with the most possible objectivity. It is supposed that on the previous process areas, these concepts were already performed, assuring that all of them are following correctly the way for what they were designed.

When the processes are evaluated and the problems documented, there is needed of a correct feedback of the involved stakeholders assuring that there is not defects already in the process. If there is identified something, the organization needs to take the appropriate corrective actions and the process needs to be evaluated again (CMMI Product Team, 2006, pp. 353 – 363).

2.2.6. Supplier Agreement Management

Supplier Agreement Management establishes and maintains the integrity of the work items, identifying, controlling and auditing the elements.

For come up with this process area, firstly is needed the determination of the type of acquisition that will be used for the products to be acquired and consequently, the suppliers will be selected and the corresponding agreements with the suppliers will be established.

The monitoring of the supplier processes is important for the good perform of the process creating the companies normally a special department only dedicated to this concept. The monitoring process needs to be accepted by the stakeholders (CMMI Product Team, 2006, pp. 439 – 455).

This is the last step that one controls in the maturity level 2. When all the above steps are controlled, means that probably the work can be repeated and, in consequence, probably the company is assuring the maturity level 2.

2.3. Maturity level 3: Defined

At level 3, the processes used in development projects are described in organizational level standards. Every individual development project establishes their processes by using the organization's set of standard processes.

As in maturity level 2, there are several process areas that the company needs to accomplish for assure that they are implementing correct the maturity level. In the present case, these process areas are: Decision Analysis and Resolution, Integrate Project Management, Organizational Process Definition and Organizational Process Focus, Organizational Training, Product Integration, Requirements Development, Risk Management, a possible technical solution and finally, the Validation and Verification (CMMI Product Team, 2006, pp. 33 – 34).

Based on the present maturity level, later, on 'Chapter 7. Tools of Process Mining for supporting CMMI Assessment of concrete process areas' the process areas 'Decision Analysis and Resolution' and 'Organizational Process Focus' will be developed in detail and how to improve them by the

usage of the tool Process Mining related on ‘Chapter 3. Process Mining and Analysis’ will be explained in detail focusing not also in which points this tool can be applied but also for the process areas ‘Decision Analysis and Resolution’ and ‘Organizational Process Focus’, the methodology for detecting these points will be explained and developed for teaching how the points where the application of Process Mining is possible can be detected.

But before perform last concept, on the following sections we will refer an abstract of all the process areas of the present maturity level.

2.3.1. Decision Analysis and Resolution

The purpose of Decision Analysis and Resolution is analyzing the possible decisions by using a formal assessment process that evaluates possible alternatives with an established criterion.

This area has basically application in the technical process area but also can be applied in non-technical problems, especially when the project are planning and can have multiples alternatives to be solved (CMMI Product Team, 2006, pp. 131 – 144).

For coming up with the first one of the process areas of the maturity level 3, firstly the organization will need to establish the different criterion that will be used for evaluate the alternatives that they will select. After knowing both the evaluation criteria and the alternative solution, the organization will need to select evaluation methods for the alternatives, use it on the alternatives and select the one that they will consider more adequate for the process they are performing (CMMI Product Team, 2006, pp. 131 – 144; Bahill, 2009).

2.3.2. Integrated Project Management

Integrated Project Management refers to the management of the project with the specific procedures from every particular process. There is one step of CMMI dedicated only to this topic because not all the projects of an organization follow the same process and there are necessary several decisions for the correct management of all of them.

The present step select the called “organizational process assets”, a set of standards procedures for the software development. The aim of Integrated Project Management is to select the lifecycle for perform the processes and develop the software and establishing the work environment for the project based on the organization’s work environment standards identifying the most relevant stakeholders (CMMI Product Team, 2006, pp. 145 – 177).

2.3.3. Organizational Process Definition

This process has the purpose of establish and maintain a usable set of organizational process assets and work environment standards.

The set of standard processes in the organizations are tailored by projects to create their defined processes. On the other hand, the work environment standards are used to guide creation of project work environments (Dalton, 2011).

In this step, as is it said, when the process elements and their critical attributes are identified, the aim is to find the relationships between the process elements and then, ensure that the organization's set of standard processes satisfies the process needs and objectives of the organizations and document this processes (CMMI Product Team, 2006, pp. 219 – 240).

2.3.4. Organizational Process Focus

The aim of the forth perspective of maturity level 3 is to plan and implant the organizational improves based on the strengths and weaknesses of the organizational processes based on the process areas defined above.

The present process area has clear steps because it is based on the way to implement process for improve. Follow this direction, the steps that 'Organizational Process Focus' follows are: firstly, determine the opportunities for improve processes. When these opportunities are defined, the organization will plan and implement the improvements (CMMI Product Team, 2006, pp. 241 – 260).

2.3.5. Organizational Training

The present process area is based on the development of the knowledge of the people that will perform the process that were defined on the previous process areas.

On the step 'Organizational Training', the organization needs to identify the training needed by the employees and provide it with the aim of addressing the needs (CMMI Product Team, 2006, pp. 275 – 293).

2.3.6. Product Integration

The purpose of Product Integration is to assemble the product from the product components, ensure that the product and deliver it.

The scope of this process area is to achieve complete integration between the product components and with the incremental stages because the critical aspect is the management of the product components to ensure compatibility among the interfaces.

This process may begin with analysis and simulations and steadily progress through increasingly more incremental functionality until the final product is achieved. Several examples of these procedures can be: test environment parameters, calculate the probability of proper functioning or calculate the lead time from order to delivery (CMMI Product Team, 2006, pp. 293 – 312 and Software Quality Assurance, 2011).

2.3.7. Requirements Development

The purpose of Requirement Development is to manage the requirements of the project's products and product components and to identify inconsistencies between those requirements and the project's plans and work products. The reason why this analysis is performed is because the customer needs have to be produced and analyzed. The steps for coming up with the present process areas are the following (Dalton, 2011).

First of all, there need to be several objectives criteria for the evaluation and acceptance of requirements as, for example, the consistence between components or if the property is clearly or not. Then, one needs to analyze the requirements to ensure that the established criteria are met and knowing if these needs are viable for the participants (CMMI Product Team, 2006, pp. 388 – 407).

2.3.8. Risk Management

The purpose of the process area ‘Risk Management’ is to identify potential problems before they occur and, consequently, try to mitigate the possible adverse impacts on achieving objectives that can derive because of these risks.

For this reason, there must exist thresholds for each risk category and also, a definition on the extent for knowing which thresholds are applied in every category. When this step is made, one can establish a risk management strategy with the corresponding tools and methods that every organization themselves decide and also the mitigation techniques to be used. Then, the organization will try to identify the risks, evaluate them and prioritize by categories. When everything is done, one can handle these risks and try to mitigate with the most possible effectiveness (CMMI Product Team, 2006, pp. 420 – 438).

2.3.9. Technical Solution

On this process area of maturity level 3, technical solution, the operational concepts and scenarios should be evolved. One needs to know which the weaknesses and the strengths of the product are and also, other concepts than the organization considers important for the good direction of the project.

For doing these steps, the first point is to identify the technologies currently in use and the new product technologies that can provide a competitive advantage. When everything is identified, the responsible needs to generate several alternative solutions obtaining a complete requirements allocation for each one and develop the best alternative solution (CMMI Product Team, 2006, pp. 456 – 482).

2.3.10. Verification and Validation

In the last of the steps of maturity level 3, Verification and Validation, there is the aim to ensure that the selected work products meet their specified requirements and also, to demonstrate that a product or product component fulfills its intended use when placed in its intended environment.

(Jokela and Lalli, 2003) notes that although Verification and Validation process areas are similar, they address different issues. Validation demonstrates that the product, as provided, will fulfill its intended use, whereas Verification focuses the attention if the work product properly reflects the specified requirements.

There are several different methodologies to perform these steps. Take starting for the identification of the key principles, features and different phases throughout the life of the project, then the determination of which categories of user needs are to be validated or also, needs maintenance.

When the products are selected, the user selects the evaluation methods and reviews the validation selection (CMMI Product Team, 2006, pp. 483 – 514).

For Dalton (2011), it exists a lot of evaluation methods for performing the present process areas. These methods goes from a load, stress and performance testing, a functional decomposition-based testing to the final acceptance tests for Verification and also discussions, prototype demonstrations or pilots of materials for the Validation step. The election of one or another method depends on which kind of products are you evaluating. Also, there are a lot of criteria for ensure that the work products meet their requirements as standards, organizational policies or test parameters.

Finally, all the results must be compared with the established verification criteria to determine their acceptability (CMMI Product Team, 2006, pp. 483 – 514).

Finishing with maturity level 3, as was said in the beginning, on 'Chapter 7. Tools of Process Mining for supporting CMMI Assessment of concrete process areas', the process areas 'Decision Analysis and Resolution' and 'Organizational Process Focus' will be developed deeply on a selection made for knowing if the tool of Process Mining can be used for improve the CMMI Model in general by applying it on the respective process areas.

When maturity level 3 is correctly addressed, the companies go to maturity level 4 and 5, the levels for the optimization.

2.4. Maturity level 4: Qualitatively Managed and Maturity level 5: Optimized

Maturity level 4 and 5 normally goes together because it is difficult to split the task from one than the other. Both levels are based on the totally improvement of the processes and the innovation in a huge level, arriving to the organization in general.

In maturity level 4, the quantitative objectives for quality and process performance are already established and used as criteria in managing projects and processes (Baumert and McWhinney, 1992, pp. 149 - 208).

In this level there are two big steps for doing: The Quantitative project management and also, the Organizational process performance. There are explained in detail below.

2.4.1. Quantitative Project Management

This step focuses their attention to the management of the project's defined processes to achieve the quality. These processes vary widely including monitoring the performance of the sub processes, monitoring the project for determine the project's objectives for quality or recording statistical for creating a quality management data. Normally these processes can be measured with the typical attributes like the mean time between failures or the number of defects in a particular lot of products (CMMI Product Team, 2006, pp. 364 – 387).

2.4.2. Organizational Process Performance

After knowing the quantitative effects of the components, the next step is to establish and maintain a quantitative understanding of the performance of the organization's set of standard processes in

support of quality and process-performance objectives and provide also, a process-performance data, baselines and models to quantitatively manage the organization's projects.

Like the previous step, the Organizational Process Performance has different levels. First, review the organization's business objectives related to quality and process performance for define the objectives for quality. When these objectives are defined, the organization needs to negotiate their priorities and also, revise the organization's quantitative objectives (CMMI Product Team, 2006, pp. 261 – 274).

On the other hand, maturity level 5 focuses on continuing improving process performance. As well in maturity level 4, the quantitative process improvement objectives for the organization were established, they need of a continually revision to reflecting the changing business objectives. This is the aim of the maturity level 5 that, similarly to maturity level 1, has not a defined process areas for perform it.

The purpose of this level is to select and deploy incremental and innovative improvements that measurably improve the organization's processes and technologies. This improvement refers to all of the ideas that would change the organization's processes and technologies to better meet the organization's quality and process-performance objectives (CMMI Product Team, 2006, pp. 38 – 40).

As several earlier levels, for improving the organization in general, one needs to focus first in one process area and try to collect the processes proposals. One example of criteria that can be used for selecting measures is to decide which measures represent better the user's view of the performance. Then, analyze the costs and benefits of the process and in consequence, look for several innovative processes for implement identifying at the same time, the potential risks that each process can have inside. When the user agree with everything, the process can be implemented with the corresponding documentation and the appropriate monitoring.

The final challenge of this level is that all the measures taken in these levels should be comparable from one product to another because if it's not, it is quite difficult to use specific context usability measures and probably, they will have to use more universal measures (Software Quality Assurance, 2011 and Robbins, 2004).

3. Increase CMMI level

Before arriving to the step of the assessment of the CMMI levels, one needs to know when the company decides for increasing of maturity level.

Companies decide to assess in concordance with the steps of the maturity level they are implementing or they think that they are implementing. Consequently, CMMI Assessment will show if they are implementing correctly all the process areas of every maturity level.

For assuring that the organization will ask for assessment in the correct moment, all the stakeholders involved on every process area needs to be perfectly identified including all the representatives from each discipline of the organization, like Process Management, Quality Assurance, Training, etc.

Out of this, is common on the organizations to evaluate themselves before asking to the Software Engineering Institute by the usage of metric reports like MINITAB or the creation of a Process

Schedule where all the activities can be listed and know consequently, if they are following the expected timetable and the expected goals(Robbins, 2004).

Finally, is also useful to create a watch list with the potential areas of improvement that the project would like to consider. For coming up with this step the used tool is the brainstorming (Robbins, 2004).

On the other hand, the normal time for increase from one maturity level to another is different depending on the level that the company wants to rise. This concept is showed on the 'Figure 4.1. Time to increase the CMMI level', extracted from (Kinder et al., 2005).

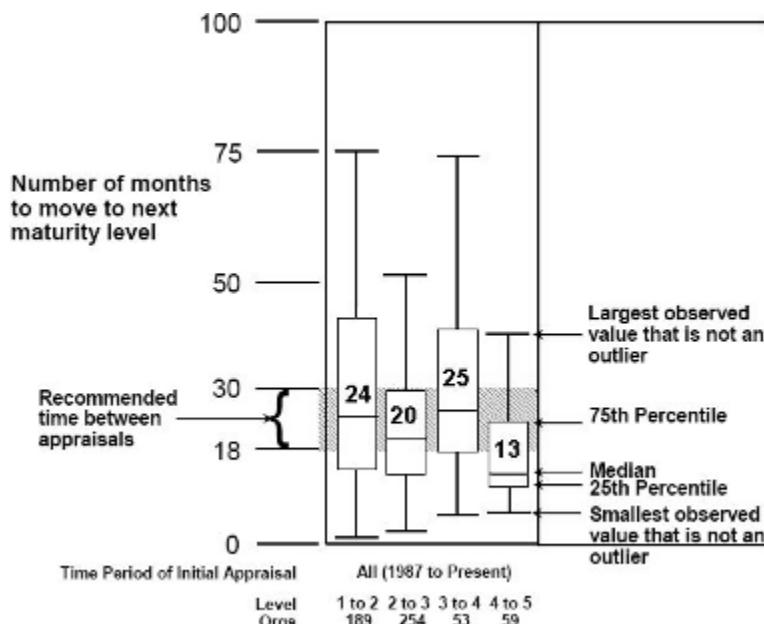


Figure 4.1. Time to Increase the CMMI level

4. Summary of the Chapter

On 'Chapter 4. CMMI Description', we presented the official levels of the improvement model, CMMI based on the official descriptions that especially the (SEI Webpage, 20) proposes.

Without entering in-depth inside every maturity level, we defined the goal of every level and we described, when it was necessary, which the concrete process areas to arise are and which tools are normally used by the organizations for come up with the different levels.

On the last part of the chapter, concretely on section '3. Increase CMMI level', we described how the organizations identify the moment when they reach any maturity level and they decide to increase to the next level. For clarify this concept, on that section, we also attached one graphic that shows which the standard time for pass from one maturity level to another is.

We didn't develop deeply all the process areas because it is not the aim of the present Master Thesis but, connecting with the main aim, on 'Chapter 7. Tools of Process Mining for supporting CMMI Assessment of concrete Process Areas', we will discover if Process Mining can be a helpful tool for improve their assessment of concrete process areas and, with this aim, we will create an standard methodology for finding matches between both concepts and we will apply it for the process areas: Decision Analysis and Resolution and Organizational Process Focus, both from maturity level 3.

Chapter 5. CMMI Assessment

1. Introduction

When a process is implemented, their assessment is an important and necessary fact to consider. Process assessment should give to the organizations an understanding of the current situation of the software process, which compared with the desired process, should establish a baseline for the improvement (Samalikova et al., 2010b). On this section, we will develop the assessment of the CMMI Model.

CMMI Assessment is the evaluation process that is used for the Software Engineering Institute (SEI) for controlling the correct implantation of the CMMI Model. In contrast to an evaluation, an assessment is an appreciation that an organization does it for them; whereas an evaluation is an appreciation where an external group arrives to the organization and searches the capacity of the organizational processes for establish several decisions about the futures business of the company (Builes Ramírez, 2004). Out of this, the Software Engineering Institute (SEI) accept both words as correct because as we will explain later, the team that comes up with the assessment/evaluation is formed both by people from the own company and people designed by SEI and they have the common goal of evaluate how is the company implanting the CMMI Model.

In definition, CMMI Assessment is basically tools for the improvements of the processes. They analyze the strengths and the weaknesses of how an organization really works by examining its business, management and engineering processes and their analyses and results can only be understood within the framework of the software development of the organization (SEI Webpage, 2011; Donovan and Bush, 2005, chapter 4).

CMMI Assessment has several principles, used as evaluation principles or goals of the own assessment, which are normally followed by most of the companies that are implementing the model. According to (Donovan and Bush, 2005, chapter 4), these principles can divide in the following:

- Use a reference model orientated to processes with a formal process of assessment for analyzes how the organization really works comparing to the reference model.
- Try to involucrate and motivate the workers but also the high direction of every company with the auto-analysis efforts towards a positive change stimulating the technical and the organizational cultures to evolve.
- Focus on the aims of the business and consolidating the improvements.
- Observe confidentiality.
- Direct the assessment in a collaborative way of all the parts of the company.
- Educate the organization providing a huge knowledge to the workers about their own company and stimulating the organizations to contemplate the best practices of the industry comparing with the organization. This point is important because during an assessment is the time when an organization is more receptive to learn new techniques.

To perform all of these aims, every company can use three different classes of assessment methods (SEI Webpage, 2011):

- Class A: This class is the most typical for the CMMI Methodology. Is a complete method for the in-depth methodologies because can find the level of maturity that is already in every company and also, evaluates each maturity level in a precise way.
- Class B: This class is intended to the pre-evaluations. Is less systematic and depth than the Class A but it's useful for the initial evaluations or assessments. Don't proportionate punctuation about the level of maturity.
- Class C: Is the most cheap and fast class. Evaluate certain risks areas without making excessive data.

The following image can illustrate better these definitions:

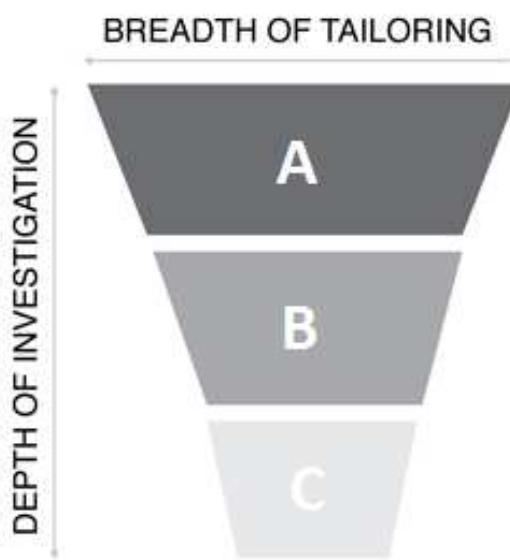


Figure 5.1. CMMI Assessment Classes

For all the classes mentioned above, the standard methodology is called SCAMPI, initials of 'Standard CMMI Appraisal Method for Process Improvement'. It was designed for proportionate classifications at the quality reference with the CMMI Models.

SCAMPI Methodology is coordinated by the own SEI on the hand of the candidates that SEI considers more appropriate in every case. Normally these assessments are performed in groups of between 4 and 9 persons, all of them from the same company but coordinated for an authorized assessor of the SEI. The number of involucrate persons depends of the CMMI maturity level of every organization and the class or the in-depth that every organization wants to implement. These candidates are formed by the SEI depending on the method of assessment that every company wants to implement (Builes Ramírez, 2004; SCAMPI Upgrade Team, 2011).

2. Procedure of CMMI Assessments

The procedure for evaluate CMMI is quite similar in all the companies and also for every one of the classes mentioned above with only several changes depending of the depth (the class) of the process. This process assess if the conditions of the maturity level are correctly implemented but also, can determinate if the maturity level that each company is implemented is correct or not.

But before any possible assessment, the candidates that are selected by SEI for be ‘Lead Appraisals’ did a course in the SEI dependencies that varies depending on the SCAMPI category that they will implement. Even so, these courses have normally duration of 4 years. These courses can divide into: SCAMPI courses for high maturity (class A), SCAMPI courses for classes B and C and for team leaders and SCAMPI courses for the development, acquisition and services, which is aimed to the people that complement the assessment team (SEI Webpage, 2011).

These courses have the aim that the ‘Lead Appraisals’ can make reasonable judgement regarding on the organization’s implemented processes relative to the appraisal reference model and can base their judgements on the collection of objective evidence for each practice of every different process area. The ‘Lead Appraisals’ also have to motivate their appraisal team to seek and consider these objective evidences determining practice implementation and goal satisfaction (SCAMPI Upgrade Team, 2011).

Focusing on the own assessment, SCAMPI assess every company for knowing in which maturity level they are and if they are accomplishing correctly with the ideas of this level. This procedure is based on the next steps:

- The SEI in collaboration with the company to evaluate decide which is the category that corresponds in every case and assign an assessment team of between 4 and 9 persons, depending on the category that the company are. These persons will be designed by the own company and they will be coordinated by a ‘Lead Appraisal’ decided by the SEI.
- The team plans and prepares themselves for the assessment or evaluation. Both words are correct and accepted by the SCAMPI, because the team is formed both by persons of the own company and persons designed by the SEI.
- They conducts the assessment addressing the individual clues and also, estimates how is collaborating and ensuring the quality requirements.
- The team made the ‘Lead Appraisal’ with the competent needed competences and also the ‘SCAMPI Definition Document’ where are described the requirements, the activities and the associated practices with the processes that composed the assessment.

Below, these phases are developed according with (SEI Webpage, 2011; Bdigital, 2011; Arteaga, 2011).

2.1. Plan and preparation for the assessment

In the first phase after the selection of the possible assessment group, the aim is to think and analyze all the possible requirements, understand the business, tracing the possible targets that will be fulfilled and prepare the ground for the evaluation itself. The steps of this stage are the following:

- Analyze the requirements: This step is based on understanding the needs of the organization business and try to match the similarities between the business aims and the evaluation aims.
- Develop the assessment plan: After the requirements, the team needs to document them and also the estimations that they have the risks and all the practical considerations. The aim is to agree the assessment plan with the organization.
- Prepare the team: In this important step, the organization needs to satisfy itself with the qualified team that is in charge on the execution of the assessment.

- Obtain and analyze the initial evidences: This step focalizes on the obtaining of information that can facilitate the preparation of the assessment. The team also needs to identify the potential strengths and weaknesses and, in consequence, knowing a preliminary understanding of the operations and the organizational processes.
- Prepare the recollection of the objective evidence: The last step of this phase is to plan and document the strategies for the data collection including data sources or possible tools and technologies that can be used for this aim.

2.2. Conduct the assessment

The next step of the procedure for performing the CMMI Assessment is the assessment itself and how to obtain the objectives evidences for at the end, generate the results of the assessment, within which are the determination of the process area level, their capacity, among others. The steps in that case are:

- Review the objective evidence: This first step is based on the collection of information about the implemented practices in the organization, following a previously defined recollection plan.
- Verify and validate the objective evidence: This step focuses on verify the implementation of the practices in the organization. In this point, the team compares every implemented practice with the definition of the CMMI Model and the assessment team assigns it a valuation.
- Document the evidences: After recollecting and verifying the information, the assessment team has to create logs that document the implementation of the practices, taking care of the strengths and weaknesses finded above.
- Generate the assessment results: In the last step of this phase, the team has to realize the qualification of the satisfaction with the goals according to the valuations assigned above and also, the qualification of the levels of capacity and maturity according to the satisfaction with the process areas.

2.3. Report the results

The last phase of the CMMI Assessment procedure is submit the results of the assessment to the organization, so that they can be used to take future actions and, also, preserve the data and the event logs of the evaluation for a possible future use.

3. Strengths and Weaknesses of the Procedure

The above procedure is generated and accepted by the SEI and also for the companies that are implementing the system because it's a step by step plan and tries to focus not only in the weak points of the company but gathering information throughout all the company using for this reason workers of the own company. But apart from the strengths, this procedure has several weak points to take into account because can be important for the company that implements and evaluates the model. On this section, these weaknesses will be identified.

3.1. Strengths and Weaknesses of Plan and preparation

Before the evaluation itself, there is also several problems detected on the section 'Plan and preparation for the evaluation'. These weak points are related following.

The members that will form the Assessment Team are decided in cooperation between the SEI and the company that is implementing the model. They will be directed by a 'Lead Appraisal' formed on the SEI but all the other members of the Team will be workers of the own company. Depending on the evaluation Class and also, the size of the company, this team will have more members. This can be a weak point because this team must meet certain requirements to achieve best results. These requirements are listed below in correspondence with (Höggerl and Sehorz, 2006).

- The Assessment Team members should understand the business of the organization and have an interest in seeing if their organization improves its processes.
- The Assessment Team members must have a solid software engineering background and is preferable is they have experience with the management and with the measurement tools.
- The members should be selected to provide the best possible coverage of the business units' domain and environment.

These features are not always strictly complained and can introduce the first problems in the team, especially if the members are not ready enough.

During the previous preparation for the assessment can appear problems with the initial catch of information because data is not always easy to collect. The theory says only that the team needs to identify the potential strengths and weaknesses but even having the tools, normally is not an easy job. Normally these weaknesses are not focused only in one part of the company but in the whole general.

There is also a typical confusion between the product requirements and the customer requirements because the step of the Requirements Management doesn't make a distinction between them. But this kind of problem shows normally disorganization in the company and can be solved with a correct description of the process and an accurate collection of data. Below, the normal way for collecting data will be analyzed in detail for all the different assessment classes in particular.

3.2. Strengths and Weaknesses of Conduction of the assessment

Similarly to the step of Plan and Procedure, the assessment or evaluation of CMMI Model itself tries to focus in the different sections of the company taking care of validating and documenting the different steps on the conduction. But the problem of this kind of assessment is that is not concrete and also can be a little abstract if the team has no the sufficient experience evaluating or also, no sufficient experience working in the own company that is assessing. But, apart from the feeble points related in the previous sections, it is possible to find more weaknesses in this step.

(Shih et al., 2009) looking for problems of CMMI Assessments in companies from Taiwan and also SCAMPI lead appraisals in their blogs note that is typical in all the organizations that during the process of the assessment, the workload instead of reduce, increases because the workers sometimes are forced to realize more activities than in the standard operations. They also need time for familiarize with the new processes, the called resistance at change (Shih et al., 2009; Ghezzi et al., 2003; Arteaga, 2011; Dalton, 2011).

Another problem that can arise is the catch and introduction of data. As it is said above, data sometimes is hard to collect because the weaknesses of a company normally are problems of the whole company, not only a department or a section.

If there is not a well-implemented program, the collection of data can be useless or not provide the satisfaction that the Assessment Team wants according to the valuations. This fact is typical of Class C, the most superficial Class because it's only based on interviews and questionnaires. For this reason, the most in-depth evaluations use special programs that help the collection of data. Below, the Data Collection will be developed in detail.

4. Procedure depending of the maturity level

The previous section describes the procedure of the CMMI Assessment in general but for every maturity level of the CMMI, the steps and the goals are different. For this reason one can think that probably the more in-depth evaluation classes are used normally for evaluate the highest maturity levels. SEI makes no differences between levels and says that all the evaluation classes are compatible with the CMMI Product highlighting that Class A is normally the most appropriate Class to implement (SEI Webpage, 2011).

5. Data Collection depending on the Class

As it is said above, the assessments are divided into three different categories: Class A, B and C. These classes identify the level of in-depth that the organization wants for their assessment; normally this level is also different depending on the size of the company because the prize between one class and another varies significantly.

The way for collecting data varies too between the classes because the in-depth of the assessment and also, the economic concept are different. This fact is not an easy job because there is not an established frequency or an exact method for collecting data that provides security in the way of reliability and uncertainty (Dimov and Chandran, 2010). Anyway, and knowing that software process assessors recognize the possibility to choose from different information gathering approaches and techniques, the SEI standardizes a normal way for collecting data depending on the Class that they decide the company is.

5.1. Data Collection for Class C

The Class C is the assessment Class designed for the companies that wants to do a fast and not in-depth assignment. In consequence, the data collection in this case will not use the same techniques that the Class A assessments.

The normal procedure that the assessment team realizes is to ask about a Product Backlog, a dynamic list of the requirements and their interactions, a Daily Scrum with the daily status of the company, an Story that defines the customer functionality and also a Planning Game with the goals defined for the own company for a short term (SEI Webpage, 2011; Pikkarainen and Mantyniemi, 2006). With these concepts, they can see the assessment of the company. This previous procedure is common in all the different Classes.

On the other hand, the normal way for collecting data for knowing if the company is properly implementing the CMMI is the realization of interviews with the different organizational levels of the company and with the key staff members, like software developers, with the aim of knowing if the workers are sure about the level they are and, also taking especially care about what they think the more experienced workers and focusing in the topic of the further evaluation and the catalogue of measures that the own company is trying to implement. Another normal way is to consult the customer, normally using the on-line service of the own company with several times, making

interviews too. These ways of working are designed especially for counteract and remedy the normal problems that this class, that is the most common class that specially small companies wants to implement because is the most cheap one, has like because not focuses deeply on the processes as Class B or Class A.

This type of Class don't use statistical programs or specialized methodology for determine the well implementation of the process. The way for decide a valuation according if the organization is well implementing the process that they are assessing, is own the decision of the appraisals based on the conclusions extracted from data collected previously (Pino et al., 2007; Pleeger, 1995; Robbins, 2004).

The common problems that this way of assessment has the documentation overload, high resource requirements that cannot be assessed by using this present class or a lack of guidance (Brodman and Johnson, 1997; Samalikova et al., 2010b). Several experts proposed various adaptations of CMMI Assessment for small and medium organizations based on the same concepts than above, the application of interview techniques with the key staff members but particularizing for every different organization (Wilkie et al., 2007; Samalikova et al., 2010b).

The usage of this kind of controlled reviews and also, searching if they are thinking about alternative solutions that can help to achieve the balance when they have problems of costs, schedule, performance or quality among others will show to the Assessment Team if the company is satisfying the requirements of the step of CMMI they are performing and also, will show if the product and service is working (Kasse, 2007).

5.2. Data Collection for Class B

Class B, as it is said in the introduction, is a Class that focus more on the processes than Class C. It's normally the Class designed for the initial or pre-evaluations and shows in a more profound level that the previous Class how the organization is working.

In the assessment of this type of Class, apart from those studies made in the Class C assessments that also are used in the others Classes, is common the usage of internal audits or information captured by supporting tools as document reviews (the called 'derived strategy' because uses existing implemented information as an anchor for improve) or measurement repository. Out from the own and existing documentation, common concrete tools used estimations of the size of work product, estimations of effort and cost or statistics of efficiency or coverage. Also, there is also common the usage of diagrams for discovering if the company is following the estimated planning or if the company has a clear responsibilities. Examples of these kinds of diagrams are the ROI, Pertt or Gantt diagrams and, on the other hand, for knowing the roles of the personal, are common the usage of organizational diagram (Samalikova et al., 2010b; Reitzig, 2009).

Sometimes, and depending of the company, the Assessment Team can investigate more in-depth using programs like Minitab looking for the quality of the products and trying to discover the stakeholders of every problem but according with (Robbins, 2004; Pino et al., 2007), these kind of procedures are more typical for the evaluation of Class A and will be explained deeper in the following section.

5.3. Data Collection for Class A

Class A is the most typical for the CMMI Methodology. Is the most complete method and their goal is to evaluate the maturity level in a precise mode.

The tools mentioned previously on data collection for Class C and B, like the interviews and questionnaires with the organization workers and, also with the customers or potential customers of the company are in this Class also important because shows with accuracy what the stakeholders think about the process that the company is implementing. But in this level, the Assessment Team needs to focus deeper in the processes for knowing if the organizational vision is the real one.

Consequently, for collecting data in a proper way, apart from the interviews and questionnaires with the involved stakeholders, there is useful the usage of data that comes from information systems that mature organization are already using in most of the cases. According with (Kindler et al., 2005), some of these systems that can provide data in a structured way are the followings:

- Transaction-based Systems provide information in a form about the different transactions of the company. As examples, one can mention ERP or CRM among others.
- Product Data Management Systems, which are the normal systems for following and control data for a particular process.

The data extraction uses normally the following fields: name of the study, date, authors, methodology followed, results, objectives of the study, number of the persons involved, information related to the improvement models, the improvement proposal, key factors in the success of a SPI program, the improvement processes and the subjective results of the study. Following a systematic and coherent initiative, one can identify easily the stakeholders and which the models to manage are but also, can minimize the resistance at change and, in addition, can help to understand the past, to control the present and to predict quantitatively and see if they can take several actions to prevent defects or other problems that can occur in the future (Pino et al, 2007; Robbins, 2004).

For collect data that can be extracted both from these systems and from interviews, questionnaires, etc., is normally useful to create a centralized database, normally with using a standard like Microsoft Access, Oracle or MySQL among others, which include current and future data on cost estimate, cost experience, error data and schedule performance (Dalton, 2011). These database will be used for analyze the key measures that every organization decides and the quality of the future results and can provide a priority order for future actions (Humphrey, 2001). One typical program used for obtain results is Minitab because can create Run Charts, Pareto Charts or Control Charts for showing what is happening in the organization but also can replicate the results for seeing if an attribute is valid or not and, consequently, be sure that a variable affects or not the result and can evaluate the results in a factorial design and, in this way, have the maximal local control by applying all the possible treatments for each factor. Another type of program for these objectives can be Event Viewer or any other database (Pleeger, 1995; Robbins, 2004; Pino et al., 2007).

According with the results that this data collection shows in the big companies, one can arrive to the conclusion that, taking the results by a correct metric system defined in accordance with the goals of the improvement program and according with the specific requirements of the organization, the documentation process has more probability to be optimal (Humphrey, 2001; Shih et al., 2009; Mahner, 2008).

6. Evaluation of CMMI Assessment

After the assessment or evaluation itself, the assessment team assigns a valuation for each demonstrated evidence. For this reason, the team realize a trial about the practices for each instance of the process (the project requirements) and determines the degree of definition and implementation in the selected processes. After this, the team combine the qualifications to provide a single score that determines the ability of the process at the organizational level.

The usual rating scale for the practices is the following (SEI Webpage, 2011; Vereau, 2007):

- Fully Implemented (FI): It means that the organizational practices associated with the component are complete and consistent in terms of implementation with practices related to CMMI without having any significant weakness.
- Largely Implemented (LI): This qualification denotes that the organization has a proper approach in the definition of the practice at the level of process and its implementation in the project is ordered. But on the other hand, there is evidence of non-significant evidences.
- Partially Implemented (PI): In that case, the approach is proper in the definition of the practice at the process level but its implementation is not evident in project may not be consistent or predictable according with the CMMI practices.
- Not Implemented (NI) or Not Satisfied: This score means that there is no evidence or this is so little about the implementation of the practices or there is no suitable alternative about the showed weaknesses.
- Not Rated: There is another option that means that the associated components with the CMMI are not applicable in the context of the organization.

As an important final point, noted that for carry out with the implementation and the evaluation of all the steps of CMMI Model, the investment in terms of money and resources, that the organization needs to realize, can be really big. The results can be obtained in a term between 2 and 3 weeks, depending on their size, and may even extend on time and consuming more resources if there is no previously clear conception of the CMMI Model in the beginning of the assessment process.

7. Categories of problems once implanted CMMI

Most organizations decide to implement CMMI because of the quality. It is shown that the customers choose firstly the organizations that are evaluated successfully based with the models of the CMMI. But sometimes this concept is more a problem than the evaluation itself because there are derived several problems because the CMMI Model nor prevent human errors neither solve at 100% the losses of the organization like losses of employers, financial losses or demand supply board and so, in this way, sometimes the Assessment of CMMI can have good results but the organization could continue having problems inside them.

Software Engineering Institute (SEI Webpage, 2011) in concordance with (Glazer et al., 2008) identifies 3 big different categories of problems once implanted the CMMI Model: problems in the processes of organizational problems, technical problems and human problems.

7.1. Organizational problems

The Organizational problems are the base for the improvement of any organization. They are the problems that address the organization itself and with this goal, needs to evolve both technical and cultural involving specially focusing in the role of the personal.

First of all, is needed an effort of self-analysis, for investigate weaknesses in different situations or moments in order to fix them. The problem that can occur in that way is that people can be intimidated if they give a real test, thought this has only the objective of improve the company in general. But, out of this, there are also the characteristics of the organization that can be more or less complex. The assessment team needs to know firstly the characteristics of the organization, their evolution and improvement, their distribution but also, the iteration of their processes and the lead time that they lose normally during the processes.

Another important problem is the creation of an environment of the highest quality for the good atmosphere of the personal, the management and, also, the customers. The problem is that, in the moment of the assessment, the organization has an extra dose of work and so, several times, this goal is not possible or not in the way that the organization hopes because the assessment also needs of the monitoring, that can annoy the employers.

On the other hand, one of the goals of the CMMI assessment is that all the people of the organization can see everything in the same way. This is called 'the evaluation of transforming organizations for the way of work' (Dunaway and Bush, 2005). The problem at this way is that it is not easy that different persons think equal as others, for example: is difficult that a technician think like a manager and so, for general rule, it is difficult to arrive to one solution that satisfies everyone equally.

7.2. Technical problems

On the other hand, there are the technical problems. These are varied and very different one from the other because of the variance of the possible defects and also, because several companies think that the CMMI is the panacea for all the problems but it is not. CMMI not necessarily improve the usability of the software, as the elements to measure normally are very technician, not only about the process improvement and so, normally the performance improvement is not spectacular.

Technical problem starts with the beginning of the project and continues with every new step. One common problem is related with the code and the data event log.

CMMI Assessment has a quality assurance that creates copies of the database with the aim of discover and, also, built, underlying models. Every snapshot tries to follow the evolution of the handling of the defect and also, contains a record for each defect identifying and describing which characteristics features exists in each (like the history, the priority or the dates of start and complete) (Samalikova et al., 2010a).

These data, especially when the companies are assessing in Class A, can given to transform into an event log. Is in this event log where one can detect the several defects that probably exist as for example, the missing of fields, several incorrect sequences or only, missing of information. If it is find one of this problems, the best solution is to improve the quality of the data and try to match the realized activities with the available data with the aim of complete them, this step is called 'validation'.

Another important technical problem is related with the fact that the implementation of the CMMI and the subsequent assessment normally didn't find all the problems and also, don't offer a solution for all the weaknesses.

(Pikkarainen and Mantyniemi, 2006), basing on case studies that they did, arrive to the main conclusion that the CMMI identifies the strengths and the weaknesses of the processes but not resolve all the questions that had arisen. On that case, the most extended recommendation is to realize a ‘second run’ with a workshop where additional data can be captured and discussed with the project management. Normally this is a good way for try to identify problems in a company.

But anyway, the most important technical problem is that the complexity that exist on the code lines and the non-familiarity with them by the employees and how expensive results to provide an appropriate training to them for such cases.

7.3. Human problems

The last of the three categories of problems exposed by the SEI Institute are the human problems. These are related with the developers and the analysts of the CMMI Assessment because they can be a fountain of uncertainty if they have not experience or are not highly trained with the adequate background, they are not so motivation or also, if the size of the composition of the team is not the adequate (Samalikova et al., 2010a). But apart from the developer’s team, Human problems can be caused by the work of the employees of the company and the derived problems that they can have because of the implementation of the CMMI Model and the posterior assessment.

The human problems normally start in the phase of the Requirements Management. In this sub phase, the organization unit collects information about the inconsistencies between the project work and the requirements. Based on the requirements presented above, probably there are several differences regarding what organization believes they are doing. (Höggerl and Sehorz, 2006) indicate that for manage this situation, there is needed an important formation because even thought that the existing measurements seemed quite extensive at first sight, the case studies related with the CMMI Assessment shows that most of them were either not specified directly as a process, or simple were not enough to satisfy all the needs of the specific goals. On the other hand, in the case of small companies, it is possible to maintain guidelines without documenting and defining them, just talking to the employees but this is not the case of all the companies.

Another big problem is the fact that the implementation of the CMMI Model not lights the workload because during the implementation and also after, during the assessment, the employees are obligated to realize more activities than during the standard procedure. There is also needed time for familiarize with the procedures of the new model (Shih et al., 2009).

There also exist the problems with the consumers. When a new product is developed, normally don’t have potential consumers unless is based in an existing product that is modified by the customer needs.

On the actual markets, the companies expect some collaboration by the customers but there is not the general rule. The case studies reported by (Pikkarainen and Mantyniemi, 2006) in relation with these topics shows that the best way for fight again this inconvenience is to develop the product in iterative form with little cycles of 3 or 4 weeks. Every iteration needs to have a planning of requirements, tasks and estimations and ends with a demonstration of how is working. During this analysis, the objectives of improvement are identified and categorized. In their approach, they conclude that the experience indicate that this the most correct model for turbulent situation, especially when exists a strong resistance at change.

8. Results of Assessment

Currently, apply a level of maturity seems to become a standard for doing business. As a result, organizations are sometimes dragged into assessments against their will. An evaluation has to motivate for improve them because otherwise, can derive into frustration and if there is some revisions, can damage more than helps.

The evaluations shows differences between the perception of the own processes for the organization and how it really works and, in consequence, can recommend how to address a problem and, at the same time, tells to the organization how to use the reorganization for harness the power of the manage. In other words, an evaluation cans awareness about the need of change for an organization.

9. Summary of the Chapter

After discovering on ‘Chapter 4. CMMI Description’ what the function of the CMMI Model is for improves software processes, on ‘Chapter 5. CMMI Assessment’, we introduced the other main actor of the Thesis, the assessment of the CMMI Model.

On the present Chapter, we introduced the reader to the standard procedures and the standard methodology, called SCAMPI, that the appraisals of CMMI uses and, as a previous step to ‘Chapter 6. Tools of Process Mining for supporting CMMI Assessments’, we found the weaknesses of the CMMI Assessment, both during the assessment itself and during the plan and preparation of it. Afterwards, on ‘Chapter 6. Tools of Process Mining for supporting CMMI Assessments’, we will try to find matches between these weaknesses and the tool of Process Mining for knowing if we can use Process Mining for solve these weaknesses.

Continuing, on section ‘5. Data Collection depending on the Class’, we studied the ways of data collection depending on the type of in-depth that the organization wants to implement for their assessment. The aim of this section is to discover which data is used already for knowing if it could be compatible with the usage of Process Mining. These matches will be also provided on ‘Chapter 6. Tools of Process Mining for supporting CMMI Assessments’.

Finally, on section ‘6. Evaluation of CMMI Assessment’, we explained how the appraisal team qualifies the assessment and, on section ‘7. Categories of problems once implanted CMMI’, we described which the common problems are after the implementation of CMMI showing that this improvement model is not a panacea for optimize the processes of an organization. On ‘Chapter 6. Tools of Process Mining for supporting CMMI Assessments’, we will also see that Process Mining would be helpful for solve some of these problems.

Chapter 6. Tools of Process Mining for supporting CMMI Assessment

1. Introduction

On the previous chapters, the tool of Process Mining and the official way for evaluate CMMI were developed. After develop them and advancing conclusions, one can see that without being the solution for all the problems, Process Mining can be a helpfully tool for improve the Standard CMMI Appraisal, also called SCAMPI.

In the following sections and for come up with the objective of the present master thesis we will find the matches between the tool of Process Mining and the methodology of CMMI Assessment. But before, we will make an abstract of both concepts for clarify them before explaining the methodology followed for find the matches and, also, we will define which the matches and also the mismatches between both concepts are, where Process Mining can be exactly applied and where is not possible to use.

The aim of Process Mining is extract process information from activities performed in a real-life situation for reveal how is working the real process. This information can be divided in four perspectives, depending on what the organization wants to analyze. These perspectives are: Control-Flow perspective based on the relations between tasks, Performance perspective that tries to find the weak points of the performance of the process, Organizational perspective focused on the relations among tasks originators and Case perspective, based on the discovery of the data that affect the routing of the case(Samalikova et al., 2011).

As It is said, Process Mining is a tool that is used for discover how is really working the real process that an organization is implementing. Consequently, the investigation for knowing if Process Mining can be used for improves CMMI Assessment is not a non-sense affirmation. For watching these connections, out of knowing what Process Mining does, we will write an abstract of the other step that we want to connect; the CMMI Assessment and also, the CMMI Model for introduce the possible matches.

In every different process area of every different maturity model of CMMI there are several questions that needs to be answered correctly for knowing that the organization is well implementing the process areas inside every maturity level and, knowing consequently, if the organization is improving or not. These questions are based on the correct definition (clearly and without inconsistencies) of the concepts of every process area, the correct definition of the roles of the involved personal, if the company is realizing about the improvement of the performance that the process will show with every new improvement, among others.

On the other hand, SEI divides into three different classes of evaluation depending on the level of in-depth that every organization wants. Taking a look on the way that the Standard CMMI Appraisal Method for Process Improvement (SCAMPI) proceeds and depending on the class of evaluation the organization is implementing, the usage of Process Mining can be a helpful tool for come up with the assessment.

This standard procedure for assessing CMMI has some weak points, both during the evaluation itself and also when it's already done. These problems were recollected by multiple authors as (Brodmann and Johnson, 1997; Cater-Steel, A., 2004; Samalikova et al., 2010b) and highlight the documentation overload, the inapplicable scope of reviews, the high resource requirements or the lack of guidance, among others. These problems are especially common on small companies. The problem of the small companies is that normally they will implement the Class C assessments, that is the less in-depth method and consequently, the implementation of CMMI on these methods is not really available because of the high cost and the big differences from the actual ways of assessment. The ways for assess Class C are related on 'Chapter 5. CMMI Assessment'.

On the other hand, data collection on Class B and specially, on Class A is based on a centralized database that includes error data, schedule performance and time stamps, estimations for the future, among others. These concepts are not taken into account on Class C assessments.

The difference between Class A and Class B assessments is that Class A tries to assess more in depth than Class B. Class B is used for pre-evaluations and data collection is based on questionnaires, interviews and is also common the usage of internal tools as ROI diagram, organizational diagram or other measurement repositories according to every case. The problem of Class B is that not enters in-depth in the reasons why these problems, only shows that several items are weaknesses that can be improved. For this reason, the possible usage of Process Mining on this Class is not useful because it will provide a level of in-depth that is not needed on this kind of Class and also, the cost of the methodology will increase (SEI Webpage, 2011).

On the other hand, having a look of the procedure for come up with Class A evaluations and the weaknesses, one can see that some of them could be solved by Process Mining or at least, Process Mining can act on them improving the results. On 'Chapter 5. CMMI Assessment', these weaknesses were developed by using information extracted from the Software Engineering Institute and from several case studies.

Listing all the founded weaknesses, there is observed that these weaknesses are not centered in only one topic but on several, differencing between the most technical problems, those that involves the way of working on the organization and the human problems, that involves both the organizational environment and the relation with the customers.

Summarizing all the concepts presented on this Introduction, one can say that the fundamental idea behind SCAMPI appraisals is that the conduct of an activity or process results in objective evidences that substantiates work being done consistent with appraisal reference model practices (SCAMPI Upgrade Team, 2011). However, we argue that by using the tool of Process Mining and, knowing that it will not be the remedy for all the diseases, the approaches done by the appraisal team will improve.

How to discover the connections between this tool and the assessment of CMMI will be developed in the following sections.

2. Methodology for matching Process Mining as a tool for carrying out CMMI Assessment

After making an abstract of all the concepts studied on the present thesis knowing where Process Mining can be applied, we will explain which was the methodology followed for finally, finding matches between both concepts.

The followed methodology for coming up with the objective is basically, try to find the actual weaknesses of CMMI and, by searching which data is required, gain insight into the process. When this step is realized, knowing also where Process Mining focuses, ask the question: 'Can Process Mining solve these weaknesses?'. On the present section, we will try to clarify this methodology explaining this way of working and how discover the matches.

Once both concepts, Process Mining and CMMI Assessment, were studied, one can see that the data contained in an Event Log can basically divide in several different categories: Case identification, Task identification, Event type (when the activities are starting, running or finishing), Timestamps of start and end events (the exact day and hour when the process was starting or ending), Task originator (which is the person that is executing every task) and Additional attributes of cases (category that evolve all data that cannot be submersed in the previous categories. On the following table extracted from Samalikova et al. (2011), the points where these data is required are showed.

Required data	Event-log					
	Case id	Task id	Event type	Timestamps of start and end events	Task originator	Additional attributes of cases
Process mining analysis						
Process model discovery	x	x	x			
Conformance checking	x	x	x			
LTL checking	x	x	x		o	o
Decision mining	x	x	x			x
Throughput time calculation, bottleneck analysis	x	x	x	x		
Performance sequence analysis	x	x	x	x		
Social network analysis	x	x	x		x	

Table 6.1. Process Mining Data Requirements

Once known that is the data that Process Mining uses, one can see that, in several process areas of the CMMI Model and also, during the assessment of it, part of these data can be used. Note that if

we are talking in abstract terms, is because all these data can be used in different process areas, one will need one type of data and another process area will need totally different type of data and also, depending on which weaknesses of CMMI Assessment are you looking, the data that you will need will be different.

Once we know which data is needed on the tool of Process Mining, we will describe step by step the followed methodology for try to find the matches between the concepts of CMMI Assessment and the tool of Process Mining.

The methodology is based on follow all the steps that were defined on 'Chapter 5. CMMI Assessment' for the Procedure of CMMI Assessments. There was defined that for coming up with the implementation of the assessment, first this assessment needs to be planned and then, the team that will come up with it, can do the evaluation itself.

Following point by point the steps of the CMMI Assessment related on 'Chapter 5. CMMI Assessment', one can see the weaknesses of every punctual step. Studying these weaknesses and knowing which data is necessary for solve them, the user can see if the implementation of Process Mining is possible or not. For make more clear the possible usage of Process Mining, on the most correlated steps, we will make also a table with the tools that are used nowadays for every procedure.

2.1. Methodology for matching Process Mining with 'Plan and preparation for the assessment'

Before the evaluation itself, the evaluation needs to be well planned and prepared. Without being a really helpfully tool, in the present concept, Process Mining can be used. In this section, the methodology for arriving to this conclusion will be explained based on the steps showed on 'Chapter 5. CMMI Assessment'.

- 1- Analyze the requirements: The first step of an evaluation is the decision of which will be the requirements or the needs inside every maturity level that the company wants to assess. On this step, the data that is needed is basically which the needs of the organization are, where they want that evaluation focuses. These concepts need to be defined by the direction of the company, using normally a brainstorming session. Process Mining cannot be helpful.
- 2- Develop the assessment plan: This step focuses on the agreement about the evaluation between the organization and the Software Engineering Institute, who is the attendant of the process of the evaluation. For knowing which will be this plan, data needed is the knowledge of where the organization wants to implement evaluation and consequently, decide with SEI if this is possible. Consequently, Process Mining cannot be also helpfully.
- 3- Prepare the team: The team, both SEI Appraisals and organization employees, will be prepared by the own SEI. Data needed is the experience of the workers of the company on how the organization works because, if the appraisals know already the company, come up with the assessment will be easier. The problem of this step is that data normally is not structured already in the systematic way that uses Process Mining and consequently, Process Mining cannot be used.
- 4- Obtain and analyze the initial evidences: The first work of the assessment team is the recollection of data of evidences for determines the strengths and the weaknesses of the

company. With the standard method, these evidences are collected by interviews, questionnaires and similar. On the following table based on (CMMI Product Team, 2006; Pikkarainen and Mantyniemi, 2006) , we will try to make more clear which the tools for coming up with this step are.

Objectives of CMMI Assessment	Used tools
Recollection of evidences for determine the strengths and weaknesses	Interviews, questionnaires on the stakeholders.

On this step, the organization can see where the problems are and maybe, know consequently if they could use Process Mining or not, depending on which these problems will be. If there was the case of a really mature organization that has already data collected in a well structured way, probably the usage of Process Mining could be possible also on this step, but this is not a standard case.

- 5- Prepare the recollection of the objective evidence: Once known where the weaknesses are, the strategies must be planned including which data sources, tools and technologies that will be used for the evaluation.

Although data needed for coming up with this step is the decision of the company, one of these decisions can be the usage of Process Mining. Like previously and based on (CMMI Product Team, 2006; Pikkarainen and Mantyniemi, 2006), which tools are used on this step is showed on the next table.

Objectives of CMMI Assessment	Used tools
Plan the strategies that will be followed for review the evidences.	Joint decision between the organization's direction and the appraisal team.

As one can see, during the step of ‘Plan and preparation for the evaluation’, the tool of Process Mining is not really helpfully. The points where Process Mining can help for improve it will be developed on the section ‘Matches between Process Mining and CMMI Assessment’.

2.2. Methodology for matching Process Mining with ‘Conduct the evaluation’

On the step of ‘Conduct the evaluation’, Process Mining can be more useful than in the previous section. Similarly than above, we will explain the methodology followed based on the different steps of ‘Conduct the evaluation’, explained on ‘Chapter 5. CMMI Assessment’. Out of this concept, on the points where Process Mining can be used, we will try to make as clear as possible this relation by matching what CMMI procedure says and which tools can be used for every step.

- 1- Review the objective evidence: On this first step of the CMMI evaluation itself, the needed data is collected following the plan designed on previous steps. Nowadays, the tools used for collecting data are in-depth interviews and questionnaires on the relevant stakeholders focusing on the problems that were showed on the initial evidences and also it is common to

use data derived from information systems already implemented on the organizations like transaction-based systems or PDM Systems. These evidences are collected on centralized databases. Next table, based on (CMMI Product Team, 2006; Humphrey, 2001; Pino et al., 2007; Pleeger, 1995; Robbins, 2004) shows which tools are normally used for coming up with this step.

Objectives of CMMI Assessment	Used tools
Collect data from the processes.	Interviews, questionnaires.
Know if the steps planned for data collection are available and if the usage of event log will be possible.	Data from Information Systems. Centralized database. <ul style="list-style-type: none"> - Standard (Microsoft Access is the most common) - Personalized

Interviews and questionnaires can be used as a supporting tool but it is difficult to collect in the form of event log. But data derived from information systems as transaction-based systems or PDM Systems can be converted easily to event log by their input information. Under the assumption that these data can be collected by the form of event log, the application of Process Mining will be possible.

- 2- Verify and validate the objective evidence: For verify the evidences, the assessment team compares the evidences recollected with the CMMI Model and assigns a valuation depending if they are coming up properly with the Model or not. Nowadays, the used tools are normal databases like Access or personalized databases according to the objectives and the environment of the company. On these databases, data can be collected and the conclusions extracted.

On the other hand, for extracting these conclusions, on Class C evaluations, the most typical tool is the own decision of the appraisals. On Class A and B, the most common tools for analyze are statistical programs like MINITAB or Event Viewer, among others. All these tools are showed on the following table, extracted from (CMMI Product Team, 2006; Pino et al., 2007; Pleeger, 1995; Robbins, 2004).

Objectives of CMMI Assessment	Used tools
Compares the recollection with the CMMI Model.	Database for collect information.
Assign a Valuation.	<ul style="list-style-type: none"> - Standard (Microsoft Access is the most common) - Personalized
	Programs for analyze data. <ul style="list-style-type: none"> - MINITAB, EventViewer, etc.

As it is said in the introduction of 'Chapter 3. Process Mining and Analysis', the goal of Process Mining is to extract information from data for discover how is working the real process. If the way for collecting data not differs so much than the way of collecting data

that the organization is using, Process Mining can help to verify the evidences with the usage of their four perspectives. In this way, the strengths and weaknesses of the company can be easily identified without annoying so much the workers with the actual methodologies. These concepts are under assumption that data collection by event log is available.

- 3- Document the evidences: After recollect information, the assessment team by using databases or logs and, paying attention to the strengths and weaknesses found above, documents the implementation of the practices, the followed procedure and the found evidences.

This step is based on the previous one, data is already collected on databases, the conclusions are extracted and, consequently, the assessment team needs to document these evidences. Out of this and, based on (CMMI Product Team, 2006; Pino et al., 2007; Pleeger, 1995; Robbins, 2004), the next table shows the correlation between this present step and the used tools.

Objectives of CMMI Assessment	Used tools
Document the evidences.	<p>Database where the information was collected.</p> <ul style="list-style-type: none"> - Standard (Microsoft Access is the most common) - Personalized <p>Programs where data was analyzed.</p> <ul style="list-style-type: none"> - MINITAB, Event Viewer, etc.

Therefore, if in the previous step there is already the usage of Process Mining, this documentation will be easier to make.

- 4- Generate the evaluation results: According to the above, in the last step the team accords a valuation according to the satisfaction with the process areas. The tools used in this case are the decision of the assessment team evaluating the results. Consequently, Process Mining cannot be helpful here.

Identified the weaknesses of CMMI Assessment and knowing if it is possible to connect data with the one of Process Mining, one can see if there is or not connection between both studied concepts, Process Mining and CMMI Assessment. These possible matches will be studied more in-depth knowing in consequence if the tool of Process Mining and every one of their four perspectives could be helpful for solving those weaknesses or at least, helping the process where the weaknesses is involved. All these matches (and also, the mismatches) founded during the planning and preparation for the evaluation, the evaluation itself and also, those that can help the company to solve problems that actual CMMI Model not solves are developed on following sections.

3. Matches between Process Mining and CMMI Assessment

Process Mining exploits data and uses for extracting the derive conclusions that every different perspective can show and consequently, know if the used tools and resources were the most adequate or not. Following are several examples for the different perspectives.

As it is said in the previous section, Control-Flow perspective discovers ordering and relations between tasks. This perspective shows if the designed process is really followed, if there is any task skipped but also if every task is executed by the right task originator. Consequently, the appraisal can see missing of data or errors in the production of the process either by not following the right or official process or not be generated by the correct originator.

On the other hand, knowing the schedule performance of the process, Performance Perspective identifies the throughput time, the bottlenecks and other limited capacity resources that will show if the company is correctly planning and implementing CMMI, which the weak points are where they can continue improving and, in general, if the company is improving their performance or not.

CMMI Assessment pays special attention to the fact that the roles of the personal and their responsibilities on the product are well defined and documented. Organizational perspective focuses the attention especially on the relations among the persons involved on the process showing who is working with whom and which work is everybody doing. On this way, CMMI appraisers know easily which the responsibilities of the personal are, if these responsibilities are correctly defined when possible defects appear and which are the stakeholders of the processes.

Finally, Case perspective focuses the attention of how data influence the process discovering possible process path. This information is useful for knowing if the process is following the correct direction.

The correlation of Process Mining for CMMI Assessment starts directly during the preparation for the evaluation. When the assessment team is defined, their first step is to obtain and analyze initial evidences of the improvement of the processes recollecting and analyzing data. Using Process Mining, this step becomes easier because with the usage of the four perspectives listed above, the assessment team will identify the potential strengths and the weaknesses of the process with more comfortably either use Performance perspective that focus more on the limited capacity resources, Control -flow or Case perspective for knowing if the pattern that data is following is the correct or not or others. Also, the usage of Process Mining not relies with the judgment of the stakeholders and consequently, is a more objective tool than the interviews or the questionnaires.

During the evaluation itself, the four perspectives of Process Mining can discover if the potential weaknesses are really affecting the performance of the organization, if there are several weaknesses not identified previously and will help to verify if the maturity level that the organization wants to assure is correctly implanted or not. Examples of how Process Mining can help on this way are listed above.

Otherwise, as it is said, nowadays there is the usage of databases for collect data, whether these are standard marketed databases or personal databases for every single organization. Event log can be considered also a database because recollects the information from the process with the aim of analyze it. Consequently, the fact of how to collect data, under the assumption that the implantation of event log is available can be also solved by Process Mining and his tool, event log.

For knowing if event log is available, each record of the company needs to refer to a document and document status, each record have to refers to a person and also, has their own timestamp. Nowadays, there are several information systems that are already implemented in companies that

can help to join data of this way for, in consequence, can use Process Mining there. Based on (Kindler et al., 2005), several examples of these kinds of systems are listed following:

- Transaction-based Systems provide information in a form about the different transactions of the company. As examples, one can mention ERP or CRM among others.
- Product Data Management Systems, which are the normal systems for following and control data for a particular process can also, provide input information that can be useful for implement Process Mining.

If the organizations are already implementing these kinds of systems, the usage of event logs and, consequently, the usage of Process Mining will not be so hard to implement.

Out from the topic of databases and returning to the matches between CMMI Assessment and Process Mining, there is the moment when the results are showed. If the appraisals or the own organization are not agree with the results of the assessment, would be because of the tools and resources used during the implementation of CMMI were not the adequate or that the company didn't implement correctly the model.

On other side, different from above there is the fact that nowadays, there are common problems after the implantation of the standard of CMMI (these problems are divided into organizational, technical and human problems and were developed on 'Chapter 5. CMMI Assessment'). These problems can decrease with the usage of Process Mining because some of them are related with a non-analyzed field or a not completely solved performance problems. For solving these problems, on the standard CMMI is common the use of the concept 'second run' based on returning to apply all the process areas of the actual maturity level and discover if there were totally well implemented. With the usage of Process Mining, this fact could not be necessary because Process Mining probably will show non-identified problems of the real processes that probably are not showed on the normal databases.

4. Mismatches between Process Mining and CMMI Assessment

On the previous section we saw the matches between Process Mining and CMMI Assessment. We identified where the appraisals can use Process Mining for solving the weaknesses of the Standard CMMI Appraisal method, SCAMPI or where Process Mining can be used as a helpful weapon for identify defects on the implantation of CMMI model. But Process Mining cannot be the only tool used for assess CMMI because there are several points of the assessment where Process Mining cannot act. Following, these points will be named and developed.

First of all, Process Mining is probably not an option if the organization wants to implement one type of evaluation that differs from Class A. The organizations that want to implement Class C evaluation methods want a fast, cheap and not in-depth assessment. Because of these reasons, SEI already defined that the most useful tools are interviews and questionnaires with the involved stakeholders. Implant Process Mining on this case will be not helpful because provides a level of cost and a level of in-depth that is not sought in this class.

Also, on Class B evaluations, the implementation of Process Mining is not so clear. Although having more level of in-depth than Class C methods, Class B is specially designed for pre-evaluations and for assess it is normally used tools like diagrams for knowing the weaknesses. The usage of Process

Mining has a level of in-depth that this class is not using. Consequently, although Process Mining can be a helpfully tool for helping the assessment of this class, we are not recommend it because will provide an excessive level of in-depth and also will increment the cost in a way that is not needed by this Class.

But, also if the company can use perfectly the tool of Process Mining, there are more singular points where Process Mining will not be helpful.

The first one is that Process Mining will not clear the conduction of the evaluation. This one is an abstract procedure that has no clear steps if the team is not well experienced. How to verify and validate objective evidences and how extract this information are not clear steps and if the team has not the sufficient experience working in CMMI Assessment or don't know pretty well the company, this concept will not be easy. As it is said, Process Mining cannot help to clarify it.

Following last paragraph, also not being a helpful tool for helping the appraisals, Process Mining will not be helpfully for the own employees of the company for reducing their workload. The employees will continue need to familiarize with the new processes that the company is implanting for increase their performance. Process Mining will not help to reduce the workload, only can reduce the number of interviews and questionnaires that normally CMMI appraisal do because part of the information extracted from interviews can be extracted from the Event Log and the conclusions that Process Mining provides that are also more objective than information from interviews.

On the other hand, going more in depth in how to analyze data for extracting conclusions, Process Mining in contradistinction to MINITAB, the nowadays most common program used for the CMMI Appraisals, cannot provide direct and clear information as MINITAB provides. Process Mining can identify if an attribute is valid or not but also MINITAB can do it with the application of Pareto Charts for knowing the importance of every attribute or with the usage of factorial designs for knowing if there is any combination of effects that are the basis of the any problem that the appraisals are looking for. Consequently, the best way for coming up with the CMMI Assessment will be the usage of both programs, corroborating the conclusions extracted by one program with the other one.

But, also having an experienced team and the company well prepared for their assessment, Process Mining can be only a helpful tool for discovering possible defects extracted from data if this one is recollected correctly and is recollected on the weak points. For this reason is really important that also the assessment requirements will be totally based on the needs of the organization and also, the team and the own company needs to know that the problems that the problems affects all the company, if they focus in one department or one section, normally the problems can only decrease but not extinguish because is common that problems of one section connects with others from other sections.

5. Mismatches between Process Mining and the pre-conditions of CMMI Assessment

But, out from the evaluation itself, Process Mining has mismatches also with the pre-conditions of CMMI Assessment. On this section, this concept will be developed.

As it is said during the entire present thesis, Process Mining is a methodology for extracting information from data collection but if data is not already collected, is not useful. For this reason,

before starting collecting data, CMMI appraisal cannot have benefits from the methodology neither for analyze the requirements that the system needs nor how to difference between the product requirements and the ones from the customers, information that is useful for knowing in which way the company is improving.

Other problem not solved with Process Mining is that cannot decide which members or how many of them need the team for coming up properly with the evaluation. These concepts will be decided in coordination between SEI and the own organization based on experienced people that know the process. Process Mining could be helpfully for discovering the actual roles but probably a previous data collection with only this aim will not be useful.

And also, as it said on the section '4. Mismatches between Process Mining and CMMI Assessment', Process Mining is only helpfully for discovering defects from data if this is recollected correctly and on the correct points. If not, the problems of the company will not be solved. For this reason is really important the good definition of the assessment requirements based on the needs of the organization.

6. Summary of the Chapter

On 'Chapter 6. Tools of Process Mining for supporting CMMI Assessment', we entered on the main goal of the Thesis: find if Process Mining can be helpful for improve CMMI Assessment, focusing specially on Class A SCAMPI Appraisal Method because is the most common one and, also, is the most in-depth SCAMPI Method.

On the present Chapter, after realizing an Introduction about both concepts, Process Mining CMMI Assessment, on section '2. Methodology for matching Process Mining as a tool for carrying out CMMI Assessments', we defined the followed methodology that we used for finding matches between Process Mining and CMMI Assessment. This methodology is applied both for the assessment itself and for the plan and preparation to it because it is based on the steps defined on 'Chapter 5. CMMI Assessment'. The points where Process Mining can be really helpful were clarified by the usage of tables showing which the tools that are implemented nowadays are and if there is any connection between these tools and the tool of Software Process Mining.

Afterwards, on section '3. Matches between Process Mining and CMMI Assessment', we identified concretely which these matches are and we tried to connect it with the concrete perspective of Process Mining developed on 'Chapter 3. Process Mining and Analysis'. On the other hand, we discovered that Process Mining is not the remedy for all the weaknesses of CMMI Assessments and, connecting, on section '4. Mismatches between Process Mining and CMMI Assessment' and on section '5. Mismatches between Process Mining and the pre-conditions of CMMI Assessment', we also commented the points where Process Mining is non-viable for the aim that we are looking for finding that, there are mismatches both on the CMMI Assessments itself but, also, on the pre-conditions of this Assessments like that, Process mining cannot be used if data is not already collected or to decide which are the best members of the organization for be part of the appraisal team.

Chapter 7. Tools of Process Mining for supporting CMMI Assessment of concrete Process Areas

1. Introduction

On the previous ‘Chapter 6. Tools of Process Mining for supporting CMMI Assessment’, we discovered that the matches and mismatches between the tool Process Mining and the standard way for assess the CMMI Model, the SCAMPI are possible and we also determined which are concretely these matches and mismatches.

On that Chapter, we described a methodology followed for matching both concepts, assessment of CMMI and the tool of Process Mining for using it as a tool for supporting the own CMMI assessment.

But the methodology described on the ‘Chapter 6. Tools of Process Mining for supporting CMMI Assessment’ was focused especially on how to find the matches where Process Mining can improve the standard assessment of CMMI: which are the connections between both concepts during the planning of the evaluation and the evaluation itself.

But, for assessing CMMI, for coming up with the assessment itself, the appraisal team needs to assure that the organization is taking care and is implementing correctly every single process area inside every different maturity level of the CMMI Model.

On the present Chapter, we will develop a standard methodology that the user can follow for identify the matches between the assessment of a particular process area and the tool of Process Mining. For assuring that this methodology is working correctly, we will apply it on two different concrete process areas: Decision Analysis and Resolution and Organizational Process Focus, both from CMMI maturity level 3.

2. Standard Methodology for finding matches between CMMI Process Areas and the tool of Process Mining

As it is said in the introduction, in order to answer the research question “How can Process Mining help in assessing software processes using SCAMPI method?”, we performed the steps mentioned following.

- 1- We studied in depth the SCAMPI Appraisal Method, its aim and goals. As important information, we need to note that as it is showed on ‘Chapter 6. Tools of Process Mining for supporting CMMI Assessment’, we focused specially on Class A SCAMPI Appraisal Method because is the most common one and, also, is the most in-depth SCAMPI Method.
- 2- We selected two CMMI Process Areas and we studied both generic and specific practices. As it is said in the Introduction of the present Chapter and will be developed on the following sections, these two Process Areas are: Decision Analysis and Resolution and Operational Process Focus, both from CMMI Maturity Level 3.

The reason for selecting these two process areas is because on CMMI Maturity Level 3, the project control is already started and consequently, Process Mining can be helpful. Inside CMMI Maturity Level 3, we selected these two concretes process areas because

the concepts of both process areas are totally different and, while on Organizational Process Focus, the usage of Process Mining is quite evident, on the process area Decision Analysis and Resolution, the usage of Process Mining is not direct.

- 3- In line with SCAMPI, we attempted to identify necessary data to that process area need for their assessment
- 4- Comparing these data with the outputs of Process Mining techniques, we will arrive to the conclusions whether a certain Process Mining method can provide some of that data.

Consequently and, under the assumption that the data necessary for this particular Process Mining is available and also, that the usage of event logs on the process is possible, we will decide if use Process Mining for improve CMMI Assessment is a possible tool or not.

On the following sections, this methodology will be applied on the mentioned process areas.

3. Definitions of terms as defined in CMMI and SCAMPI documents

But before starting applying the methodology to the process areas ‘Decision Analysis and Resolution’ and ‘Organizational Process Focus’, we need to define few terms that will be used on the following sections. These terms are related with the concept of Institutionalization. As we will see, the concept of institutionalization will be a vital concept in the generic goal and the generic practice descriptions and, consequently, on the general process improvement.

The concept Institutionalization implies that the process is ingrained in the way the work is performed and, that there is commitment and consistency to performing the process (CMMI Product Team, 2006).

There are three different levels of institutionalization which will be used on the following sections. These levels are:

- Institutionalize a performed process: A performed process is a process that accomplishes the work necessary to satisfy the specific goals of a process area.
- Institutionalize a managed process: A managed process is a performed process that is planned and executed in accordance with a policy. This kind of process employs skilled people having adequate resources to produce controlled outputs, involves the relevant stakeholders and is monitored, controlled and reviewed in adherence to its process description.
- Institutionalize a defined process: A defined process is a managed process that is tailored from the organization’s set of standard processes according to the organization’s tailoring guidelines. This process has a maintained process description and contributes process related experiences to the organizational process assets.

Once known these concepts, on the following sections the methodology related on the section ‘2. Standard Methodology for finding matches between CMMI Process Areas and the tool of Process Mining’ will be applied for the process areas ‘Decision Analysis and Resolution’ and ‘Organizational Process Focus’.

4. Decision Analysis and Resolution

The purpose of Decision Analysis and Resolution is to analyze the possible decisions by the usage of a formal evaluation process that evaluates identified alternatives with the established criteria (CMMI Product Team, 2006).

This area has basically application in the technical process area but also can be applied in non-technical problems, especially when the project is planned and can have multiples alternatives to be solved. In this case, the evaluation criteria are useful for taking a formal evaluation process.

A formal evaluation process is a structured approach for evaluating alternative solutions against established criteria to determine a recommended solution to address an issue but not all the decisions are so important for require this kind of process, it depends on the circumstances of the project and determined for guidelines established by the companies. Based on (Software Quality Assurance, 2011), typical guidelines that are followed by the companies are the following:

- When a decision is correlated with topics evaluated as medium or high risk. The step of maturity level 3 'Risk Management' focus on how one decides the risk level of every possible decision.
- When a decision is related with changing work product.
- When a decision can cause delays or affect the capacity to achieve the goals of the projects.

Out of this, several examples of problems that can be analyzed by this step are related normally with the performance of the processes, the cost of the materials or the possibility of improving the lifecycle, the design risk or the production costs, among others.

4.1. Specific Process Involved

The formal evaluation process for develop the 'Decision Analysis and Resolution' step involves the following actions (CMMI Product Team, 2006; Software Quality Assurance, 2011):

- Establish the evaluation criteria.
- Identify the alternatives solutions.
- Select the methods for evaluate these alternatives.
- Evaluate the alternative solutions with the established criteria and methods.
- Select the solutions based on the previous evaluation.

In the following diagram, these steps are related in a more clear way:

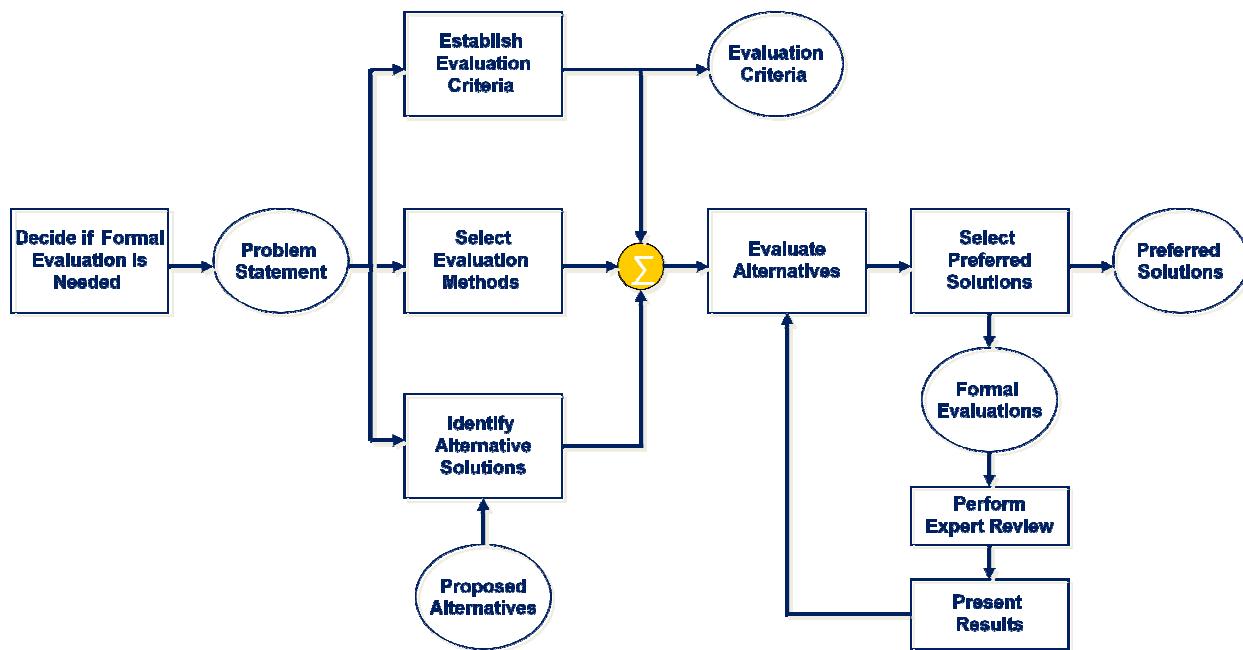


Figure 7.1. Decision Analysis and Resolution Diagram

As one can see on the previous ‘Figure 7.1. Decision Analysis and Resolution Diagram’ extracted from (Bahlil, 2009), the present process is not lineal and can be cyclic is the final results are not the liking of the company.

Below, these steps are developed:

4.1.1. Establish evaluation criteria

The evaluation criteria is the base for generate solutions. These criterions needs to agree with the requirements, the possible business cases and, the aims and needs that need to be documented in a proper way. Several examples of criteria are technological limitations or environmental impact.

There is also necessary to identify the range and the scale for classify these criteria normally using formulas that relate the evaluation parameter with a numerical weight.

Normally, these criteria are classified according with the range reflecting the needs, the aims and the priorities of the involved stakeholders. These criteria, by the usage of the scale assigned previously, will be divided for their relative importance and they will be documented for the posterior selection or, on the other hand, their rejection (Software Quality Assurance, 2011).

4.1.1.1. Tools

There is not a standard or a program for establish criteria. The common usage is a brainstorming session in concordance with market research, quizzes or customer report that can be helpful for taking decisions (Ritter and Brassard, 1998).

For number the criteria, it is useful to create a database with specific point which the solution weight and the correspondent coefficient that help to decide the importance of the criteria. If the

coefficient is large, the criteria will be more important (CMMI Product Team, 2006; Ritter and Brassard, 1998).

4.1.2. Identify alternative solutions

The aim of this sub-step is that with several alternatives solutions in the beginning of an analysis, increases the probability of an acceptable decision and the derivate consequences. These alternatives can be as unusual as the company wants but on the other hand, needs to satisfy all mandatory requirements, otherwise, will be rejected immediately.

For growing the project, first of all is necessary searching literature for knowing what others did in similar situations. This fact can show a more in-depth compression about the topic and the alternatives to consider and the possible problems that can occur during the implementation.

When the search is already done, starts the selection of the alternatives with evaluation criteria identifying the priorities of the interested parts (Software Quality Assurance, 2011).

4.1.2.1. Tools

First of all, as it is said, it is common the usage of previous experiences, know what other companies did on similar cases. For reach this goal, is useful the research on literature.

Once known which were the solutions that other companies implanted, it is necessary the contributions of the interested parts and their experiences. Know their preferences or experiences, can help to the teams to identify the limitations of every possible alternative. These limitations can be solved by a brainstorming session that can stimulate the situation with the fast interaction.

Out from brainstorming, interviews with experimented personal quizzes and work groups, the search of historical data of the processes companies but also, paying attention to market research could be a useful tools that will help to discover possible alternatives (Bahill, 2009).

4.1.3. Select Evaluation Methods

The methods for evaluate alternatives solutions in concordance with the established criteria could vary depending of the possible simulations that the organization wants to do, the availability of the used information for supporting the method or, the dependence on the different decisions that the company will take in every different moment.

When the methods are selected and implanted, one concept that the organization needs to know and take care of it, is the fact that the simulations could be modified by random activities not related with the process.

For supporting the evaluation methods, is necessary to take into account the possible cost, the timetable, the performance and the possible derivate risks (Software Quality Assurance, 2011).

4.1.3.1. Tools

The selection of methods is normally done by brainstorming and, varies depending on the analysis of the decision and the availability of information during the process. Normally, the methods are different when the requirements are not well defined as if they are.

The typical evaluation methods are: simulation or modeling, manufacturing and cost studies, surveys and questionnaires, revision of existing systems or derivation based on previous experiences.

On the other hand, the organizations needs to take care of the fact that the results could be altered for activities not related with the process; this is called noise and can affect the final result, helping to take wrong decisions (Bahill, 2009; Ritter and Brassard, 1998; Software Quality Assurance, 2011).

4.1.4. Evaluate the Alternatives and Select the Solution

All the previous steps have the match in this step because the company needs to evaluate the alternatives solutions using the criteria and the methods defined previously.

Evaluation means analyze, discuss and review all the alternatives. Sometimes, this is a cyclic process and needs of new simulations or piloting for extract punctuation or conclusions for every alternative.

Sometimes, the usage of one criterion cannot differentiate so much between alternatives. In this case, the selection can be not clear and the organization needs to know if the difference is so important for select one option or not. Also, the criteria can be modified if the company considers this appropriate or maybe, directly, new alternative solutions could be proposed, starting again the process. Because of this reason, this step is considered a cyclic process.

When the best alternative is already selected, the derivate risks need to be evaluated. Sometimes these decisions should do with incomplete information and need, in consequence, a posterior analysis for control all the risks (Anonymous, 2005; CMMI Product Team, 2006; Norousky, 2004; Software Quality Assurance, 2011).

After the final selection, all the process needs to be documented and justifying all the possible changes as well the results of interim evaluations.

4.1.4.1. Tools

As it is said above, models, simulations or piloting could be useful for the selection of the final alternative.

Out of this, the typical way to work is the establishment of relative importance and scales between the different criteria. This is called 'Rank' and when higher is the score, better is the solution for this specific criterion.

Once the solutions are ranked for each evaluation criteria, the total score for each solution is computed. At the same time, each evaluation criteria has a coefficient. The total score is the summation of all the ranks multiplied for the consequent coefficient. With this tool, the higher score will represent the better solution choice.

The following table extracted from (Roth et al., 2010; Akao, 1994) provides an example of this methodology.

Evaluation Criteria	Coefficient	Solution A	Solution B	Solution C
X	5	4	3	2
Y	3	3	2	3
Z	1	2	2	1
Total		31	23	20

Table 7.2- Table of Criteria Selection

As it is said above, the solution with the highest total score shall be selected.

In the past example, solution A would be the winner. The problem is that not always the solution is so evident, several times the total of two or more solutions is really close or equal and as it is said; more evaluation criteria will need to be exposed (Roth et al., 2010; Akao, 1994).

Out of the showed table, there is also several methods for combining data and evaluate alternatives. Examples can be Multi-Attribute Utility Technique (MAUT) that use rational methods for avoid the difficulties of the alternatives. The problem of this technique is that is focused specially on the materials science. Other possible options are the decision trees, the financial analysis or Quality Function Deployment, that transforms the demands to design quality for achieving into subsystems. Quality Function Deployment method is useful to transform customer needs into engineering characteristics but is also interesting for knowing if the alternatives are complying with the characteristics (Bahlil, 2009; Bhagat, 2010; Roth et al., 2010).

4.2. Users' Questions and Relation with Process Mining

On this process area, there are some derived generic questions that need to be answered correctly for ensure the step of Decision Analysis and Resolution is done. Related with (CMMI Product Team, 2006), these questions are the following:

- Are achieved the specific goals?
- Is institutionalized a managed process?
- Is institutionalized a defined process?
- Is institutionalized a quantitatively managed process?
- Is institutionalized an optimized process?

For finding the connections with Process Mining of every different generic questions, we will explore deeply every question knowing that the usage of Process Mining will not be possible if the process is not already executed and data is not already collected (Baumert, 1992; CMMI Development Team, 2006; Samalikova, 2011; SCAMPI Upgrade Team, 2011; Trinity-CMMI, 2011).

As a note and before develop the generic practices, say that Process Mining can only be helpful when the process is already executed and data can be collected. According with this sentence, on the following section, all the practices will be developed but the usage of Process Mining will be only developed on those ones where the process is already executed.

4.2.1. Achieve Specific Goals

The process supports and enables achievement of the specific goals of the process area by transforming identifiable input work products to produce identifiable output work products.

(4.2.1. Achieve Specific Goals) includes the following practices:

4.2.1.1. Perform Specific Practices

Perform the specific practices of the decision analysis and resolution process to develop work products and provide services to achieve the specific goals of the process area.

Process Mining can help to improve the realization of the sub-steps of this process area. But, on the other hand, talking in assessment terms, Process Mining by the usage of the four perspectives commented on 'Chapter 3. Process Mining and Analysis', can let the organization know if they are well implementing the selected solution.

4.2.2. Institutionalize a Managed Process

The organization needs to institutionalize a process as a managed process.

(4.2.2. Institutionalize a Managed Process) includes the following practices:

4.2.2.1. Establish an Organizational Policy

The aim of this practice is to establish and maintain an organizational policy for planning and performing the decision analysis and resolution process.

This policy establishes organizational expectations for selectively analyze possible decisions by using a formal evaluation process that evaluates the alternatives by established criteria.

4.2.2.2. Plan the Process

The aim of this practice is to establish and maintain the plan for performing the decision analysis and resolution process.

4.2.2.3. Provide Resources

The aim of this practice is to provide the adequate resources for perform the decision analysis and resolution process, developing the work products and providing the services of the process.

As the process is not already executed and consequently, data cannot be collected in the event log form, the usage of Process Mining cannot help to this practice.

4.2.2.4. Assign Responsibility

The aim of this practice is to assign responsibility and authority for performing the process, developing the work products, and providing the services of the decision analysis and resolution process.

4.2.2.5. Train People

The aim of this practice is train the people performing or supporting the decision analysis and resolution process. This specific training is based on how to decide which alternative is better and to train the people with the methods for evaluate the alternatives.

4.2.2.6. Manage Configurations

The aim of this practice is to place designated work products of the present process area under the appropriate levels of control.

4.2.2.7. Identify and Involve Relevant Stakeholders

The aim of this practice is to identify and involve the relevant stakeholders of the decision analysis and resolution process as planned.

4.2.2.8. Monitor and Control the Process

The aim of this practice is to monitor and control the decision analysis and resolution process against the plan for performing the process and take the appropriate corrective actions. The typical work product and measures used on this practice are cost-to-benefit ratio of using formal evaluation processes and a schedule for the execution of a trade study.

Differently from the previously practices, the practice ‘Monitor and Control the Process’ is related with the process execution.

According with (Baumert and McWhinney, 1992; SCAMPI Upgrade Team, 2011; Trinity-cmmi, 2011), the sub-practices that the appraisals will need to do on this step are the following ones:

1. Evaluate actual progress and performance against the plan for performing the process. The evaluations are of the process, its work products, and its services. Data needed in this case is related on the number of completed and still opened cases and if the performance of the process is the expected one.

These data is provided by a basic overview of a process (for example, a log inspection in Process Mining), the Control-Flow perspective (process model discovery and conformance checking) and the Performance perspective (throughput time calculation and bottleneck analysis). The analysis could be also performed on a filtered set of cases based on case attributes (for example, calculating separately throughput time for cases with high, medium and low priority respectively).

2. Review accomplishments and results of the process against the plan for performing the process. Data needed is number of completed cases and still opened cases and the timestamps of start and end events.

These data is provided by Control-Flow perspective (process model discovery, conformance checking and also, LTL checking) also giving extra information like if the task originators are the expected ones.

3. Review activities, status, and results of the process with the immediate level of management responsible for the process and identify issues. These reviews are intended to provide the immediate level of management with appropriate visibility into the process based on the day-to-day monitoring and controlling of the process.

These data is provided by an overview of the process like a log inspection in Process Mining and the usage of the four perspectives depending on the problem that the appraisals wants to look for.

4. Identify and evaluate the effects of significant deviations from the plan for performing the process. Data needed is sequence of the cases and tasks and number of completed and opened tasks.

This concept is provided by Process Mining with the usage of Control-Flow perspective (conformance checking)

5. Identify problems in the plan for performing the process and in the execution of the process. Data needed is the categorization of cases based on their performance, execution times per tasks, etc.

These data is provided by Performance perspective by the usage of throughput time calculation and bottleneck analysis and performance sequence analysis.

6. Take corrective action when requirements and objectives are not being satisfied, when issues are identified, or when progress differs significantly from the plan for performing the process.

These corrective actions include remedial actions to repair defective work products or changes on the plan including adjusts on the resources.

4.2.2.9. Objectively Evaluate Adherence

The aim of this practice is to objectively evaluate adherence of the decision analysis and resolution process against its process description, standards and procedures.

Tools for coming up with this practice are the evaluation of the alternatives by the established criteria and methods. Out of this, for evaluate the practice in the most objective way, the appraisal team needs to know how the actual process is, how many cases follows the process or if these cases are following a certain path.

These data are provided by Control-Flow perspective (process model discovery and conformance checking) and also Case perspective (decision analysis).

4.2.2.10. Review Status with Higher Level Management

The aim of this practice is to review the activities, status and results of the decision analysis and resolution with higher level management and resolve issues for provide visibility into the process.

The aim of Process Mining by their four perspectives is to discover how the real process looks like. Consequently, by having a look on the log inspection, the appraisal team can see the visibility of the process.

4.2.3. Institutionalize a Defined Process

The aim of this generic practice is to establish and institutionalize a defined process for the process area Decision Analysis and Resolution with the aim of using it for future improvements.

(4.2.3. Institutionalize a Defined Process) includes the following practices:

4.2.3.1. Establish a Defined Process

The aim of this practice is to establish and maintain the description of a defined decision analysis and resolution process. For reach this goal, the organization need to clarify properly all the steps

followed, well documenting all the steps done on this process area from the election of evaluation criteria and methods to the selected solution.

Process Mining cannot help on this practice.

4.2.3.2. Collect Improvement Information

The aim of this practice is to collect work products, measures and improvement information derived from planning and performing the decision analysis and resolution process to support the future use and improvement of the organization's processes. After collecting this information, all these concepts need to be well documented for their inclusion in the organization's process asset library and for the aim that the organization can know which the future improvements can be.

Examples of work products that this practice provides are, for example: the number of considered alternatives, the evaluation results or the recommended solutions to address significant issues.

Normally this data collection is done by using the tools related on 'Chapter 5. CMMI Assessment' that varies respecting on the class of assessment that the company is coming up. But also, Process Mining can be a helpful tool for collecting the measures of these practices and support the decisions about the future of the organization processes.

4.2.4. Institutionalize a Quantitatively Managed Process

The aim of this generic practice is to institutionalize the process in a quantitatively managed way paying attention to the performance of the process for assuring the best quality.

(4.2.4. Institutionalize a Quantitatively Managed Process) includes the following practices:

4.2.4.1. Establish Quantitative Objectives for the Process

The aim of this practice is to establish and maintain quantitative objectives for the configuration management process, which address quality and process performance, based on customer needs and business objectives.

Process Mining cannot help to establish these kinds of objectives.

4.2.4.2. Stabilize Sub process Performance

The aim of the second practice inside GG4 is to stabilize the performance of one or more subprocesses to determine the ability of configuration management process to achieve the established quantitative quality and process performance objectives.

Data needed in this practice is the timestamps of start and end of the events, the maxim throughput time and which are the resources of limited capacity.

These data is provided by the Performance Perspective of Process Mining (Performance perspective). Also, Case perspective can provide interesting information about how data attributes affects to the routing of the process and, consequently, their performance process.

4.2.5. Institutionalize an Optimized Process

Finally, the goal of the last generic practice is to institutionalize the process in an optimized way, identifying the defects and correct in concordance.

(4.2.4. Institutionalize an Optimizing Process) includes the following practices:

4.2.5.1. Ensure Continuous Process Improvement

This concept means the continuous improvement of the decision analysis and resolution process in fulfilling the relevant business objectives of the organization.

For coming up with this procedure, the organization in conjunction with the appraisal team needs to know perfectly how the process is going on, which are the areas to improve and how can these areas improve.

These data is provided by a log inspection in Process Mining because, as it is said on 'Chapter 3. Process Mining and Analysis', the own aim of Process Mining is to discover and understand how the process is working. Consequently, by their application, the appraisal team can discover where are the possible improvements that the organization can apply for continues with their process of maturity.

4.2.5.2. Correct Root Causes of Problems

The aim of the last practice is to identify the root causes of defects and other problems that are inside the decision analysis and resolution process and correct them for the improvement.

Similarly to the previous practice 'Ensure Continuous Process Improvement', data needed for this practice is know perfectly how the processes are evolving, where are the problems or the weak points for, in consequence, improve them as much as possible.

If these problems are related with the performance of the process, Performance perspective (throughput time calculation and bottleneck analysis) can help for the detection of these weak points. But, these problems cannot be related only with the topic of the performance. In this case, depending on the problem, it can be useful the usage of the others Process Mining's perspectives. For knowing which points are the ones that every Process Mining's perspectives refers, take a look on 'Chapter 3. Process Mining and Analysis'.

4.3. Summary Table

After presenting all the possible matches that the user can find between the tool of Process Mining and the process of CMMI Assessment on the concrete process area 'Decision Analysis and Resolution', we will present a summary table for make clear and synthesize all the presented relation between both concepts.

Generic Practices	Relation with Process Mining
Achieve Specific Goals	Process Mining can help for knowing if the organization is well implementing the selected solution; if the processes are following the expected patterns.

Institutionalize a Managed Process	Process Mining can help on the sub - practices related with process execution by supporting the monitor, the control and the evaluation of the process procedures and knowing if their performance is the expected.
Institutionalize a Defined Process	Process Mining can provide which the possible improvements of the process can be and consequently, help to support the decisions about the future of the organization's processes.
Institutionalize a Quantitatively Managed Process	Process Mining can provide information about the performance of the process and how data affects that performance.
Institutionalize an Optimized Process	Process Mining can help to discover where are the weak points where the organization can improve continuously and, also, can help to detect the root causes of the problem if they are related with the perspectives of Process Mining.

5. Organizational Process Focus

While being all CMMI a process for improves software, is this process area specially the one that focuses on the topic. The aim of this process area is to plan and implant the organizational improves based on the strengths and weaknesses of the organizational processes and actives including the measurement of the processes, the results of the evaluations or the recommendations, among others, with the most careful planning for assure that the improves will be well executed (Software Quality Assurance, 2011).

One important part for come up with the process improves is the planning. The organizations have to take care about the timeline of the evaluation and needs to know which the scope of the evaluation is.

All the project planning needs to be well documented explaining the weaknesses that the evaluation will need to solve, paying special attention on, when and how the improve will be implemented on the organization and, also, if there is needed the test of a pilot before the implementation of the selected solution (CMMI Product Team, 2006; Hefner, 2000).

Below, all the steps for perform the process area 'Organizational Process Focus' will be developed.

5.1. Specific Process Involved

The present process area has clear steps because, as it is said above, it is based on the way to implement process for improve. Follow this direction, the steps that 'Organizational Process Focus' follow are listed and developed below based on (CMMI Product Team, 2006; Software Quality Assurance, 2011).

- Determine the opportunities for improve processes.
- Plan and implement the improvements on the processes.
- Implement and incorporate the organizational actives developed in previous steps.

5.1.1. Determine the opportunities for improve processes

Periodically the strengths and the weaknesses of every company needs to be identified and consequently, improve them for continue satisfying the organization needs, taking into account all the different parts of the company and the lifecycle of every product. Normally the most typical process areas are related with finances, quality, human resources and marketing.

First of all, the needs of the process organization need to be identified and documented paying attention to the normal procedure of every process and their performance and productivity. Also, the needs of the company vary depending on which methodology and which kind of normative they are following. Examples of objectives that can be improved are throughput time, productivity or the elimination of defects (Glazer et al., 2008; Humphrey et al., 2001).

When the processes that need to improve are identified, there is needed to determine the criteria that will be used for the evaluations. Criteria are normally based in an international normative or a comparison with standards specifying the characteristics of time and efforts that the company considers necessary.

After this step, the organization needs to identify the possible improvements. The typical ways and tools for determine improvements are explained below.

5.1.1.1.Tools

For knowing which can be the parts to improve, normally the companies compare their data with data of other companies or, they base their decisions in interviews with the stakeholders of every process. Several companies use already database for knowing if the results corroborate what the interviews says or for directly, for knowing what results say and take decisions in consequence. Advancing opinions, this concept is one of the main aims that Process Mining provides.

On the other hand, according with (CMMI Product Team, 2006), the usual techniques that help to determine and also prioritize the possible improvements to apply are:

- An analysis of the deficiencies that compares the actual conditions with the optimal conditions.
- A force field analysis for identify the potential borders and, consequently, strategies for break them down. This analysis is based on the identification of the restrictive strengths that difficult the growing of a product or a process and also the impulsive strengths that motivate the company (Krell, 2009).
- A cause and effect analysis for knowing the possible effects of the different improvements that can be seen in advance.

The most common way for come up with these analyses is a brainstorming of the stakeholders with the adequate data extracted from interviews or other options.

5.1.2. Plan and implement improvements in the processes

For getting the success of the improvements, is necessary a good planning of the measures defined previously. For this reason, it is useful to create the called plans of actions that are used for identify the strategies, the approaches and actions for come up with the improvements previously defined.

These plans of actions include the aims of the improvements; the procedures for following the actions, the derived responsibilities, the methodology for determine the efficiency of the actions and finally, the associated risks that these improvements could cause (CMMI Product Team, 2006).

If the plans are accepted for the organization, the implementation can start documenting all the process with the most accuracy.

Normally this plans of actions needs of pilots for tasting the possible improvements, exams of the activities and revisions of the processes for discovering the weak points.

5.1.2.1. Tools

The plans of action are developed jointly for the direction and the teams that support every different product. They are the responsible of the establishment of strategies to follow and also, they are the responsible of the task of supervising the activities (Software Quality Assurance, 2011).

5.1.3. Implement and Incorporate the Organizational Actives

On the process area ‘Organizational Process Definition’, the organization defines the organizational actives. These actives are the standards that the organization will maintain in the future. They are related with the different hierachic levels of the company and cover part of the process.

On the process area ‘Organizational Process Definition’, these actives are documented containing the consequent description of the used methodology and also the methodology that will be used for the revision paying attention to the most critical facts and explaining the relations with the other elements of the process.

The typical actives are normally descriptions of the lifecycle models, the adaptation criteria for the organization like a new line of products o a personalization of an existent product, the process for realize, store and analyze the measurements, the norms for a correct environment on the organization and if it’s necessary an organization of the processes actives, the establish of a library for store the descriptions and procedures of the processes, the development, acquisition and quality plans among others (CMMI Product Team, 2006).

After define the actives, on the present process area: ‘Organizational Process Focus’, these actives will be implemented on the organization.

Similarly as previously, the display of these actives needs to be well documented and done in an order way for assure that they will be executing in a proper way the process.

For implementing these actives, the organization will need to identify the actives that need to be adopted in every step of the process and identify the necessary resources for supporting the usage of actives.

When the actives will be finally implemented, is it possible that the effect will not be the expected, in this case, the changes needs to be well documented.

All the process of implement the actives needs of the supervision and monitoring of the organization and the posterior evaluation that will determine which the methods or the tools that could be used for continuing with the improvement are, will assess the quality and efficiency of the defined actives and, in general, will show if the planned approach is correctly followed and will determine if the results are the expected or not (CMMI Product Team, 2006; Software Quality Assurance, 2011).

5.1.3.1. Tools

The present sub step is, similarly at previous, an implementation and posterior evaluation. The decision for implementing the process needs to be decided for the direction, being supported by the guidelines that the established actives shows for the deployment on the total of the organization. But on the other hand, it's common that the employees gives their opinion about which can be the topics to improve (DeWitt, 2010).

For come up with the evaluation, the usual tools are data measurements and registers of the implemented actives for, in this way, assure about the quality of the product and also the fulfillment of the results.

5.2. Users' Questions and Relation with Process Mining

Process Mining could be a powerful tool on the present Process Area because all the steps that develops needs to be assessed and Process Mining can help to clear up the derived problems that arise from this assessment.

Out of this, for accomplishing with the present Process Area, according with (CMMI Product Team, 2006) the generic questions that need to be answered correctly on this process area refers to the following topics:

- Are achieved the specific goals?
- Is institutionalized a managed process?
- Is institutionalized a defined process?
- Is institutionalized a quantitatively managed process?
- Is institutionalized an optimized process?

Following the same methodology followed on the process area 'Decision Analysis and Resolution', for finding the connections with Process Mining of every different generic questions, we will explore deeply every question knowing that the usage of Process Mining will not be possible if the process is not already executed and data is not already collected (Baumert, 1992; CMMI Development Team, 2006; Samalikova, 2011; SCAMPI Upgrade Team, 2011; Trinity-CMMI, 2011).

As a note and before develop the generic practices, say that Process Mining can only be helpful when the process is already executed and data can be collected. According with this sentence, on the following section, all the practices will be developed but the usage of Process Mining will be only developed on those ones where the process is already executed.

5.2.1. Achieve Specific Goals

The process supports and enables achievement of the specific goals of the process area by transforming identifiable input work products to produce identifiable output work products.

(5.2.1. Achieve Specific Goals) includes the following practices:

5.2.1.1. Perform Specific Practices

Perform the specific practices of the organizational process focus process to develop work products and provide services to achieve the specific goals of the process area.

Process Mining can help to improve the realization of the sub-steps of this process area specially because can be a really helpful tool for discover during the process improvement, where are the weak points and focus the improvements or that direction.

But, on the other hand, talking in assessment terms, Process Mining by the usage of the four perspectives commented on ‘Chapter 3. Process Mining and Analysis’, will help the organization to the step of evaluate if the implemented actives are working correctly. Also, this step will be the one that the appraisal team will assess by knowing if the actives are implemented correctly and if these actives solve correctly the weaknesses of the company.

5.2.2. Institutionalize a Managed Process

The organization needs to institutionalize a process as a managed process.

(5.2.2. Institutionalize a Managed Process) includes the following practices:

5.2.2.1. Establish an Organizational Policy

The aim of this practice is to establish and maintain an organizational policy for planning and performing the decision analysis and resolution process.

This policy establishes organizational expectations for selectively analyze possible decisions by using a formal evaluation process that evaluates the alternatives by established criteria.

5.2.2.2. Plan the Process

The aim of this practice is to establish and maintain the plan for performing the decision analysis and resolution process.

5.2.2.3. Provide Resources

The aim of this practice is to provide the adequate resources for perform the decision analysis and resolution process, developing the work products and providing the services of the process.

As the process is not already executed and consequently, data cannot be collected in the event log form, the usage of Process Mining cannot help to this practice.

5.2.2.4. Assign Responsibility

The aim of this practice is to assign responsibility and authority for performing the process, developing the work products, and providing the services of the decision analysis and resolution process.

5.2.2.5. Train People

The aim of this practice is train the people performing or supporting the decision analysis and resolution process. This specific training is based on how to decide which alternative is better and to train the people with the methods for evaluate the alternatives.

5.2.2.6. Manage Configurations

The aim of this practice is to place designated work products of the present process area under the appropriate levels of control.

5.2.2.7. Identify and Involve Relevant Stakeholders

The aim of this practice is to identify and involve the relevant stakeholders of the decision analysis and resolution process as planned.

5.2.2.8. Monitor and Control the Process

The aim of this practice is to monitor and control the Organizational Process Focus process against the plan for performing the process and take the appropriate corrective actions. The typical work product and measures used on this practice are the schedule for deployment an organizational process asset or the percentage of projects that are using the current organization-s set of standard processes (Software Quality Assurance, 2011).

Differently from the previously practices, the practice ‘Monitor and Control the Process’ is related with the process execution.

According with (Baumert and McWhinney, 1992; SCAMPI Upgrade Team, 2011; Trinity-cmmi, 2011), the sub-practices that the appraisals will need to do on this step are the following ones:

1. Evaluate actual progress and performance against the plan for performing the process. The evaluations are of the process of implementing actives but also, the used work products and its services. Data needed in this case is related on the sequence of cases, which of them are complete and which are still opened and, is also important to take care of the fact if the performance of the process is the expected one or not.

These data is provided by a basic overview of a process (for example, a log inspection in Process Mining), the Control-Flow perspective (process model discovery and conformance checking) and the Performance perspective (throughput time calculation and bottleneck analysis). The analysis could be also performed on a filtered set of cases based on case attributes (for example, calculating separately throughput time for cases with high, medium and low priority respectively).

2. Review accomplishments and results of the process against the plan for performing the process. Data needed on this step for knowing how the organization is implementing the actives, is number of completed cases and still opened cases and the timestamps of start and end events.

These data is provided by Control-Flow perspective (process model discovery, conformance checking and also, LTL checking) also giving extra information like if the task originators are the expected ones.

3. Review activities, status, and results of the process with the immediate level of management responsible for the process and identify issues. These reviews are intended to provide the

immediate level of management of the actives with appropriate visibility into the process based on the day-to-day monitoring and controlling of the process.

These data is provided by an overview of the process like a log inspection in Process Mining and the usage of the four perspectives depending on the problem that the appraisals wants to look for.

4. Identify and evaluate the effects of significant deviations from the plan for performing the process. Data needed is sequence of the cases and tasks and number of completed and opened tasks.

This concept is provided by Process Mining with the usage of Control-Flow perspective (conformance checking)

5. Identify problems in the plan for performing the process and in the execution of the process, knowing if the improvements were well identified and well implemented. Data needed is the categorization of cases based on their performance, execution times per tasks, etc.

These data is provided by Performance perspective by the usage of throughput time calculation and bottleneck analysis and performance sequence analysis.

6. Take corrective action when requirements and objectives are not being satisfied, when issues are identified, or when progress differs significantly from the plan for performing the process.

These corrective actions include remedial actions to repair defective work products or changes on the plan including adjusts on the resources.

5.2.2.9. Objectively Evaluate Adherence

The aim of this practice is to objectively evaluate adherence of the organizational process focus process against its process description, standards and procedures.

Data needed for evaluate how are working the implemented plans of actions and the organizational actives, is how the actual process is working, which cases are completed and which are still opened, which pattern are following the cases, which are the real tasks originators.

For knowing how every decision implemented on the process, there is Case perspective (decision mining) that specially focuses on this topic discovering how data influences to the pattern of the process. Other perspectives of Process Mining focuses on the other concepts related on the previous paragraph providing data needed. Examples are Organizational perspective (Social Network analysis) and Control-Flow perspective (Conformance checking and LTL checking).

5.2.2.10. Review Status with Higher Level Management

The aim of this practice is to review the activities, status and results of the organizational process focus process with higher level management and resolve issues for provide visibility into the process.

The aim of Process Mining by their four perspectives is to discover how the real process looks like. Consequently, by having a look on the log inspection, the appraisal team can see the visibility of the process, how are working the implementations that the organizations did in the process and if these implementations are generating some problems that can be solved by modifying the implementations.

5.2.3. Institutionalize a Defined Process

The aim of this generic practice is to establish and institutionalize a defined process for the process area Organizational Process Focus with the aim of using it for future improvements.

(5.2.3. Institutionalize a Defined Process) includes the following practices:

5.2.3.1. Establish a Defined Process

The aim of this practice is to establish and maintain the description of a defined organizational process focus process. For reach this goal, the organization need to clarify properly all the steps followed, well document the planned improvements and the organizational actives defined and done on this process area.

Process Mining cannot help on this practice.

5.2.3.2. Collect Improvement Information

The aim of this practice is to collect work products, measures and improvement information derived from planning and performing the organizational process focus process to support the future use and improvement of the organization's processes. After collecting this information, all these concepts need to be well documented for their inclusion in the organization's process asset library and for the aim that the organization can know which the future improvements can be.

Examples of work products that this practice provides are, for example: used criteria for select process improvements or actives, the situation on a calendar of the improvement activities, among others.

Normally this data collection is done by using the tools related on 'Chapter 5. CMMI Assessment' that varies respecting on the class of assessment that the company is coming up. But also, Process Mining can be a helpful tool for collecting the measures of these practices and support the decisions about the future of the organization processes.

5.2.4. Institutionalize a Quantitatively Managed Process

The aim of this generic practice is to institutionalize the process in a quantitatively managed way paying attention to the performance of the process for assuring the best quality.

(5.2.4. Institutionalize a Quantitatively Managed Process) includes the following practices:

5.2.4.1. Establish Quantitative Objectives for the Process

The aim of this practice is to establish and maintain quantitative objectives for the configuration management process, which address quality and process performance, based on customer needs and business objectives.

Process Mining cannot help to establish these kinds of objectives.

5.2.4.2. Stabilize Sub process Performance

The aim of this practice is to stabilize the performance of one or more sub-processes to determine the ability of configuration management process to achieve the established quantitative quality and process performance objectives.

Data needed in this practice is the timestamps of start and end of the events, the maxim throughput time and which are the resources of limited capacity.

These data is provided by the Performance Perspective of Process Mining (Performance perspective). Also, Case perspective can provide interesting information about how data attributes affects to the routing of the process and, consequently, their performance process.

5.2.5. Institutionalize an Optimized Process

Finally, the goal of the last generic practice is to institutionalize the process in an optimized way, identifying the defects and correct in concordance.

(5.2.5. Institutionalize an Optimizing Process) includes the following practices:

5.2.5.1. Ensure Continuous Process Improvement

This concept means the continuous improvement of the decision analysis and resolution process in fulfilling the relevant business objectives of the organization.

For coming up with this procedure, the organization in conjunction with the appraisal team needs to know perfectly how the process is going on for discovering if any implemented active can be improved because is not working on the expected way.

These data is provided by a log inspection in Process Mining because, as it is said on ‘Chapter 3. Process Mining and Analysis’, the own aim of Process Mining is to discover and understand how the process is working. Consequently, by their application, the appraisal team can discover where are the possible improvements that the organization can apply for continues with their process of maturity.

5.2.5.2. Correct Root Causes of Problems

The aim of the last practice is to identify the root causes of defects and other problems that are inside the decision analysis and resolution process and correct them for the improvement.

Similarly to the previous practice ‘Ensure Continuous Process Improvement’, data needed for this practice is know perfectly how the processes are evolving, how the implanted improvements are working and if there are problems or the weak points for, in consequence, improve them as much as possible.

If these problems are related with the performance of the process, Performance perspective (throughput time calculation and bottleneck analysis) can help for the detection of these weak points. But, these problems cannot be related only with the topic of the performance. In this case, depending on the problem, it can be useful the usage of the others Process Mining’s perspectives. For knowing which points are the ones that every Process Mining’s perspectives refers, take a look on ‘Chapter 3. Process Mining and Analysis’.

5.3. Summary Table

After presenting all the matches that the user found between the tool of Process Mining and the process of CMMI Assessment for the concrete process area ‘Organizational Process Focus’, we will

present a summary table for make clear and synthesize all the presented relation between both concepts.

Generic Practices	Relation with Process Mining
Achieve Specific Goals	Process Mining can help for evaluate if the implemented actives are working correctly and they solve the weaknesses of the organization.
Institutionalize a Managed Process	Process Mining can help on the sub - practices related with process execution by supporting the monitor, the control and the evaluation of the process procedures and knowing if their performance is the expected.
Institutionalize a Defined Process	Process Mining can provide which the possible improvements of the process can be and consequently, help to support the decisions about the future of the organization's processes.
Institutionalize a Quantitatively Managed Process	Process Mining can provide information about the performance of the implanted process and how data affects that performance.
Institutionalize an Optimized Process	Process Mining can help to discover the weak points and, consequently, the possible improvements of the implanted processes and also, discover where are the roots of these weak points.

6. Summary of the Chapter

Continuing with the relations between Process Mining and CMMI Assessments, on the present Chapter, we developed deeply these relations.

On the previous 'Chapter 6. Tools of Process Mining for supporting CMMI Assessment', we found the matches and mismatches between both studied tools, assuring that the application of Process Mining can be used for improve the actual way for assessing CMMI Model.

But those matches, also being concrete, were not applicable on the assessment of the concrete process areas inside every maturity level of the CMMI Model, the areas that the appraisal team needs to evaluate for ensuring that the organization is well implementing the maturity level. Consequently, on the section '2. Standard Methodology for finding matches between CMMI Process Areas and the tool of Process Mining' of the present Chapter, we developed a standard methodology that the user can follow for identify the matches between the assessment of particular process areas and Process Mining.

After realizing on section '3. Definition of terms as defined in CMMI and SCAMPI documents', an explanation of several technical words that were used on the following sections, on section '4. Decision Analysis and Resolution' and on section '5. Organizational Process Focus', we applied the previous methodology for the assessment of two concrete process areas of the CMMI Model. The two process areas were selected because of their different characteristics.

The followed strategy for both process areas was the same, after developing deeply than on ‘Chapter 4. CMMI Description’ which is their function and discovering which are the usual tools for coming up with the specific processes inside the process areas, on the sub-sections ‘Users’ Questions and Relation with Process Mining’, we discovered where concretely the appraisal team can use Process Mining for assess the particular process areas, confirming the fact that Process Mining can only be a help when the process is related with process execution. For clarify the matches, on the sub-sections ‘Summary table’, we also created a table with the matches between Process Mining and the concrete generic practices that the appraisal team needs to assess of every single process area.

Chapter 8. Conclusions and Future Research

The present Master Thesis is based on the idea to improve the actual way for assessing CMMI by the usage of the tool of Process Mining. This tool is used for knowing how process implanted in companies are really working so it is not rare to think that maybe could be useful for helping CMMI Assessment.

For arriving to the conclusions, we studied in-depth how is actually done the assessment of CMMI and how is working the standard for coming up with this procedure, the standard SCAMPI. On the other hand, we also studied what is Process Mining exactly and which can be the possible usages.

Once studied both concepts, on ‘Chapter 6. Tools of Process Mining for supporting CMMI Assessment’, we tried to find where are the matches between both concepts by studying which tools are needed in every step of CMMI Assessment and knowing if there is any connection with the tools or the aims that also Process Mining uses.

But the concept of matching Process Mining and the CMMI Assessment on general is kind of abstract, with this aim, on ‘Chapter 7. Tools of Process Mining for supporting CMMI Assessment of concrete process areas’, we developed a concrete methodology for finding matches between Process Mining and the assessment of concrete process areas of CMMI. This methodology is based on the generic questions that need to be answered by the appraisal team for showing that the process area is correctly implemented. For ensuring that the developed methodology works correctly, we applied on two different process areas of CMMI: ‘Decision Analysis and Resolution’ and ‘Organizational Process Focus’, both from maturity level 3.

1. Comments to the results

The first thing that we discovered is that the tool of Process Mining could not only help to improve the actual way for assessing CMMI, but also could be a helpfully tool for helping to collect data. With the usage of event logs since the beginning, the companies can see in the moment how is every new implementation working, if the results are the expected or not. This idea is based on the concept that the quality of the process affects the quality of the product. Consequently, with the usage of Process Mining, the own process of CMMI Assessment can improve. On the present section, we will develop which were the conclusions extracted from the present Master Thesis and how and where Process Mining can help to improve CMMI Assessment.

On ‘Chapter 6. Tools of Process Mining for supporting CMMI Assessment’, we found that Process Mining, without being a remedy for all the diseases, can help to improve the actual standard for assessing CMMI, the SCAMPI methodology. On that Chapter, we saw that there are some weak point that, with the usage of Process Mining, can reduce the uncertainly that they have nowadays. These points are specially related with the way of data collection and the tools that are used nowadays for coming up with the assessment.

Also, on the chapter mentioned on previous paragraph, we saw that nowadays, there is already in several companies the usage of data records and several information systems that can be helpful for implementing Process Mining and their way of data collection, the event logs, without a lot of problems.

Finally, on ‘Chapter 6. Tools of Process Mining for supporting CMMI Assessment’, we also showed that some problems that appears on the organization after the implantation of CMMI can decrease by the usage of Process Mining because some of them are related with non-analyzed field or not completely solved performance problems.

But the problem of trying to implement Process Mining on the standard of evaluation SCAMPI for improve it is that the user cannot find a concrete methodology for discovering more points where the Process Mining can be useful. With this aim, on ‘Chapter 7. Tools of Process Mining for supporting CMMI Assessment of concrete process areas’, we developed a methodology for trying to discover where Process Mining can help the assessment of CMMI on concrete process areas. For showing that the methodology works, we applied on the process areas ‘Decision Analysis and Resolution’ and ‘Organizational Process Focus’.

On ‘Chapter 7. Tools of Process Mining for supporting CMMI Assessment of concrete process areas’; we showed that Process Mining can only be helpful on those processes related with Process Execution, when data is already collected.

Under the assumption that data collection by the usage of event logs is available and discovering which data is needed in every step described of the used methodology, we found that the implementation of Process Mining is possible and can be really useful in several concrete weak points developed but that will not be a panacea that will solve all the weak points that can be identified nowadays on SCAMPI.

As it is said in the Introduction of ‘Conclusions’, we only applied this methodology on two concrete process areas: ‘Decision Analysis and Resolution’ and ‘Organizational Process Focus’, both from maturity level 3. The reason for choosing these process areas is because, having a look on the general process areas (that are listed on ‘Chapter 4. CMMI Description’), one can see that the aim of ‘Organizational Process Focus’ is implement actives on the company and show if they are working correctly or not. A first view to this concept shows that can be related with Process Mining and, consequently, the possible implementation of it can be an interesting topic to study. On the other hand, the process area ‘Decision Analysis and Resolution’ is based on the analysis of the alternatives that the organization can follow for their improvement. This idea has not a clear matching as ‘Organizational Process Focus’ with Process Mining and, consequently, the finding or not of possible connections is also interesting because, as we saw on ‘Chapter 7. Tools of Process Mining for supporting CMMI Assessment of concrete process areas’, there are some points where the tool of Process Mining can help for the improvement of the assessment of ‘Decision Analysis and Resolution’.

On the other hand, on the present Master Thesis, we discovered the idea that Process Mining cannot only be helpful for improve the way for assess CMMI, but also can be helpful for improve the actual implementation of the CMMI Model on the companies. This topic was not the main research of the present Master Thesis and, consequently, we didn’t develop it. But, as we will say on the following section ‘Future Research’, it can be an interesting topic to study.

2. Future Research

The present research arrived to the expected conclusions: Process Mining can be a helpful tool for improve CMMI Assessment and, as it showed both on ‘Chapter 6. Tools of Process Mining for

supporting CMMI Assessment' and 'Chapter 7. Tools of Process Mining for supporting CMMI Assessment of concrete process areas' for the particular process areas 'Decision Analysis and Resolution' and 'Organizational Process Focus', we can conclude, as it is said on the previous section, that Process Mining can improve the way for assessing CMMI.

For ensuring that Process Mining can help on the assessment of concrete process areas, future research could focus on this step and implement the methodology described on 'Chapter 7. Tools of Process Mining for supporting CMMI Assessment of concrete process areas' to the other process area of the different maturity levels of CMMI and see, in consequence, if this methodology can be an standard for all the process areas of all the maturity levels of CMMI or needs of several changes or developments.

On the other hand and focusing on a topic not developed on the present Master Thesis, we observed that out of using Process Mining for improve the assessment of CMMI, Process Mining could be also helpful for improve the own implementation of CMMI Model on the companies. Without being the goal of the Master Thesis, once developing the process areas 'Decision Analysis and Resolution' and 'Organizational Process Focus', we observed possible connections where Process Mining can help to improve the actual way of implementing CMMI Model on the organizations, especially on the fact that the organizations can see clearly if they are well implementing their improvements or not. Without ensuring, we think that the development of this direction can be successful.

Finally, another way of research could be the implementation of Process Mining for improving or helping other process improvement methodologies studying both how can Process Mining help their assessment or, as it is said on the previous paragraph, how can Process Mining can help to the own implementation of these models. Examples of process improvements methodologies that can be studied are: Six Sigma or Kaizen Method.

Chapter 9. References

The references used for the present Master Thesis are listed below in alphabetical order and then further, if it is necessary chronologically.

Akao, Y. (1994). *Development History of Quality Function Development*. Asian Productivity Organization, pp 339. Tokio, Japan.

Anonymous (2005). *Decision Analysis and Resolution Process (by a client of The Process Group)*. The Process Group Post. Processgroup.com/newsletter.htm.

Arteaga, D. (2011). *CMMI in Spanish (original in Spanish)*. cmmi-en-castellano.blogspot.com

Bahill, T. (2009). *The Decision Analysis and Resolution*. University of Arizona, Department of Systems and Industrial Engineering. Arizona.

Baumert, J., McWhinney, M. (1992). *Software Measures and the Capability Maturity Model*. Carnegie Mellon Software Engineering Institute. Pittsburgh, Pennsylvania.

Bdigital (2011). *The CMMI Model*. bdigital.eafit.edu.

Bhagat, A. (2010). Decision Analysis and Resolution (DAR) process. flixia.com

Bolognino, E. (2011). *Towards Configuration Management supports for Process Mining to Improve Software Processes*. Technische Universiteit Eindhoven, Division of Information Systems.

Boras, A. et al.(2009). *A Software Quality Assurance Tool for Process Using CMMI*. Arab Academy for Science and Technology and Garyounis University, Department of Computer Science. Libya.

Bozkaya M. et al. (2009). *Process Diagnostics: A Method Based on Process Mining*. Proceedings of the 2009 International Conference on Information, Process and Knowledge Management. Washington DC, USA: IEEE Computer Society.

Brozman, J. G. and Johnson, D. L. (1997). *A software process improvement approach tailored for small organization and small projects*. International Conference on Software Engineering. Boston, IEEE Computer Society.

Builes Ramírez, C. A. (2004). *Support to the intern evaluation of CMMI in organizations by a control questionnaire (article original in Spanish)*. Universidad EAFIT of Medellin, School of Engineers. Dept. of system informatics. Medellin, México.

Cater-Steel, A. (2004). *An evaluation of software development practice and assessment-based process improvement in small software development firms*. PhD Thesis. Griffith University, Queensland, Australia.

CMMI Product Team (2006). *CMMI for Development. Version 1.2*. Carnegie Mellon Software Engineering Institute. Pittsburgh, Pennsylvania.

Cynosure Software Solutions (2010). cynosure.co.in/quality.php.

-
- Dalton, J. (2011). Ask the CMMI Appraiser. askthecmmiappraiser.blogspot.com.
- DeWitt, D. (2010). *How to Develop a Nonprofit Organizational Focus Plan*. Associated Content. Associatedcontent.com.
- Dimov, A., Chandran, S. (2010). *How do we collect data for Software Reliability Estimation?* Sofia University, Bulgaria in collaboration with Mälardalen University of Sweden.
- Dunaway, D., Bush, M. (2005). *Why do CMMI Assessments?* Addison-Wesley Professional. Boston Massachusetts.
- Ghezzi, C. et al. (2003). *Fundamentals of Software Engineering. Second Edition*. Prentice Hall, Pearson Education, International, New Jersey.
- Glazer, H. et al. (2008). *CMMI or Agile: Why not embrace both?* Carnegie Mellon Software Engineering Institute, Technical Note. Pittsburgh, Pennsylvania.
- Hefner, R. (2000). *CMMI Organizational Guidelines*. sunset.usc.edu/classes/cs510_2000/notes/cmmi.pdf.
- Hochstein, L. et al. (2008). *An Environment for Conducting Families of Software Engineering Experiments*. Advances in Computers, Vol. 74. University of Nebraska in collaboration with University of Maryland and Fraunhofer Center Maryland.
- Höggerl, M., Sehorz, B. (2006) *An Introduction to CMMI and its Assessment Procedure*. University of Salzburg. Dept. of Computer Science. Salzburg, Austria.
- Humphrey, W. (2001). *Software Process Improvement at Hughes Aircraft*. IEEE Computer Society Press Los Alamitos, California.
- Jokela, T., Lalli, T. (2003). *Usability and CMMI: Does A Higher Maturity Level in Product Development Mean Better Usability?*. University of Oulu. Department of Information Processing Science. Hawaii, United States of America.
- Kasse, T. (2007). *20 Points for Quality and Process Improvement: CMMI Assessment Experience with Medium and Small Companies*. Kasse Initiatives, LLC. Conference on March 2007, Austin, Texas.
- Kindler, E. (2005). *Incremental Workflow Mining Based on Document Versioning Information*. Software Engineering Group, University of Paderborn, Germany.
- Krell, H. (2009). *The Force Field Analysis (article originally in spanish)*. Ilvem: Train your Mind. ilvem.com.
- Mahner, T. et al (2008). *Siemens Process Assessment and Improvement Approaches: Experiences and Benefits*. Siemens AG, Corporate Technology Software. Munich, Germany.
- Norausky, G. (2004). *Decision Analysis and Resolution: 'Can This Process Area Be Used Across Organizations and Disciplines?'*. Norausky Process Solutions, Inc. 4th Annual CMMI Technology Conference & User Group.

-
- Pikkarainen, M., Mantyniemi, A. (2006). *An Approach for Using CMMI in Agile Software Development Assessments: Experiences from three case studies*. VTT Technical Research Centre of Finland. Helsinki, Finland.
- Pino, F. J. et al.(2007). *Software Process Improvement in Software Enterprises: A Systematic Review*. Springer Science+Business Media.
- Pfleeger, S. L. (1995). *Experimental design and analysis in Software Engineering*. Annals of Software Engineering. Carnegie Mellon Software Engineering Institute. Pittsburgh, Pennsylvania.
- Ramesh, A. (2005). *Process Mining in PeopleSoft*. Technische Universiteit Eindhoven. Division of Mathematics and Computer Science.
- Reitzig, R. (2009). *CMMI Process Improvement - Its not a technical problem, it's a people problem*. Cognence Inc. presentation.
- Ritter, D. and Brassard, M. (1998). *The Creativity Tools Memory Jogger*. goal/qpc. Goalqpc.com.
- Robbins, K. (2004). *Jumping from CMMI level 3 to level 5 in 9 months*. Northrop Grumman Corporation. Huntsville SPIN-UAH Technology Hall. Division Reference # - 133-09-04. Huntsville, Alabama.
- Roth, R. et al.(2010). *Multi-Attribute Utility Analysis*. msl1.mit.edu/maua_paper.pdf.
- Samalikova et al. (2010). *Configuration management tools as event-log sources for software process mining*. Technische Universiteit Eindhoven, Division of Information Systems.
- Samalikova, J. et al. (2010a). *Toward Objective Software Process Information: Experiences from a case study*. Technische Universiteit Eindhoven, Division of Information Systems.
- Samalikova, J. et al. (2010b). *Information gathering in software process assessment*. Technische Universiteit Eindhoven, Division of Information Systems.
- Samalikova et al. (2011). *Data from configuration management tools as sources for software process mining*. Technische Universiteit Eindhoven, Division of Information Systems.
- SCAMPI Upgrade Team (2011). *Standard CMMI Appraisal Method for Process Improvement (SCAMPI), Version 1.3: Method Definition Document*. Carnegie Mellon Software Engineering Institute. Pittsburgh, Pennsylvania.
- SEI Webpage (2011). sei.cmu.edu.
- Shih, C. et al.(2009). *An Empirical Study on the Performance Assessment of CMMI Adoptions in Taiwanese Enterprises*. National Taiwan University of Science and Technology. Department of Information Management. Taiwan.
- Sillitti, A. et al.(2004). *Deploying, Updating, and Managing Tools for Collecting Software Metrics*. University of Bolzano, Italia.
- Software Quality Assurance (2011) *The CMMI Easy Button*. software-quality-assurance.org

Sommerville, I. (2006). *Software Engineering. Eight Edition*. Addison-Wesley, Boston, Massachusetts.

Stark, M. (2002). *The CMMI: 700 pages of process model in 1 lecture*. UM: Experimental SW Engineering Group. November 2002.

Thayer, R. and Sommerville, I. (2002). Software Engineering. Volume 2: The Supporting Processes. Second Edition. IEEE Computer Society Press, Los Alamitos, California.

Trinity - CMMI (2011). trinity-cmmi.co.uk.

Van Der Aalst, W. M. P. et al. (2005). Business Process Mining: An industrial application. Technische Universiteit Eindhoven, Department of Technology Management in collaboration with Pohang University of Science and Technology, South Korea. Information Systems 32 (2007) 713-732.

Vereau. E. (2007). *My standard of evaluation summary SCAMPI*. vereau.org.

Wilkie, F. G. et al. (2007). *A low-overhead method for software process appraisal*. Journey of Software Process: Improvement and Practice. John Wiley & Sons, Inc. New York.