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Software Quality Journal

ISSN 0963-9314

Software Qual J
DOI 10.1007/
s11219-011-9154-7

Springer

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Abstract In the past years, both industrial and research communities in Software Engineering have shown special interest in Software Process Improvement—SPI. This is evidenced by the growing number of publications on the topic. The literature offers numerous quality frameworks for addressing SPI practices, which may be classified into two groups: ones that describe "what" should be done (ISO 9001, CMMI) and ones that describe "how" it should be done (Six Sigma, Goal Question Metrics-GQM). When organizations decide to adopt improvement initiatives, many models may be implied, each leveraging the best practices provided, in the quest to address the improvement challenges as well as possible. This may at the same time, however, generate confusion and overlapping activities, as well as extra effort and cost. That, in turn, risks generating a series of inefficiencies and redundancies that end up leading to losses rather than to effective process improvement. Consequently, it is important to move toward a harmonization of quality frameworks, aiming to identify intersections and overlapping parts, as well as to

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Published online: 21 July 2011

create a multi-model improvement solution. Our aim in this work is twofold: first of all, we propose a theoretical harmonization process that supports organizations interested in introducing quality management and software development practices or concerned about improving those they already have. This is done with specific reference to CMMI-DEV and ISO 9001 models in the direction "ISO to CMMI-DEV", showing how GQM is used to define operational goals that address ISO 9001 statements, reusable in CMMI appraisals. Secondly, we apply the theoretical comparison process to a real case, i.e., a Small Enterprise certified ISO 9001.

Keywords Harmonization · Mapping · SPI · Multi-model · CMMI-DEV · ISO 9001 · GQM

1 Introduction

The constantly changing market scenario, following the globalization and competition of international markets, has been motivating companies to move toward continuous innovation and improvement of processes and products. Consequently, quality management and SPI in general become of strategic importance, not only as internal improvement factors, but also as success factors once a company decides to face the global market and as it interacts with contractors, suppliers, and customers. In this situation, SPI efforts come about from the need to achieve competitive advantage with respect to customer satisfaction, business profitability, market share, product and service quality, cost reduction, and so on.

The literature offers numerous reference models, standards, best practices, and technologies for addressing software process improvement practices. In general, we can classify the frameworks into two groups: those that describe *what* should be done, as for example ISO 9001 (2000) and CMMI (SEI 2006), and those that describe *how* it should be done: Six Sigma, Team Software Process (Humphrey 2006), PMBOK (PMI 2009), GQM (Ardimento et al. 2004; Basili et al. 1994). These all offer unique features and address particular problems. In some cases, they are discipline-oriented; others relate to the enterprise as a whole. Moreover, when different approaches are combined, mapped, or harmonized, they can be classified as *what*/*what* or *what*/*how* combinations (Ferreira and Machado 2009). An example of a *what*/*what* combination is (Mutafelija and Stromber 2003), which maps CMMI and ISO, while a *what*/*how* combination is reported in (Hefner and Sturgeon 2002), which maps CMMI and Six Sigma. When organizations decide to adopt improvement initiatives related to different organizational functions and different hierarchical levels, many models may be involved. Each of these optimizes the best practices provided, in order to address the improvement challenges as well as possible. This may at the same time, however, generate confusion and overlapping activities, as well as extra effort and cost. That, in turn, risks generating a series of inefficiencies and redundancies that end up leading to losses rather than to effective process improvement. Consequently, it is important for an organization to have guidelines available that assist them in harmonizing quality frameworks, identifying intersections, and overlapping parts in order to develop a multi-model improvement solution.

A recent study (Violino 2005) has pointed out that more and more product development organizations are tending toward multi-certifications, with specific attention to ISO 9001, CMM, and ITIL technology standards. In (Paulk 2008), the author discusses how companies cannot just ignore the "quagmire" of standards and models that have been

published, even if they want to. Indeed, some of these have been explicitly requested by customers and by the market or imposed by statute or regulation. In Europe especially, interest in multi-certifications has increased. That is because in some sectors and in calls for bids on behalf of government institutions and public administrations, multi-certifications have become compulsory and are explicitly requested. Our work focuses on ISO and CMMI improvement frameworks. It has to be recognized that it is reasonable for an ISO-certified organization to have numerous doubts and questions such as: what should be done to assess CMMI maturity levels?; to what extent does the company already satisfy CMMI-DEV requirements?; should the company implement CMMI-DEV independently of ISO 9001?; are there any overlapping areas that allow reuse of information and data collected in the ISO certification for CMMI appraisals?

If an ISO 9001-certified organization wishes to have ongoing improvement of its processes, the adoption of CMMI would be a good choice, since this provides more detailed practices for process improvement than ISO 9001 (Yoo et al. 2006). However, it is important to note that compliance with ISO 9001 allows organizations to have more wide-ranging beneficial effects, ones which are beyond the scope of coverage afforded by CMMI. Although, ISO 9001 is a generic standard for quality management (and is therefore not directly concerned with software engineering best practices), it has been highly significant for the software industry, as it is more feasible to adopt (in cost and time) compared with other standards, especially for small companies (Pino et al. 2008).

Although the two constellations have been developed independently and have different purposes, they have intersections and connections with each other. It is therefore interesting to investigate how the models are related, which parts of the ISO standards are reusable, and how they can be used in the best way for a CMMI assessment. Analogous relations in the opposite direction, from CMMI to ISO, are also applicable.

Furthermore, given the present need to harmonize different improvement technologies; in this paper, we propose a harmonization process used to compare the ISO 9001 and CMMI-DEV models. The approach has been applied from two perspectives: theoretical and applicational. From the theoretical point of view, the two models have been analyzed and compared, based on the documents provided by the certification institutes (ISO 2000; SEI 2006). With the second perspective, the output of the theoretical comparison has been verified by applying it to a real case, i.e., an Italian SME that operates in the ICT sector. In this paper, the comparison will be described in the direction of from ISO 9001 to CMMI-DEV. It has been carried out considering the "shall" statements of the ISO 9001 standard and the specific practices of the CMMI-DEV model.

The goal of the work can therefore be summarized as follows:

Analyze ISO 9001 standard statements
For the purpose of comparing it
With respect to the degree of coverage and relationship with specific practices of CMMI in favouring reuse
From the viewpoint of management
In the context of product development organizations interested in multi-certifications with application to an ISO-certified SME

This work intends to support and guide a software organization in harmonizing, integrating, managing, and aligning its quality management and software development activities by using the ISO 9001 and CMMI-DEV models. In this sense, our contribution is twofold and can be formalized in two research questions that set out the research goal stated above in detail:

RQ1: to what extent are the practices described in the CMMI-DEV and ISO 9001 models related? (i.e., the *what*/*what* combination of ISO 9001 and CMMI-DEV v.1.2 models)
RQ2: how can a certified organization implement its quality model by using a GQM-based approach ? (i.e., the *what*/*how* perspective that integrates ISO 9001 and GQM and shows how measurement goals are defined to operationally address ISO statements that can be reused in a CMMI appraisal).

The harmonization between the two models has been performed in line with a harmonization process, which is part of a more general harmonization framework, proposed by the authors in (Pardo et al. 2010a). By executing this process, we have obtained a harmonization strategy that has three tasks it wishes to perform. First of all, it aims to carry out a theoretical comparison between both models. The second proposal is to define operational goals, based on the GQM approach, from ISO 9001 statements that can be reused in the CMMI-DEV-specific practices they are related to. Finally, the strategy proposes to apply the results of the mapping in a real case.

The rest of the paper is structured as follows. Section 2 provides a quick overview of the frameworks considered (ISO 9001:2000, CMMI-DEV v.1.2, GQM); Sect. 3 discusses open issues, taking as its perspective works which are related to, and which can be compared with, our proposal. In Sect. 4, the general harmonization framework is summarized. Section 5 provides a detailed description of the harmonization process, with insight into the progress from theoretical sub-processes to the application ones. Here, we show how the theoretical model has been applied to a real context. Among the various data collection and validation methods that the literature offers, grouped into three categories (observational, historical and controlled) by (Zelkowitz and Wallace 1998), we have chosen an observational method. In other words, we chose a case study, as it is the one that best suits the characteristics of our work. More precisely, data were collected over time as the steps of the application sub-process were carried out, which was consistent with the research goal of the study. An Italian ISO 9001-certified SME that was considering undergoing a CMMI appraisal. Before the actual assessment, we carried out the observational study, in which we applied the findings of the theoretical comparison to the company's QMS. The aim was to analyze to what extent the body of knowledge they had, related to ISO 9001, could be reused in CMMI. The paper concludes with a discussion of results and future work.

2 Reference models in pills

This section will provide some general and concise information to the reader on the three models that we have considered in our work.

2.1 ISO 9001:2000

ISO 9001:2000 is an international standard that gives requirements for an organization's Quality Management System ("QMS"). It is part of a family of standards published by the International Organisation for Standardisation-ISO, often referred to collectively as the "ISO 9000 series". For this reason, suppliers refer to being "ISO 9000 certified", or having an "ISO 9000-compliant QMS", meaning by this that they claim to have a QMS that meets the requirements of ISO 9001:2000, the only standard in the ISO 9000 family that can be used for the purpose of conformity assessment. It is important to understand, however, that ISO is the body that develops and publishes the standard—ISO does not itself "certify"

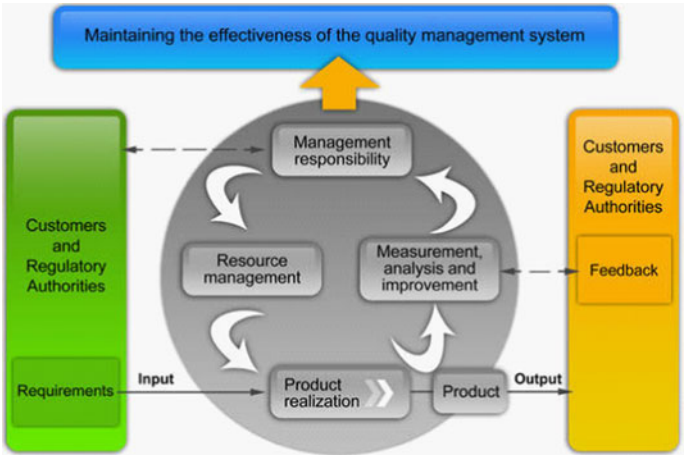


Fig. 1 Model of a process-based QMS

organizations. A process model based on the QMS is shown in Fig. 1. This model shows that customers play a significant role in defining requirements as inputs. Monitoring of customer satisfaction requires the evaluation of information on the customer's perception as to whether the organization has met the customer requirements.

The objective of ISO 9001:2000 is to provide a set of requirements which, if effectively implemented, will provide the organization with confidence that they can provide goods and services that meet needs and expectations and comply with applicable regulations. The requirements cover a wide range of topics, including the commitment to quality on the part of the supplier's top management, its customer focus, adequacy of its resources, and employee competence. Other issues included are process management (for production, service delivery and relevant administrative and support processes), quality planning, product design, review of incoming orders, monitoring of purchasing, measurement of its processes and products, and calibration of measuring equipment. Processes to resolve customer complaints, corrective/preventive actions, and a requirement to drive continual improvement of the QMS are covered too. A further version, the ISO 9001:2008, was released in 2008. It is worth noting that it does not introduce additional requirements if compared with the earlier edition in 2000; neither does it change the intent of ISO 9001:2000 (ISO Press 2008).

2.2 CMMI

Capability Maturity Model Integration (CMMI) is a process-improvement approach that provides organizations with the essential elements of effective processes that ultimately improve their performance. Developed by a group of experts from industry, government, and the Software Engineering Institute (SEI) at Carnegie Mellon University, CMMI models provide guidance for developing or improving processes that meet the business goals of an organization. CMMI can be used to guide process improvement throughout a project, a division, or an entire organization (Godfrey 2008).

CMMI currently addresses three areas of interest:

1. Product and service development—CMMI Development (CMMI-DEV),
2. Service establishment, management, and delivery—CMMI for Services (CMMI-SVC), and

LEVEL	CONTINUOUS REPRESENTATION Capability Levels	STAGED REPRESENTATION Maturity Levels
Level 0	Incomplete	N/A
Level 1	Performed	Initial
Level 2	Managed	Managed
Level 3	Defined	Defined
Level 4	Quantitatively Managed	Quantitatively Managed
Level 5	Optimizing	Optimizing

Fig. 2 Comparison of continuous and staged representation levels

3. Product and service acquisition—CMMI for Acquisition (CMMI-ACQ).

Although it originated in software engineering, its use has become much more generalized over the years, embracing other areas of interest. These include the development of hardware products, the delivery of all kinds of services, and the acquisition of products and services. This generalization of improvement concepts makes CMMI extremely abstract. CMMI is the successor of the capability maturity model (CMM) or Software CMM. The CMM was developed from 1987 until 1997. In 2002, CMMI Version 1.1 was released. Version 1.2 followed in August 2006, and version 1.3 in November 2010.

An organization cannot be certified in CMMI; instead, an organization is appraised. Appraisals are typically conducted for one or more of the following reasons: to determine how well the organization's processes compare to CMMI best practices and to identify areas where improvement can be made; to inform external customers and suppliers of how well the organization's processes compare to CMMI best practices; or to meet the contractual requirements of one or more customers.

Depending on the type of appraisal, the organization can be awarded a maturity level (Staged Representation) rating (1–5) or a capability level achievement profile (Continuous Representation). Figure 2 summarizes both representations in levels.

The continuous representation enables an organization to select a process area (or group of process areas), as well as to improve processes related to it. This representation uses capability levels to characterize improvement with respect to an individual process area. On the other hand, the staged representation uses predefined sets of process areas to define an improvement path for an organization. This improvement path is characterized by maturity levels. Each maturity level provides a set of process areas that characterize different types of organizational behavior.

2.3 Goal question metrics (GQM)

The main idea behind GQM is that measurement should be goal-oriented and based on context characterization.

According to (Ardimento et al. 2004; Basili et al. 1994), the measurement model has three levels (Fig. 3):

- Conceptual Level (GOAL): a goal is defined for a specific purpose based on the needs of the organization, for a variety of reasons, with respect to various quality models and from various points of view, in a particular environment.

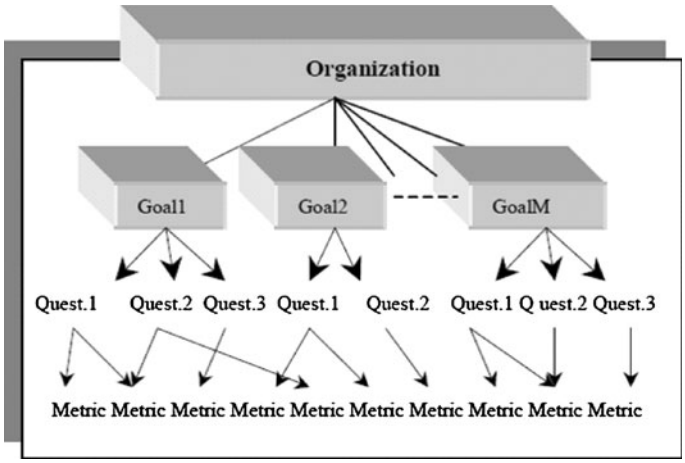


Fig. 3 Goal question metrics (GQM) structure

- Operational Level (QUESTION): a set of questions is used to characterize the way the achievement of a specific goal is going to be performed.
- Quantitative Level (METRIC): a set of collectable data is associated with each question, in order to answer them quantitatively.

The definition of a quality model with the GQM approach consists of a six-step process where the first three steps are about using business goals to drive the identification of the right metrics. The last three steps are about gathering the measurement data, interpreting it, and making effective use of the measurement results to drive decision making and improvements. More precisely, the six steps are described as follows:

1. GOAL: Develop a set of corporate, division and project business goals and associated measurement goals.
2. QUESTION: Generate questions (based on models) that define those goals as completely as possible in a quantifiable way.
3. METRICS: Specify the measures that need to be collected to answer those questions, as well as to track process and the product's conformance to the goals.
4. COLLECT: Develop mechanisms for data collection.
5. INTERPRET: Validate and analyze the data in real time to provide feedback to projects for corrective action. Thus, measurements are used to answer the questions and to conclude whether or not the goal is achieved.
6. CONCLUDE and IMPROVE: Analyze the data in a postmortem fashion, to assess conformance to the goals and to make recommendations for future improvements.

3 Open issues and related works

A main weakness in the current literature is that there are few detailed strategies for addressing the harmonization of multiple reference models operatively. Moreover, the few works that do face the topic do not present a straightforward replicable process, which is general enough to be applied to any reference model (Mutafelija and Stromber 2003, 2009; Siviy et al. 2008a).

The literature provides a wide range of models that can be taken as references for the improvement of an organization's processes, like models for: quality management improvement, such as ISO 9001; software quality management, such as CMMI, ISO 12207, and ISO 90003, IT governance, like ITIL, PMBOK, and COBIT; security management systems for example ISO 27000; or IT Service Management, as for instance, ISO 20000 and SWEBOK. Given their heterogeneity and differences, organizations have a wide selection of possible solutions to choose from for their specific problems and needs (Pardo et al. 2009, 2010a). This variability seems to be a positive aspect on the one hand, and on the other, it is onerous, given that each approach defines its own structure of process entities, definitions, and quality systems, which increases the complexity in the implementation of multi-models in a single organization. Organizations must, therefore, define the most appropriate means of choosing and implementing multi-models in this huge quantity, with inevitable effort and costs. But the question is "How can this be done?" Harmonization represents a solution toward working simultaneously with multiple models (Pardo et al. 2009). The multi-model environments in software process improvement are present when an organization decides or needs to integrate different practices or characteristics into its processes that are present in several models (Siviy et al. 2008b).

In the last 4 years, there has been an ever-increasing interest within the software engineering community in defining solutions for these types of environments. This is shown by initiatives and projects such as: the PrIME project (SEI 2010), ARMONÍAS project, (ARMONÍAS 2009), Enterprise SPICE (SPICE 2008). According to the systematic review described in (Pino et al. 2008, 2010b), the most frequently used assessment models in integration with other models are ISO/IEC 15504 or SPICE (about 18%), while the most common process reference models are CMM (13%), CMMI (25%), and ISO 9001 (18%). In most of the studies that involve these models, the way of achieving CMM or CMMI is analyzed, taking ISO 9001 as a basis. Although the major aim is to reuse parts of the ISO standards in a CMM or CMMI environment, it is difficult for an ISO-certified organization to implement CMMI easily, because of the differences in the language, structure, and details of the two sets of documents; see (Yoo et al. 2006).

There is a considerable amount of improvement frameworks that range across various domains, and there are applications that companies must inevitably deal with if they want to remain competitive in the market. To overcome the difficulty of understanding, comparing, and identifying the framework that best suits organizational needs, some authors have proposed classification taxonomies to guide users in the midst of the range of available models. In (Paulk 2008), the author proposes a classification that divides its ten attributes into 3 main categories. In (Ferreira et al. 2010), the authors extend the taxonomy by characterizing size and complexity measures and applying them to software best practice models: ISO 9001:2000, 15288, 12207, and CMMI-DEV. In (Halvorsen and Conradi 2001), the authors propose a SPI framework classification, consisting of 25 relevant characteristics, grouped into 5 categories, used to point out similarities and differences at a high level. Another work worth mentioning is Heston and Phifer (2011), where the authors consider six key industry standards. Their work is based on the observation that each standard has a "sweet spot" or a set of business issues for which it is well suited. They thus analyze the DNA of each model and identify 18 quality building blocks, called Q-Genes, which represent a high-level view of elements incorporated into the six reference models and standards considered.

Furthermore, the literature presents some works that involve comparisons and mappings between different versions of CMMI and other process models, including ISO 9001. Among these, some relate to *what/what* combinations, such as CMMI & ISO. A mapping

between two models is described in a more precise manner in Mutafelija and Stromber (2003) and Mutafelija and Stromber (2009), while Yoo et al. (2006) propose a model for integrating ISO 9001 and CMMI. A proposal for transiting from ISO 9001 to SW-CMM level 4, based on the experience of an organization, is illustrated in Jalote (1999). A comparison and correspondence between ISO 9001 and SW-CMM are shown in Paulk (1993, 1994, 1995). In Kitson et al. (2009), a comparative analysis of the CMMI-DEV v.1.2 and the ISO 9000 family is discussed, while an ontology for the integration of quality standards in ISO 9001:2000 and CMMI for collaborative projects is described in Ferchichi et al. (2008). Some works that involve relationships, comparisons, and mapping between different versions of CMM(I) and SPICE (ISO/IEC 15504) can be found in Siviy et al. (2008a), Lepasaar et al. (2002), Wangenheim and Thiry (2005), and Rout and Tuffley (2007). Finally, the PRIME project presents the value of harmonization process improvement in organizations when different models are in use (Siviy et al. 2008b, c).

It is worth noting that in most mapping/comparison studies, the procedures and steps are not described or explained. Moreover, most related comparison techniques do not adopt a comparison scale that allows us to establish a range for the relations identified between the models being compared. That being so, the comparison inevitably suffers from subjectivity. In the proposals that integrate or unify models, the steps followed for their integration are not shown. Consequently, the approach is not replicable from others. They are mostly theoretical works and none have been applied to real enterprise data. Furthermore, no insight is given on the *what*/*how* perspective. To the best of our knowledge, none of the studies adopts or indicates a strategy used for defining the measurement goals in an attempt to harmonize the models.

The contribution of the proposal described in this paper consists in taking into account and addressing the issues above, in order to provide organizations with a replicable stepwise strategy for harmonizing quality standards.

We have carried out a comparison between the following versions of models: ISO 9001:2000 and CMMI-DEV v1.2. After formalizing and carrying out the theoretical comparison (theoretical sub-process), we carried out a case study and applied it to real data of an Italian SME (application sub-process). Details and results are presented in the next sections. For the development of our comparison, we have followed a well-defined process, similar to the one defined and adopted in other comparisons carried out by the authors with respect to other SPI improvement frameworks: ISO 12207–CMMI-ACQ in Pino et al. (2009a), ISO/IEC 15504–15507–CMMI-DEV in Pino et al. (2010), and ISO 12207–CMMI-DEV in Pino et al. (2009b).

4 Harmonization framework

As pointed out in Siviy et al. (2008a), the efforts performed by organizations with respect to multi-model environments do not follow a well-defined harmonization structure, on *what to do* and *how to do it*. In this work, we present a strategy that guides the harmonization of multiple process reference models through a systematic stepwise approach, general enough to be applied to any reference models that are being taken into account. This strategy can help organizations to improve and harmonize not only software processes but also management, IT governance, and security ones. It has been obtained after carrying out the process and the framework for supporting multi-model harmonization proposed by Pardo et al. (2010a), presented in Fig. 4.

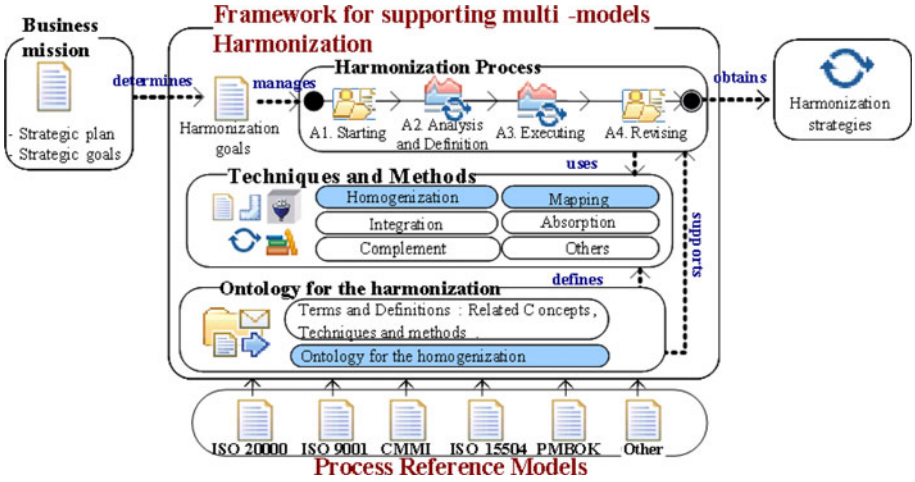


Fig. 4 Harmonization framework

In general, the harmonization framework defines as follows: (1) A guideline for determining the harmonization goals, based on the strategic plan and goals defined in the organization's mission; (2) A harmonization process for driving multi-model harmonization, with which to manage and lead the harmonization of models step by step; (3) A harmonization ontology, which presents the terms, concepts and relationships for supporting the harmonization models, and (4) A Set of Techniques and Methods, which facilitates the configuration and definition of the harmonization strategies. The harmonization strategy is the work product resulting from the implementation of the harmonization process. Given the goal of this paper, we will focus on the harmonization process that we propose for harmonizing different models and which is described in the next section.

5 Harmonization process

Organizations with a defined SPI strategy will most likely follow it to assess and assure quality. Furthermore, their business, organizational and production processes will probably be either modeled formally according to SPI frameworks (CMMI; ISO, TQM, SPIQ, etc.) (Halvorsen and Conradi 2001; Paulk 2008) or defined informally, based on the previous history and experience collected within the organization itself. Independently of the framework adopted, the description of organizational processes contains details on: activities, procedures, products produced, relationships with other activities, tools, and technologies used to execute them, as well as the quality model (i.e., goals, metrics and interpretations) defined to assess the achievement of desired quality levels. In this sense, an organization's quality model must be structured so that its goals (G_i) relate to specific process model grains (P_j) specified by the SPI framework referred to (e.g., Process areas for CMMI, statements for ISO 9001, etc.), forming a matrix [$G \times P$] (Table 1) where each crossing (G_i, P_j) means that the goal G_i measures that process-specific grain P_j.(Ardimento et al. 2004).

In this scenario it is reasonable for an organization with a specific SPI strategy to want to, or have to, conform to other frameworks, due to explicit requests on behalf of

Table 1 Goal × process model matrix

Goals	Process grain				
	P_1	P_2	P_j	…	P_n
G_1	×				
G_2		×			
G_i			×		×
…					
G_k	×		×		

contractors, public administrations or because of restrictions in bids. For the sake of simplicity, let us define the process model of the current SPI framework applied in the organization as P_{Current}, and the process model of the new SPI framework the organization wants to address as P_{Target}. An interesting question is therefore:

- how can an organization shift painlessly from P_{Current} to P_{Target} and reuse as much of the information produced in P_{Current} as possible?
- given an SPI framework (e.g., ISO or CMMI), how can an organization operationally define a quality model (i.e., measurement goals and interpretation models) for it?

To answer both these questions, which address the two research questions related to the goal of the paper as set out in the introduction, we have defined a harmonization process that is made up of two sub-processes: theoretical comparison process and application process. A general overview is given in Fig. 5. In the next two sections, we will provide a description for each part, pointing out the results of the theoretical comparison in the first case, and the application of the comparison to a real ISO-certified company, in the second.

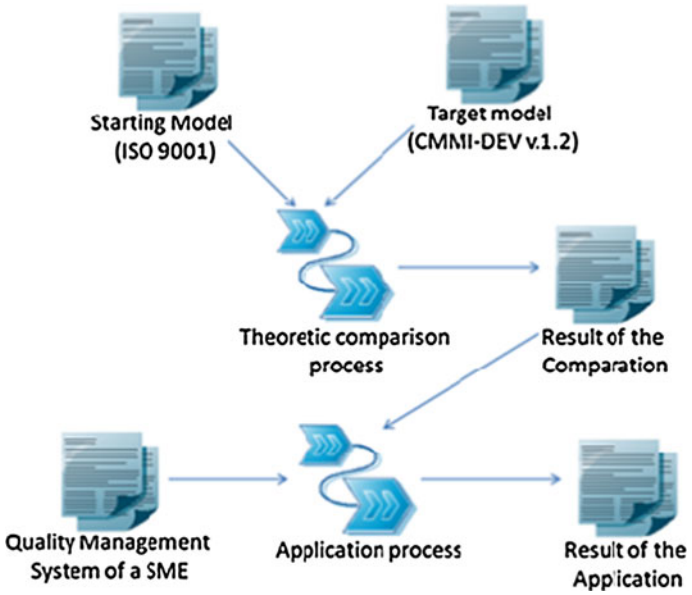


Fig. 5 Harmonization process

It is worth noting that the process is general and can be instantiated to any couple of SPI frameworks (P_{Current}, P_{Target}). In this specific work, we have considered P_{Current}: ISO 9001:2000 and P_{Target}: CMMI-Dev v.1.2.

5.1 Theoretical comparison sub-process

Mapping is one of the most widely used strategies for the harmonization of models. Based on previous studies carried out by the authors of this paper (Baldassarre et al. 2010a, b), and on work carried out in literature, mentioned in the related work section, we have defined a theoretical comparison process (Fig. 6) (Pino et al. 2010) that can be applied to map quality certifications. The purpose of this process is to provide a guideline for performing a step-by-step comparison and mapping of different models, aiming to guarantee the reliability of results obtained. We refer to it as a theoretical process, in that it is general enough to be used to compare and map any quality models and because it is applied using the documents released by the certification institutes (e.g., SEI for the CMMI constellation, ISO for the ISO Family, ICMB for the ITIL certification, and so on.). For instance, this process has been used for other comparisons carried out: ISO 12207–CMMI-ACQ in Pino et al. (2009a), ISO 12207–CMMI-DEV in Pino et al. (2009b), and ISO/IEC 15504–15507–CMMI-DEV in Pino et al. (2010).

In this section, we describe the theoretical comparison process, with specific reference to ISO 9001 and CMMI-DEV models, in the direction "ISO to CMMI-DEV".

First of all, the documents (artifacts) used as input to the sub-process must be identified. In this specific case, the theoretical comparison sub-process considers the ISO 9001:2000 standard as Starting Model, i.e., supposing that an enterprise is certified ISO 9001, and sees CMMI v1.2 as the Target Model. The outcome of the theoretical sub-process is a document (*Result of Comparison*) that maps the two models and points out the relationships between them. In this case, we are talking about the extent to which ISO satisfies CMMI requirements and whether there are any overlapping areas that may allow a reuse of information and data collected in the ISO certification to assess any of the CMMI levels,

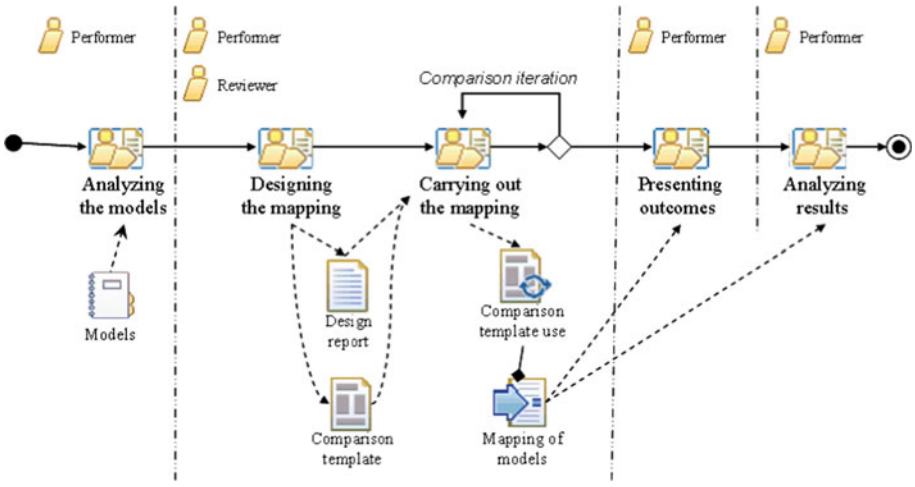


Fig. 6 Detailed representation of the comparison process

enabling there to be a quantitative analysis (*what/what relation*). In order to organize and manage the people and activities involved in the comparison, we have followed the process shown in Fig. 6 and assigned two roles: the performers and the reviewers. A performer is a person responsible for the analysis of models, who implements the harmonization techniques. This person must be able to analyze the models, as well as relate them to each other and make comparisons between them. On the other hand, a reviewer is a person responsible for guiding the implementation of the harmonization process activities. He/she has the qualities of leadership and management.

In the next paragraphs, we describe each step, together with each role involved, and we comment on the outcomes of the comparison with reference to the two models being considered.

5.1.1 Analyze the models

This task involves: (1) acquiring knowledge about the selected models (ISO 9001:2000 as the starting model, CMMI-DEV v.1.2 as the target one) and (2) analyzing the structure and fixing the abstraction level to consider, based on the information extracted from the official documents.

In our specific case, in the ISO 9001 standard, the selected level of detail was the "shall statement", i.e., the phrase that identifies a requirement that the QMS must fulfill. An example of "shall statement" is "The organization shall establish, document, implement and maintain a quality management system and continually improve its effectiveness in accordance with" (cap 4.1 General Requirement). This choice is due to the fact that, in order to be certified, an organization must assure that all of the requirements are defined and applied in their QMS (and therefore documented in their quality manual). In CMMI, we refer to specific practices or generic practices, since the definitions of the process areas, as well as the goals for each process area, are too generic.

For each model, we chose the entities defined in each standard that were comparable at the same level of abstraction not too detailed, which would increase the risk of losing focus on the goal of the work, but at the same time not too general, which would entail the risk of obtaining weak relations.

5.1.2 Design the mapping

This step involves: (1) establishing the process entities to be compared, based on the research needs pointed out in the previous step, (2) fixing the direction of the comparison, (3) defining the comparison scale, and (4) defining a comparison template.

In our case: (1) the process entities for the comparison are the *shall* statements of the ISO 9001 standard and the *specific practices* of CMMI-DEV and (2) the direction of the comparison is from ISO 9001 to CMMI-DEV. A discussion on the relevance of defining the direction of the comparison when that involves process entities of low level abstraction is presented in Pino et al. (2009a). (3) In order to express the degree of relationship between an ISO 9001 Process and a CMMI-DEV Process Area, we have defined a discrete scale (scale of comparison). Each of the elements of the scale has been associated with a set of numeric values that are described in terms of percentage. This scale is made up of the following elements:

- Strongly (*S*) related (86–100%): there is a direct connection between the two entities; they have common aims, and the application methods are the same;

- Largely (*L*) related (51–85%): the two entities have many concepts in common and many of them have the same application methods;
- Partially (*P*) related (16–50%): there is a relationship between the two entities, but there are no formal applications specified;
- Weakly (*W*) related (1–15%): some kind of fragmented relation is perceivable between the two entities.
- Non-related (*N*) (0%): no relationship can be identified.

The numeric values are obtained by dividing the number of specific practices (from a process area of CMMI) that are related to statements (in ISO 9001:2000) by the total number of specific practices defined in that process area.

5.1.3 Carry out the mapping

In this step, the comparison is performed through an iterative and incremental procedure. To be specific, the process is iterative, because the comparison (analysis and determination of the relationship between the ISO 9001 and CMMI-DEV process entities) is executed completely on one CMMI-DEV process area first, and then on the others in turn. It is also incremental, in the sense that the comparison outcome (i.e., the final product of the theoretical comparison process) grows and evolves with each iteration until it becomes the final one. Using this, iterative and incremental approach has enabled us to deal with the complexity entailed in a comparison in which entities of low-level abstraction are involved. The roles involved in the comparison were three people as performers and two reviewers. For each process area, the three performers carried out the comparison by mapping ISO statements to CMMI-specific practices. They worked individually. Next, at the end of each iteration, performers met and brought their work together, to merge their individual results into a single version. Here, reviewers had discussions with the performers, aiming to solve any discrepancies between them in the quest to come up with the final comparison results.

The mapping is tracked on a spreadsheet that displays the ISO statements as rows and the CMMI-DEV process areas with detailed Practices as columns (see Table 2). Operatively: given a "shall statement", we have taken into account the related process areas based on the introductory notes of each process area, as well as the objectives that it aims to reach (Generic Goal and Specific Goal). This first selection is needed to narrow the scope for each "shall" statement. After that, each ISO 9001 entity was compared with the generic and specific practices of the selected process areas, keeping in mind the main goal of the ISO statement with respect to the CMMI practices. The strength of the relationship was then rated according to the scale specified previously. As one can imagine, the process can be generalized to any entities of models being compared and mapped.

5.1.4 Present the outcomes

The outcome of the mapping is a document (Result of Comparison), made up of two parts that specify the correlations between the two models considered according to a general view and then to a more specific one. The first part of the results shows the intersections of the ISO 9001 statements with the CMMI process areas, together with their degree of relation (Table 2). The degree of relationship indicates the extent to which an ISO 9001 statement supports or has any connection with a CMMI process area; the second part shows in more detail how the ISO "shall" statements relate to each CMMI-specific practice, and

Table 2 Overview of the comparison between ISO 9001 and CMMI-DEV 1.2

Direction of the comparison:
From ISO 9001 to CMMI
Process entities for the comparison:
For ISO 9001: Statements shall of the standard.
For CMMI: Specific practices
Research question:
What ISO 9001's statements can offer support to specific practices of CMMI? What ISO 9001's statements are closely related with the support to CMMI's specific practices?
Comparison goal:
To determine which statements (shall) of ISO 9001 have a close relationship with some specific practice of CMMI. The goal is know which is the degree of fulfilment of the specific practices of CMMI based on the statements described in ISO 9001.
Scale of comparison:
- *S - Strongly related (86% to 100%)*
- *L - Largely related (51% to 85%)*
- *P - Partially related (16% to 50%)*
- *W - Weakly related (1% to 15%)*
- *- Non-related (0%)*

		Process Areas of CMMI-DEV																			
		CONFIGURATION MANAGEMENT	PROJECT MONITORING AND CONTROL	SUPPLIER AGREEMENT MANAGEMENT	REQUIREMENTS MANAGEMENT	PROJECT PLANNING	PROCESS AND PRODUCT QUALITY ASSURANCE	MEASUREMENT AND ANALYSIS	INTEGRATED PROJECT MANAGEMENT +IPPD	ORGANIZATIONAL TRAINING	VALIDATION	VERIFICATION	TECHNICAL SOLUTION	REQUIREMENTS DEVELOPMENT	ORGANIZATIONAL PROCESS FOCUS	ORGANIZATIONAL PROCESS DEFINITION +IPPD	PRODUCT INTEGRATION	QUANTITATIVE PROJECT MANAGEMENT	ORGANIZATIONAL PROCESS PERFORMANCE	CAUSAL ANALYSIS AND RESOLUTION
Level		2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4	4	5
Degree of coverage		P	P	P	L	P	P	P	P	L	L	P	W	L	L	P	W	P	P	L
Statement ISO 9001:2000	4 Quality managementsystem																			
	4.1 General requirements			W											P	P				
	4.2 Documentation requirements																			
	4.2.1 General														W	W				
	4.2.2 Quality manual														W	P				
	4.2.3 Control of documents																			
	4.2.4 Control of records																			
	5 Management responsibility																			
	5.1 Management commitment																			
	5.2 Customer focus										P			W						
	5.3 Quality policy														W	W				
	5.4 Planning																			
	5.4.1 Quality objectives																	W	P	
	5.4.2 Quality management system planning																			
	5.5 Responsibility, authority and communication																			
	5.5.1 Responsibility and authority																			
	5.5.2 Management representative																			
	5.5.3 Internal communication								W											
	5.6 Management review																			
	5.6.1 General														P					
	5.6.2 Review input																			
	5.6.3 Review output																			
	6 Resource management																			
	6.1 Provision of resources																			
	6.2 Human resources																			
	6.2.1 General																			
	6.2.2 Competence, awareness and training					W				L										
	6.3 Infrastructure								W											
	6.4 Work environment								W							W				
	7 Product realization																			
	7.1 Planning of product realization					P								W		W		W		
	7.2 Customer-related processes																			
	7.2.1 Determination of requirements related to the product													P						
	7.2.2 Review of requirements related to the product				P									W						
	7.2.3 Customer communication								W											
	7.3 Design and development																			
	7.3.1 Design and development planning					W			W		P	W								
	7.3.2 Design and development inputs													P						
	7.3.3 Design and development outputs								W				W							
	7.3.4 Design and development review		P																	
	7.3.5 Design and development verification											W								
	7.3.6 Design and development validation										P									
	7.3.7 Control of design and development changes	P																		
	7.4 Purchasing																			
	7.4.1 Purchasing process			P																
	7.4.2 Purchasing information													W						
	7.4.3 Verification of purchased product			P								W								
	7.5 Production and service provision																			
	7.5.1 Control of production and service provision																			
	7.5.2 Validation of processes for production and service provision						P				L									
	7.5.3 Identification and traceability	W																		
	7.5.4 Customer property																			
	7.5.5 Preservation of product																W			
	7.6 Control of monitoring and measuring devices																			
	8 Measurement, analysis and improvement																			
	8.1 General																			
	8.2 Monitoring and measurement																			
	8.2.1 Customer satisfaction																			
	8.2.2 Internal audit						P								P					
	8.2.3 Monitoring and measurement of processes		W															W		
	8.2.4 Monitoring and measurement of product										P	P								
	8.3 Control of nonconforming product		W		P															
	8.4 Analysis of data							P							W					
	8.5 Improvement																			
	8.5.1 Continual improvement														P					
	8.5.2 Corrective action		P																	
	8.5.3 Preventive action																			L

Table 3 Detailed view of the relationship between ISO 9001 statements and specific practices of the CMMI "organizational process definition + IPPD process area"

	CMMI capability level	3		
		SP 1.1 establish standard processes	SP 1.2 establish lifecycle model descriptions	SP 1.6 establish work environment standards
	Relationship degree	*P* (partially) 33%		
4. Quality management system				
4.1 General requirements		*P* (22%)		
4.2 Documentation requirements	4.2.1 General		*W* (11%)	
	4.2. 2 Quality manual	*P* (22%)		
5. Management responsibility				
5.3 Quality policy		*W* (11%)		
6. Resource management				
6.4 Work environment				*W* (11%)
7. Product realization				
7.1 Planning of product realization		*W* (11%)		

it also specifies the degree of the relationship with respect to each statement, as well as to the entire process area. Of course, the non-related areas not marked in Table 1 are not taken into consideration in the second part. As example, we have reported the results of the second part for the CMMI process area "organizational process definition + IPPD" (Table 3). A detailed presentation of the results for all the CMMI process areas can be found in Baldassarre et al. (2010c, pp. 46–57).

5.1.5 Analyze the results

Tables 2 and 3 show the relationships between the two models compared. Figure 7 outlines a general picture of the coverage of ISO statements with respect to each CMMI process areas for all maturity levels, expressed as a percentage, based on the results of the mapping carried out.

The results show that the ISO 9001 standard covers most of the CMMI-DEV practices only partially. That being the case, an organization that is ISO 9001-certified, interested in appraising, for example, a CMMI maturity level 2 (white bars in Fig. 7) must focus its effort on: planning processes that define project activities (Project Planning) and on developing and enacting measurement and control practices as support to information management (Measurement and Analysis). It must also center its efforts on controlling the integrity of final or intermediate products continuously, through configuration management (Configuration Management). The other process areas needed for the appraisal have a general coverage of about 50%. The reader should keep in mind, though, that this does not necessarily mean that half of the practices are covered. It is rather that an ISO 9001-certified organization will most likely already have enough documentation to recognize half of the practices required.

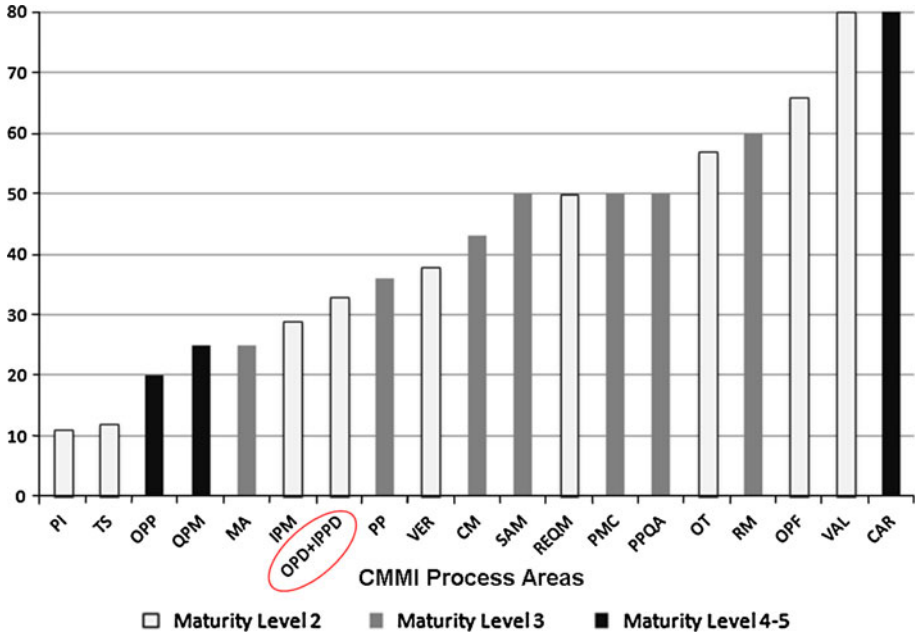


Fig. 7 Coverage and potential reuse in percentage of ISO 9001 with respect to CMMI-DEV process areas

If an organization were to choose a continuous representation, the process areas covered most would be those related to planning, implementation, and development of improvements in organizational processes (Organizational Process Focus). As well as these areas, product and component requirements validation (Validation), development of abilities and knowledge (Organizational Training), management of process and product requirements, and identification of inconsistencies (Requirement Management) are among the areas with most coverage, as are identification of the problems and corrective actions to enact (Causal Analysis and Resolution). These are the process areas covered most by the ISO standard, where the coverage is around 60%. Note that, although the degree of coverage is higher than for the previous areas, the nature of the comparison does not assure the actual coverage of the practices, which inevitably depends on how each organization defines and executes its activities. This aspect is faced in the application sub-process, where the results of the theoretical comparison sub-process are applied to a real case, described in the next section.

5.2 Application sub-process

If, on the one hand, the comparison sub-process points out the overlapping common areas between the two SPI frameworks, and therefore provides a *what/what* perspective, instantiated in this case on ISO 9001 and CMMI, on the other, the application sub-process applies the comparison results to a specific organization's quality management system (QMS).

Indeed, if an organization that is, let's say, ISO 9001 certified, intends addressing CMMI, it would be worth investigating what part of the data and information collected with the ISO standard could be reused for a CMMI appraisal (Yoo et al. 2006). In our proposal, this is done by formalizing a GQM-based quality model and then, according to

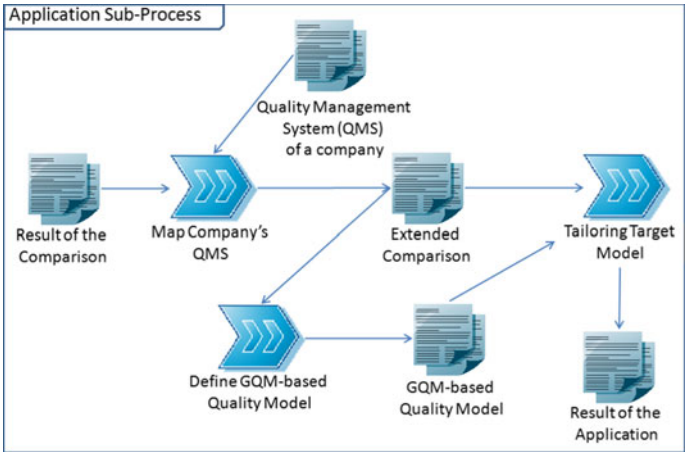


Fig. 8 Application sub-process

the overlapping areas, reusing the data/information related to the intersections. To be more specific, this part of the harmonization process addresses the second aspect of the research goal and defines how to structure a quality model through operational goals, based on the mapping results and in accordance with the organization's QMS. It therefore refers to a *what/how* perspective, where ISO 9001:2000 provides "what" to do and GQM provides "how" to do it.

The detailed steps of the application sub-process are represented in Fig. 8.

In the following lines, we will describe each of the three steps that make up the sub-process and comment on their application to the data of an Italian SME through a case study. The company involved in the application operates in the ICT sector and, for reasons of confidentiality, it will be referred to as SME. It is ISO 9001:2000-certified, apart from having other certifications of the ISO family. The company allowed us to access their entire QMS, structured in conformance to the chapters of the standard. The company was considering undergoing a CMMI appraisal. So, before the actual assessment, we carried out an observational study in which we applied the findings of the theoretical comparison to the company's QMS. The aim was to analyze to what extent they could reuse any of their ISO 9001 data for the CMMI appraisal.

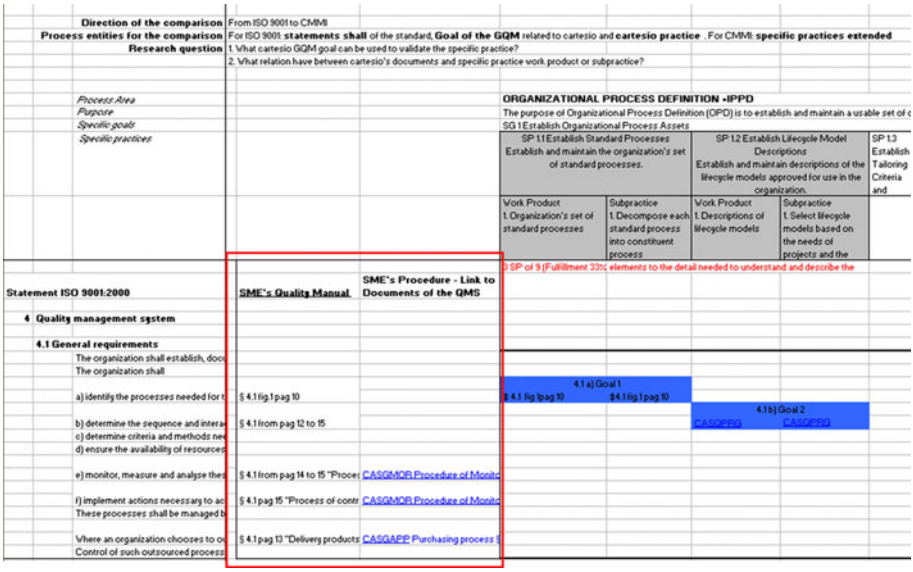
5.2.1 Map company's QMS

This step starts from the outcome of the sub-process of the theoretical comparison, i.e., the theoretical mapping of the two frameworks. Moreover, it consists in extracting the relevant documents from the QMS, based on the relationships pointed out in the general comparison. The aim is to identify the specific documents, procedures, guidelines, templates, and operational instructions that can be used in the future CMMI-DEV quality model.

The result of this step is an extension of the comparison (Extended Comparison), which not only contains the mapping of the two SPI frameworks, ISO 9001 and CMMI, in Tables 2 and 3. As well as this, and with respect to each relation identified, it also specifies the documents of the QMS explicitly. An example is shown in Table 4.

The two columns added are as follows: *SME's QMS*, which contains the references to the paragraphs of the QMS and *SME's Procedures*, which refers to the procedures, through

Table 4 Extract of extended comparison



links. This was done for each ISO statement that had a relationship with a CMMI process area (i.e., shaded areas traced during the theoretical sub-process). This step is important because the references can be reused when the SME decides to shift to the target SPI framework, i.e., CMMI, and must define the target quality model. The question this step answers is "How are the ISO 9001 statements, which are mapped with CMMI specific practices, traced in the SME's Quality Manual and other procedures?"

5.2.2 Define GQM-based quality model

The second step of the sub-process consists in defining a quality model. This is done by adopting a GQM-based approach (Ardimento et al. 2004; Basili et al. 1994), according to the output of the previous step. In particular, the task is to analyze the QMS documentation traced in the extended comparison in depth and define measurement goals based on the areas mapped. The quality model produced allows us to measure the organization's processes quantitatively with respect to the areas mapped.

This step provides insight on the *what*/*how* perspective mentioned in the previous sections, in that it shows us how to produce a quality model operatively by instantiating ISO 9001 statements (*what to do*) through GQM measurement goals (*how to do it*).

The result of this step is a matrix like the one in Table 1, where the process P_{Current} is ISO 9001, and the process grains are the ISO statements, while the Goals are the GQM measurement goals related to each statement. In Table 5, we show an example of a measurement goal, with questions and metrics defined for the ISO Shall Statement n.4.1. In our application case study, the procedure was iterated for each statement of the framework to obtain a complete quality model for all the ISO statements. The question this step answers is "Given an ISO Statement, how can the related SME's QMS and Procedures be measured through operational GQM goals?"

Table 5 Goal for ISO shall statement 4.1

Statement ISO 9001:2001		4.1 General requirements (a) identify the processes needed for the quality management system and their application throughout the organization Goal 1
Object of study		Management manual (quality management system)
Purpose		Evaluate
Quality focus		Defined processes' correctness
Point of view		Management
Context		Italian SME
Question	Metric	Description
Q 1.1	M 1.1.1	List of processes expected for the quality management system
Q 1.2	M 1.2.1	List of processes for the quality management system actually executed
Q 1.3	M 1.3.1	Level of adhesion of defined processes to the standard normative
Q 1.4	M 1.4.1	Level of completeness of defined processes for the quality management system
Q 1.5	M 1.5.1	Level expected of adhesion of defined processes to the standard normative
Q 1.6	M 1.6.1	Level expected of defined processes for quality management system

This information is then used to evaluate the degree of coverage of the CMMI practices with respect to each "shall statement".

5.2.3 Tailoring toward the target model

The last step of the sub-process collects the results of the previous steps and organizes them according to the CMMI-DEV practices. It consists in identifying to what extent the CMMI-DEV process areas are covered by the ISO statements, based on the measurement goals (GQM-Based QM) defined in the previous step and the mapping applied to the SME (Extended Comparison). Given a process area (e.g., organizational process definition + IPPD), the goals that relate to that process area are identified. These goals are extracted from the previous step, based on the mapping results with the ISO Statements. Next, a similar activity is done with respect to the work products and sub-practices of the process area considered. In other words, for each work product and sub-practice, we evaluate their degree of coverage with respect to the SME's QMS. Table 6 reports the result of the step with respect to the organizational process definition + IPPD process area. For each specific practice, the goals of the ISO quality model that can be reused in CMMI assessment are specified; for each work product and sub-practice, the coverage is highlighted in shaded tones, together with a specification of the document in the SME's QMS. Furthermore, the degree of coverage (completeness) of the goals, work products, and sub-practices with respect to each Specific Practice and the entire process area are also shown. The application process is incremental and iterative, as with the theoretical comparison, in that it is applied to each process area, one at a time.

In this way, we assure that the migration toward the target model (P_{target}), CMMI, reuses as much as possible of what is already defined in the current model ($P_{current}$). This time, the step produces a matrix like the one in Table 1, where the process grains are the specific practices of the CMMI process areas and the goals are the GQM-based measurement goals reused from the quality model defined in the previous step.

Table 6 Coverage of CMMI process area from ISO statements

Process Area	**ORGANIZATIONAL PROCESS DEFINITION +IPPD**											
Purpose	The purpose of Organizational Process Definition (OPD) is to establish and maintain a usable set of organizational process assets and work environment standards.											
Specific goals	SG 1 Establish Organizational Process Assets									SG 2 Enable IPPD Management		
Specific practices	SP 1.1 Establish Standard Processes Establish and maintain the organization's set of standard processes.		SP 1.2 Establish Lifecycle Model Descriptions Establish and maintain descriptions of the lifecycle models approved for		SP 1.3 Establish Tailoring Criteria	SP 1.4 Establish the Organiza	SP 1.5 Establish the Organizat	SP 1.6 Establish Work Environment Standards Establish and maintain work environment standards.		SP 2.1 Establish Empowermen t Mechanisms	SP 2.2 Establish Rules and	SP 2.3 Balance Team and
	Work Product 1. Organization's set of standard processes	Subpractice 1. Decompose each standard process into	Work Product 1. Descriptions of lifecycle models	Subpractice 1. Select lifecycle models based on the needs of				Work Product 1. Tailoring guidelines for the	Subpractice 1. Specify the selection criteria and procedures for tailoring the			
Statement	4.1 a) Goal 1 4.2.1 d) Goal 7 4.2.2 b) Goal 8 5.3 a) Goal 2 5.3 e) Goal 4 7.1 the Goal 1 7.1 Planning Goal 2		4.1 b) Goal 2					6.4 Goal 6				
Work Product	1. Organization's	§ 4.1 fig.1pag	1. Descriptions of	CASQPRG				1. Tailoring guidel				
Subpractice	1. Decompose each 2. Specify the critica 3. Specify the relatic 4. Ensure that the or 5. Ensure that the or 6. Ensure that there 7. Document the orgi 8. Conduct peer rev 9. Revise the organi	§ 4.2.1 fig. 2 §4.1 fig.1 pag 10 §4.1 fig.1 pag 10 §4.1 fig.1 pag 10 CASQMOR CASQMOR	1. Select lifecycle 2. Document the d 3. Conduct peer re 4. Revise the desi	CASQPRG CASQPRG				1. Specify the se 2. Specify the sta 3. Specify the 4. Document the 5. Conduct peer t 6. Revise the tailo				
Specific Practice Goal completeness	S(86%)		W(10%)					L(80%)				
Specific Practice Work Product and Subpractice completeness	S(100%)	L(66%)	S(100%)	W(50%)				N(0%)	N(0%)			
Completeness	P(19%)											
Process Area Work Product Completeness	P(22%)											
Process Area Subpractice Completenesses	W(12%)											

The matrix of the target model is obtained as follows: $[G \times P_{\text{target}}] = [G \times P_{\text{current}}] \times [P_{\text{current}} \times P_{\text{target}}]$, where $[G \times P_{\text{current}}]$ is the set of goals for each ISO statement, and $[P_{\text{current}} \times P_{\text{target}}]$ is the mapping between ISO and CMMI. In our application, the completeness of the target model matrix indicates the degree of coverage and therefore of potential reuse, of the CMMI-DEV with respect to ISO. With reference to Table 6, we can see that the completeness of the process area goal, work product, and sub-practice is of 19, 22, and 12%, respectively. Although the matrix is not complete for the areas that are not mapped and for those that are not related, it assures that the existing quality model is reused as much as possible.

For reasons of space, we are not able to show the results of every single process area. The detailed results with respect to each process area can be consulted in Baldassarre et al. (2010c, p. 81). The overall results of the application process on the Italian SME are displayed in Fig. 9.

The results are shown with respect to the comparison sub-process, which represents the theoretical mapping of the two SPI frameworks, and to the application sub-process, where the comparison was applied to the QMS of a real enterprise.

As can be seen, the percentages related to the process areas in the application sub-process are lower than the ones defined in the comparison. This was predictable, because the application not only considers the theoretical comparison, but also how it is actually accomplished within the enterprise. These results relate to the QMS of the Italian SME considered and therefore represent a first application of the harmonization process in the direction from ISO to CMMI.

6 Conclusions and future work

The growing attention of the software engineering community toward improvement practices, as well as the range of improvement frameworks, has motivated our work, on the

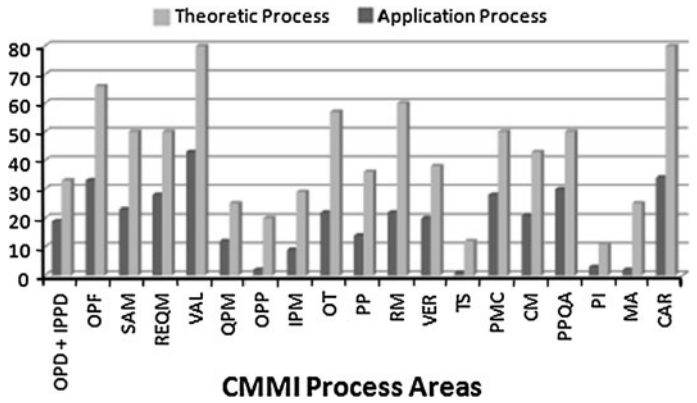


Fig. 9 Degree of coverage in percentage of CMMI process areas with respect to theoretical and application sub-processes

one hand. On the other hand, the lack of methods, techniques, or guidelines that guide organizations operatively in implementing and managing reference models for software process improvement has also been a motivating factor.

In this paper, we have presented a stepwise harmonization process for mapping quality models. The process is general and can be applied to any couple of process reference models. In this case, the harmonization has been undertaken with respect to establishing a relationship between ISO 9001:2000 and CMMI-DEV v.1.2. In addition, we defined a theoretical comparison sub-process between ISO 9001:2000 statements and CMMI-DEV process areas (RQ1) and then, through the application sub-process steps, we applied the results of the theoretical comparison to the QMS of an ISO-certified organization (RQ2).

The harmonization process taken together as a whole can help an organization to: (1) understand both the differentiating and the overlapping features of the improvement models, (2) determine and understand which of these improvement models can support the organization's mission, and (3) carry out an analysis before transiting to a new quality standard, given the amount of parts, documentation, processes, or existing resources that can potentially be reused in the best of ways for the new target model.

The contribution of our proposal is that first of all, we give a detailed presentation of the stepwise process carried out for the mapping that highlights the overlapping parts between the models. This is general and can be replicable and instantiated to any couple of improvement frameworks. Then, we show how GQM is used to define operational goals that address ISO 9001 statements, reusable for CMMI appraisals. The theoretical mapping is then applied in a case study on real industrial data, to provide insight into the actual coverage and reusable parts.

The well-defined step-by-step process has helped us organize and manage the work performed for the mapping, with the aim of reducing the two types of errors in the comparisons described by Yoo et al. (2006): error type I, which occurs when common parts between models are classified as new parts, and thus, the number of reusable parts decreases; and error type II, which occurs when a false correspondence is considered valid, with the risk of omitting items that should be implemented. The harmonization process avoids these particular errors, firstly because the *Result of Comparison* document, i.e., spreadsheet of the mapping results (Tables 2, 3) highlights the relationship between each

ISO statement and the CMMI-specific practices with respect to each process area. The aforementioned errors do not occur, secondly, because the theoretical comparison is verified and checked against real data (application sub-process) where, for each correspondence traced in the theoretical sub-process, identified by a shaded area and degree of coverage, the reference to the QMS documents is provided (Table 4).

Furthermore, the iterative and incremental harmonization process applied to ISO 9001:2000 and CMMI-DEV reference models has led to the following advantages:

- The performing of the mapping starts with a process area, to reduce the complexity and scope of each iteration;
- Each iteration of the mapping is short and provides feedback for the next iteration;
- There is an integration of the results of each iteration into the final report:
- With the design of the mapping the iterations can be carried out both independently and in parallel;
- The complexity of each iteration is easier to manage.

Taking into account the processes of ISO 9001:2000 and their relationship with process areas of CMMI-DEV, we can observe that there is (1) strong coverage with none of the process areas; (2) large coverage of CAR, VAL, OPF, RM, and OT; (3) partial coverage of PPQA, PMC, REQM, SAM, CM, VER, PP, OPD + IIPD, IPM, MA, QPM, and OPP; and (4) weak coverage of PI and TS. It is important to highlight that a strong degree of coverage (or relationship) does not mean that a process area of CMMI-DEV is satisfied. It only indicates that most of the specific practices of this process area are connected to the processes of ISO 9001:2000.

An observational method, consisting of a case study, has been carried out to apply the theoretical comparison process to the QMS of an ISO 9001-certified company. It should be said that in case studies, researchers monitor and collect data over time with respect to a specific project goal and certain attributes (Zelkowitz and Wallace 1998; Wohlin et al. 2002). Similar data are often collected from a class of projects, in order to build a baseline. The baseline is then used as a reference point so that it might be possible to generalize the conclusions. In that sense, this work can be seen as a first application of the harmonization process. It may therefore serve as a preliminary validation of this process. From the findings obtained in our work, it is possible to start building such baselines (which can serve as reference for other projects of this type). The strength of using an observational method like a case study is that it has low costs. Indeed, the company would have undergone the CMMI appraisal anyway, with or without our application, so the only additional cost consisted of applying the harmonization process to the company's QMS (existing and available), as well as in pointing to how much information could be reused in the CMMI assessment.

On the other hand, the weakness of any case study, and therefore of our contribution, is the uniqueness of the results, so it is not always possible to compare findings from one context to another, and determining trends and statistical validity is not so straightforward. This is why data from a class of projects and contexts should be collected to define a baseline and from there, start generalizing results. Several other applications will be necessary and will have to involve various types of certified organizations of different dimensions. We are aware of these limitations and are therefore carrying out other studies. Our first application has concerned an SME; we are currently applying the harmonization process to a large ISO 9001-certified IT company. We expect that there will be a higher coverage and percentage of reuse in this second case study, because large enterprises are most likely to have better formalized procedures and activities and therefore a more

detailed QMS, which leads to a more specific GQM quality model. However, these are currently only hypotheses that are waiting to be confirmed or rejected in our future work.

Another limitation may be the correctness of the mapping resulting from the theoretical comparison. A risk in this sense is that mapped areas are actually not intersected (false positives), whereas existing relations may have been missed, committing the type I and II errors described previously. We have tried to supersede this threat, by involving two roles in the process and by having more than one person cover each role. Furthermore, "performers" worked independently to avoid influence or bias from other performers. They merged their results only after completing the individual tasks. On the other hand, "reviewers" were knowledgeable experts with solid experience concerning both improvement models considered. Of course, the correctness of the mapping can be verified and improved only by applying it to real cases. We believe our work is a first step in this direction.

Acknowledgments We acknowledge the assistance of the following projects: DIPIS (Italian MIUR, EU and Regione Puglia grants), ARMONIAS (PII2109-0223-7948, JCCM of Spain), PEGASO-MAGO (TIN2009-13718-C02-01, FEDER and MEC of Spain), INGENIOSO (PEII11-0025-9533, JCCM of Spain).

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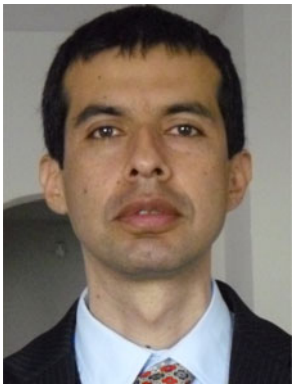

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