Identifying criteria for multimodel software process improvement solutions – based on a review of current problems and initiatives

Zádor Dániel Kelemen¹*, Rob Kusters² and Jos Trienekens²

¹SQI – Hungarian Software Quality Consulting Institute, 1085 Budapest József krt. 53. 3. em. 22/a, Hungary
²Eindhoven University of Technology, Eindhoven, Netherlands

SUMMARY

In this article, we analyze current initiatives in multimodel software process improvement and identify criteria for multimodel solutions. With multimodel, we mean the simultaneous usage of more than one quality approach (e.g., standards, methods, techniques to improve software processes). This paper discusses first the current problems regarding the use of multiple software quality approaches. Subsequently, multimodel initiatives are categorized into three different groups, respectively: quality approach harmonization, quality approach integration, and quality approach mapping. Based on an analysis of the strengths and weaknesses of current multimodel initiatives in these three classes, we derive a set of criteria, which can provide a basis for multimodel software process improvement solutions. Copyright © 2011 John Wiley & Sons, Ltd.

Received 18 February 2011; Revised 7 April 2011; Accepted 6 May 2011

KEY WORDS: multimodel; software process improvement; integration; harmonization; mapping; quality approach

1. INTRODUCTION

Many different quality approaches are available in the software industry. Discovery of approximately 315 quality approaches of 46 different organizations has been reported by Moore [1]. Some of the approaches, such as ISO 9001 [2] are not software specific, that is, they define general requirements for an organization, and they can be used at any company. Others, such as Automotive SPICE [3], have been derived from a software specific approach [4], and can be used for improving specific (in this case automotive) processes. Some are created to improve development processes [5–8], others focus on services [9,10], and again others are related to particular processes such as software testing [11] or resource management [12]. A picture of interrelations among 39 different quality approaches was published by Sheard in 2001 [13].

A number of differences among quality approaches exist, for example one difference between ISO 9001 and CMMI for Development is in focus. ISO 9001 has a general business process focus and can be used in any business domain; CMMI for Development has a process specific focus and is mainly applied by software and system companies. Differences in structure and granularity also exist between quality approaches, for example both CMMI for Services and ITIL focus on services. However, whereas CMMI defines process areas, goals, and practices, it does not define the concrete steps of the processes. ITIL contains very detailed descriptions and provides process flowcharts for guiding service implementations.

*Correspondence to: Zádor Dániel Kelemen, SQI – Hungarian Software Quality Consulting Institute, 1085 Budapest, József krt. 53. 3. em. 22/a., Hungary.
E-mail: kelemen.daniel@sqi.hu

Copyright © 2011 John Wiley & Sons, Ltd.
There can be different situations in which the usage of multiple approaches is needed, for example to strengthen a particular process with various aspects of multiple quality approaches or to reach certification of compliance to a number of standards.

This is not without problems. Take the example that a company needs to conform to ISO 9001, CMMI, and ITIL in its quality system. These approaches differ at least in focus, structure, and granularity. Using them in a single quality system is not trivial, but it can be very useful.

If we look for one process, we can find its best practices and requirements in many different quality approaches. Taking as an example the peer review process, we can see that the initial idea of applying peer reviews in software development comes from Fagan [14]. Later, the concept of peer review has been widely applied by different parties; for example in CMM, the requirements for a peer review process are represented as a key process area [15]; in CMMI for Development, the peer review appears in specific goal levels [5]; whereas in CMMI for Services, the peer review is represented as a specific practice [9]. The peer review is also applied in many other quality approaches in many different ways, such as SPICE [4], ISO 12207 [16], or IEEE 1028 [17]. Software testing books also highlight the importance of peer reviews, describing it as a preliminary testing technique [18,19]. Wiegers describes how to “humanize” peer reviews, giving recommendations and templates for process implementation [20].

Given the existence of so many approaches, which focus on peer reviews, an organization has to take decisions. First of all, it has to be decided which approaches have potential for the organization. In many cases, one approach does not contain enough information for process implementation (e.g. in case of peer reviews - CMMI for Services). Consequently, the organization may need to use more approaches, and the decision has to be made how the chosen approaches have to be used simultaneously.

The problem of creating processes using multiple quality approaches can also be recognized in other areas, such as configuration management, requirements management, requirements engineering, or software project management.

In this paper, we call the multimodel problem the problem of the simultaneous usage of multiple quality approaches. We call the multimodel initiative all the initiatives, which are aimed at solving the multimodel problem. An initiative, which solves the multimodel problem is called a multimodel solution. The output (or result) of a multimodel initiative is called a multimodel result. In this paper, we review problems connected to multimodel software process improvement (MSPI) and analyze current initiatives (grouped in categories) aimed to solve the problem of MSPI; then we define criteria for MSPI solutions.

The structure of this paper is as follows: section 2 clarifies the terminology used and the work already done on MSPI. In section 3, we briefly describe our research approach. Section 4 describes details of literature search. Section 5 highlights the main problems in the simultaneous usage of multiple quality approaches, and section 6 gives an overview of MSPI initiatives. In section 7, the analysis and an identification of the criteria for multimodel solutions are presented. Section 8 describes threats to the validity of this research, and section 9 ends this paper with conclusions.

2. BACKGROUND

The problem of multimodel process improvement can be separated into two steps, which are: (i) making a selection from multiple approaches [21–23]; and (ii) the simultaneous usage of chosen approaches [24,25]. In this section, we clarify the definitions and terms that we use in this paper. As the first step is less complex and current solutions are mature enough to solve it, we review in this section, and later we focus on the second step – which we call the multimodel problem, and which will be addressed from section 3 onwards.

2.1. Terms used

In ongoing research in the area of software process improvement, different terms are used for software quality approaches. Examples are: quality standard, quality assurance method, improvement framework [23], software process improvement (SPI) framework [22], quality model, improvement
technology [26], and process improvement model [24]. In order to emphasize that each standard (e.g. ISO 9001 or ISO 12207), method, and (improvement) technology framework (e.g. CMMI, SPICE) is a specific approach to software quality, we call each of them an approach. An approach, which is connected to software quality is called a software quality approach. The term multimodel approach will be used for initiatives, which are aimed at solving the multimodel problem. Consequently, multimodel software process improvement (multimodel SPI or MSPI) means software process improvement on the basis of multiple quality approaches.

2.2. Solutions for the first step: making a selection from multiple approaches

Quality approaches can be classified on the basis of particular characteristics (e.g. based on orientation, on level of detail, on a specialization, on their results, on the authority of a process group using them, etc.). Such classifications can help companies to choose among quality approaches on the basis of their specific needs and wishes.

2.2.1. Quality through Managed Improvement and Measurement. An initiative for the classification of quality approaches is the Quality through Managed Improvement and Measurement (QMIM) framework [21,27]. This framework shows how quality standards and quality models are connected to three different types of quality objects, that is process, product and resource, and their specifications, that is definitions, quality attributes, and metrics. The QMIM framework supports companies in selecting suitable quality approaches, for example standards and/or models, for the software quality problems they are confronted with.

2.2.2. Taxonomy based classification. In the same period that the QMIM framework has been developed, a very similar idea has started to evolve, namely the definition of taxonomies for the identification of the main characteristics of quality approaches, enabling comparison between quality approaches in a structured and consistent way. An example is the taxonomy by Halvorsen and Conradi. They proposed 25 characteristics of quality approaches (so called “SPI Frameworks”) grouped in five categories [28,22]. Halvorsen and Conradi’s taxonomy has been discussed and elaborated further, first by Paulk [23] and subsequently by Ferreira et al. [29].

2.2.3. Process Improvement in Multimodel Environments. Process Improvement in Multimodel Environments (PrIME) is a research project on multimodel process improvement launched in 2008 by the Carnegie Mellon Software Engineering Institute (SEI) [30]. It focuses on the maximization of the return on investment of process improvement activities in multimodel environments [31]. SEI’s preliminary results are published in six whitepapers [32,26,31,33,25,34]. Among other outcomes, it supports the idea of taxonomies; it defines a strategic classification taxonomy for quality approaches. The classification helps companies in choosing from different quality approaches.

We call all these initiatives classifications of quality approaches. A classification of quality approaches supports companies in selecting quality approaches and in deciding on directions for improvement in accordance with the specific requirements of the company. Classifications describe important characteristics of quality approaches (e.g. with respect to their purpose, their application domain, or their level of detail). Although comparison and selection is supported by these classifications, the second step – the simultaneous usage of multiple quality approaches – is not supported. In the remainder of this paper, we focus on the simultaneous usage of multiple quality approaches (which we refer to as the multimodel problem).

3. RESEARCH APPROACH

The objective of this paper is to identify criteria for multimodel solutions. This will be based on answering the following questions:

1. What are the problems encountered when using multiple quality approaches?
2. What are the characteristics of current multimodel initiatives?

Then our final question is: What criteria should an MSPI solution meet?
In order to answer these questions, we followed the research steps 1, 2, 3, and 4 discussing them in sections 4, 5, 6 and 7. Table I describes the research questions, connected research steps, and the sections of this article in which the research steps are discussed.

The work is based on a literature survey. This survey has been executed using the guidelines from Kitchenham’s guide on performing systematic reviews [35].

The resulting criteria can be used for the development of MSPI solutions.

4. LITERATURE SEARCH

We performed a literature search with two goals: first, to serve as input to step 2 of the research – identifying problems of MSPI, and also serving as input to step 3 – looking for current initiatives in using multiple quality approaches.

4.1. Search space

The literature search had the same search space for both goals, which included books, journals, conferences, theses, webpages, presentations and technical reports in the area of process improvement, standardization, integrated models, and multimodel software process improvement.

The literature search was conducted in a number of public electronic databases including IEEE, ACM, ScienceDirect, Citeseer, and Google Scholar. Additional materials were gathered from nonpublic sources, for example from CMU Software Engineering Information Repository, which included reports on practical results of SPI. The World Wide Web was also searched for relevant webpages and presentations.

4.2. Conducting the literature search

Choosing the right search terms is essential to the result of the literature search. For finding the most accurate keywords, we followed two steps:

1. Well-known papers in the field were manually analyzed to collect suitable search terms, for example: [22,23,27,31].
2. Papers found during the literature search were processed using an open-source text mining tool, RapidMiner. All texts were tokenized to words; stopwords were filtered using an English dictionary and a specialized dictionary for filtering useless words (e.g. “page”). Tokens were also filtered by length excluding one-letter words, and then upper cases were transformed into lower cases. Later, different stemming algorithms were applied.

The application of basic text mining techniques helped us:

1. To find close variants of the keywords found in articles analyzed previously (e.g. granularity – grain);
2. To find all occurrences of different variants of keywords.

<table>
<thead>
<tr>
<th>Research question</th>
<th>Research step</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are the problems encountered when using multiple quality approaches?</td>
<td>1 Literature search on MSPI (input for steps 2 and 3)</td>
<td>4 Literature search</td>
</tr>
<tr>
<td>What are the characteristics of current initiatives?</td>
<td>2 Identifying problems of MSPI</td>
<td>5 Problems of Using Multiple Quality Approaches</td>
</tr>
<tr>
<td>What criteria should an MSPI solution meet?</td>
<td>3 Analyzing MSPI initiatives based on problems identified</td>
<td>6 Multimodel Initiatives</td>
</tr>
<tr>
<td></td>
<td>4 Identifying a criteria for MSPI solutions</td>
<td>7 Analysis</td>
</tr>
</tbody>
</table>

Table I. Research questions, steps, and paper sections.

4.2.1. Keyword search. Our targeted field was the MSPI. Search terms were combined by Boolean operators combining terms of the main field by AND operator (e.g. “multimodel” AND “software process improvement”). The OR operator was also used between terms within the field. Different spellings and synonyms of search terms were applied as discussed previously. For example, in the case of the term “multimodel,” the following terms were used: “multimodel”, “multi-model”, and “multi model”; and for the terms “software process improvement”, also “SPI” was used. Identical search terms were applied to all databases mentioned in section 4.1.

4.2.2. Search through references and manual search. In order to discover multimodel-based quality approaches – as an addition to keyword search – several quality approaches were checked (e.g. CMMI, SPICE, iCMM, Enterprise SPICE, etc.). As another addition to the keyword-based search, references of relevant sources were checked manually (e.g. all references of [31]).

4.2.3. Inclusion criteria. All materials of the final set were checked manually, and all sources connected to MSPI were included whereas irrelevant sources were excluded from the library.

4.2.4. Exclusion criteria. After checking samples of articles found in keyword search, similarly worded research fields were excluded using exclusion operators (“−”): for example publications containing the term “multi-model” in the field of process modeling were manually checked, and in case of irrelevancy, sources were excluded by applying exclusion terms (e.g. one such exclusion term was: “multi-model view of process modeling”). Sources addressing different research topics containing useless information (e.g. there were sources containing only references) and duplicates under different names were also excluded.

4.3. Search results

Articles, technical reports, theses, methodologies, mapping documents, presentations, and quality approaches connected to MSPI were collected using the “Zotero” open source reference manager tool. After applying exclusion criteria, a final set of literature sources has been developed, which contains 58 articles and further sources, 78 in total (see the list in [36]).

For research step 2, problems of MSPI have been identified, based on the final set of sources, which are discussed in more detail in section 5. For research step 3, an identification of MSPI initiatives has been performed (see the discussion in section 6).

Further details of the literature search are given in [36]. This includes the list of literature sources, the pure and stemmed wordlists (using the previously mentioned Porter and Snowball algorithms), wordlist summary, occurrences and variants of important search terms.

5. PROBLEMS OF USING MULTIPLE QUALITY APPROACHES

In this section, we address problems of the simultaneous usage of multiple quality approaches, as found in the literature search. As described in section 4.2, a variety of search terms was used to achieve these results.

5.1. The problem of recognizing and handling differences of source quality approaches (in terms of structure, granularity, terminology, content, size, and complexity)

One of the main problems in multimodel environments is the difference in structure and terminology of the quality approaches and the difficulty of recognizing the similarities between them [26]. As [37] states: “besides that, the structure of the models is not necessarily similar”, it is “difficult to establish relations without the previous and careful assessment of each one, and establishing the granularity to be adopted”. Misunderstanding the granularity of quality approaches can erode the benefits of SPI efforts [24,26]. Granularity is also an issue when making comparisons and mappings of different quality approaches [38].

Rout and Tuffley state that models “may have differences in structure and content”, and “when the structure of the model is significantly different from the reference model, the mapping might be quite
In [40], it is stated that the SAFE+CMMI extension “was developed so that CMMI appraisers and users can become familiar with the structure, style, and informative content provided, to reduce dependence on safety domain expertise”. As a consequence of differences in terminology and structure of quality approaches, the CMMI framework was developed in such a way that it includes both “a common terminology, common model components, common appraisal methods, and common training materials” [41]. Size and complexity can influence the selection [29] and simultaneous usage of multiple quality approaches.

5.2. The problem of traceability of multimodel results

Siviy et al. suggest the mapping of quality approach requirements to organizational processes in order to achieve traceability, which can be used for audits, assessments, and benchmarks [26]. Salviano confirms that traceability can be achieved via a “mapping” process [42]. Traceability of process models back to source artifacts is considered important by [43]. Salviano suggests a number of characteristics for his process improvement methodology called PRO2PI. Among other issues, he highlights traceability as the necessity to trace back multimodel results to relevant process improvement models [42]. Rout and Tufley [39], Halvorsen and Conradi [22] suggest how to “map” different approaches. Also, Rout and Tufley consider that references from the “mapping” to quality approaches could serve as a solution for using multiple quality approaches.

The need for traceability also appears in models such as CMMI. CMMI for Services OPD SP 1.2 Subpractice 4 states that “adherence to applicable process standards and models is typically demonstrated by developing a mapping from the organization’s set of standard processes to relevant process standards and models.” This mapping is a useful input to future appraisals [5,9,52].

5.3. The problem of changeability of multimodel results

The literature recognizes the need for changeability; however, it uses different terms for it, such as flexibility [40,44], adaptability [44] or dynamism [42]. When changes occur in processes, the impact on the source quality approaches should be checked [31]. In developing a unification of CMMI and CENELEC standards, a proposal was to unify these two frameworks into a single structure, but “flexible” enough to support the necessary “adaptations” [44].

5.4. The problem of the completeness of multimodel results

Reaching a sufficient level of completeness of multimodel results (or outputs) can be an issue of a multimodel solution. In case that the multimodel result is not sufficiently complete, it could be difficult to understand and build a process from it. [45,46]. In the opposite case, Cugola and Ghezzi mention with respect to process modeling languages: “PMLs tend to force process designers to over-specifying the process for completeness” [47]. Similarly, to over-specification of process models, over-specification of multimodel results can occur. In the latter case, if the multimodel result is too detailed, it can be confusing, and people can be lost in details.

5.5. The problem of supporting multimodel appraisals

We define appraisal as assessments, audits, reviews, benchmarks or measurements, which are aimed at the discovery of the conformity of organizational processes to a quality approach. Multimodel appraisal support means that the conformity of processes can be appraised against multiple quality approaches. This can happen preferably at once or separately. This aspect was considered important in MSPI by different authors [5,40,48–51].

5.6. The problem of repeatability and documentation of the multimodel solution

Several multimodel initiatives describe only the multimodel result. For example, many mappings describe only the mapped elements, or CMMI gives a list of quality approaches used during its development, but no description is available of how the final multimodel result was achieved. Questions may arise such as “What process/methodology was followed?” “How repeatable is the process?” or “Is the solution itself documented?”
As source quality approaches are often described textually, comparisons, mappings or integrations are frequently done in a subjective manner. In order to ensure the repeatability and transparency, a description of the process by which a multimodel result is achieved should be available [38].

Summarizing the problems, which influence the quality of an MSPI solution, we can define three problem categories, which cover the process of multimodel solution:

- Problems connected to the differences (in terms of structure, granularity, terminology, content, size, and complexity) among source quality approaches. These quality approaches are the inputs of MSPI solutions.
- Problems connected to process repeatability and documentation.
- Problems connected to multimodel results (in terms of traceability, changeability, completeness, and appraisal support).

These problems are considered by the community to be of importance in using multiple quality approaches. We will use them as a basis for a discussion in the next section on the strengths and weaknesses of the available multimodel initiatives.

6. MULTIMODEL INITIATIVES

After collecting multimodel initiatives, we categorized them based on their view on how to solve the multimodel problem. We will distinguish in this section three different categories: quality approach harmonization (which we will address in section 6.1), quality approach integration (to be addressed in section 6.2), and quality approach mapping (which we will address in section 6.3). We call a multimodel initiative Harmonization when characteristics of standalone quality approaches are aligned to each other (such characteristics can be e.g. structure or terminology). A multimodel initiative is called Integration when instead of having standalone quality approaches, approaches are put into a single “integrated” one. And finally, we call a multimodel initiative a Mapping when specific parts of different quality approaches, such as requirements or terminologies are compared. In the following subsections, we will discuss each of these three categories and examples of multimodel initiatives.

6.1. Quality approach harmonization

Sheard states: “As process and quality frameworks continue to change, a consensus is emerging on the need for greater compatibility” [13]. In this section, we summarize initiatives aimed to enhance the compatibility among quality approaches.

**Category definition:** Quality approach harmonization is the process of releasing a modified quality approach or the extension of an existing quality approach in accordance (or in a harmonized way) with one or more quality approach(es). In this sense, harmonization results in a modified approach or addition that carries several characteristics of one or more quality approach(es) with which it is harmonized. Such common characteristics can be for example the common terminology, the common structure, or the common way of process descriptions. Furthermore, harmonized quality approaches often take into account what the other quality approach states with which they are harmonized; they avoid contradictions; they contain references to existing approaches, etc.

The International Organization for Standardization (ISO) harmonizes its most widely used standards. For example ISO 9001 and ISO 90003 have been developed with the same structure (i.e. chapters) and terminology in order to help companies in extending their ISO 9001 quality management system with ISO 90003. Moreover, if we look at the reason of releasing the latest version of ISO 9001 (released in 2008), we can find that a goal of this release was to enhance the compatibility with other ISO standards [2]. No new requirements were added, and all the modifications are focused on a concretization and a refinement of expressing requirements.

A further example of a harmonization of standards is the relation of IEEE 1028:2008 and IEEE 12207:2008. The first can be used to facilitate the achievement of different outcomes of the latter one: namely the chapters 7.2.6 – Software Review Process, and 7.2.7 – Software Audit Process [17].

Extending a certain approach or tailoring it to other areas in a harmonized way is also quite usual, in particular, in the case of CMMI. CMMI started to be a model for software and system development.
Now, it has got three different constellations: one for development [5], one for services [9], and one for acquisition [52]. In addition to the constellations, different extensions exist (e.g. SAFE + for safety [40] or RASM in railways industry [44]).

TMMi [11] is another example of an extension of a quality approach. TMMi states: “The development of the TMMi Reference Model has used the TMM framework as one of its major sources. In addition to the TMM, the TMMi model development was guided by the work done on the Capability Maturity Model Integration”.

These examples show that both quality standardization and SPI organizations are concerned regarding the problem of MSPI, especially in increasing the compatibility among quality approaches. ISO, IEEE, and SEI make clearly visible steps towards the facilitation of companies to deal with the multimodel problem.

6.1.1. Strengths. The main strength of a quality approach harmonization is the increased compatibility among standards. This is implemented in different ways. For example in the case of the ISO 9001 standards family, a unified terminology and structure is provided for ISO 9001 and 90003. In the case of IEEE 1028 and ISO/IEEE/IEC/ 12207, requirements are aligned, which means that the requirements of the one standard satisfy the requirements of the other one, see for example IEEE 1028. In addition to this, IEEE 1028 can be used as a subroutine of other quality approaches, which define requirements for reviews and audits, for example SPICE or CMMI.

6.1.2. Weaknesses. An initiative for solving the multimodel problem is a well-planned and maintained quality approach harmonization. From an MSPI point of view, a weakness of the quality approach harmonization initiatives is that they are applied only to a limited number of standards. Therefore, extending a Quality Manual System with quality approaches with a different structure could be difficult, for example the ISO 9001–90003 line works only for ISO 9001-like standards. In case that CMMI would be used in combination with ISO 9001-like standards, the multimodel problem would appear again. The process of harmonizing quality approaches is also usually only vaguely documented.

Table II summarizes characteristics of quality approach harmonization.

6.2. Quality approach integration

Category definition: An integrated quality approach is a quality approach, which has been established on the basis of multiple quality approaches. Quality approach integration is the process of developing an integrated quality approach. A clear difference between this category and the previous harmonization category is that the source quality approaches are not left standalone, but that they are put together into a single, integrated quality approach carrying new shared characteristics, often replacing the source approaches.

Recognizing the need for using multiple quality approaches simultaneously, integrated quality approaches were developed both on a commercial and a non-commercial basis. From among the many

<table>
<thead>
<tr>
<th>Problem</th>
<th>S/W</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handling differences of quality approaches</td>
<td>S</td>
<td>Common structure, granularity, terminology, size, and complexity are aligned in many cases.</td>
</tr>
<tr>
<td>Repeatability and documentation</td>
<td>W</td>
<td>Usually, there is no guidance or documentation on how the harmonization is developed, how it could be repeated.</td>
</tr>
<tr>
<td>Traceability</td>
<td>S</td>
<td>Traceability is supported; in many cases, the harmonized approaches often carry the same characteristics. For example, in case of ISO 9001–90003, there is a clear traceability of requirements.</td>
</tr>
<tr>
<td>Changeability</td>
<td>W</td>
<td>Changes occurring in one standard can be taken into account in development of other standards, but these are not reflected automatically.</td>
</tr>
<tr>
<td>Completeness</td>
<td>S</td>
<td>In this case, quality approaches are standalone, completeness depends on the authors and independent from harmonization.</td>
</tr>
<tr>
<td>Appraisal support</td>
<td>–</td>
<td>Multimodel appraisals can be performed easier because of commonalities, but there is no clearly documented solution for this issue.</td>
</tr>
</tbody>
</table>
such integrated quality approaches, some of the best known are CMMI [5,9,52], iCMM [6], and Enterprise SPICE [53].

A strong point of iCMM is that it clearly defines the source of the terms used and also provides a mapping table between itself and the source quality approaches used [54]. In this way, the traceability back to the source quality approaches is assured. Enterprise SPICE is a continuation of iCMM and tries to integrate even more approaches than its ancestor.

A commercial example of an integrated quality approach is CITIL, a combination of CMMI and ITIL. It “supports the improvement of both the development and the operation aspects of IT products and services” [55].

6.2.1. Strengths. The main strengths of integrated quality approaches such as CMMI, SPICE, iCMM, or Enterprise SPICE are the unified terminology, structure, content, granularity, size, and complexity. Furthermore, iCMMI and Enterprise SPICE provide traceability back to the source models via a mapping table.

6.2.2. Weaknesses. Integrated quality approaches are the multimodel result of an integration process, and they neither provide information on the way the integration problem was solved nor on how to integrate new approaches.

Table III summarizes characteristics of quality approach integration.

6.3. Quality approach mapping

**Category definition:** Quality approach mappings focus on the identification of the requirements of two different quality approaches. Subsequently, the identified requirements of the first approach are mapped to the requirements of the second approach. Quality approach mappings often include a terminology mapping as well, see for example [22], [50], and [39]. Many different comparison methods exist for the mapping of different quality approaches, for example: [48,28]. Whereas Halvorsen and Conradi define four types of such methods, respectively: characteristics comparison, framework mapping, bilateral comparison, and needs mapping comparison, other researchers such as Ekert [48], Mutafelija [49,50], or Rout and Tuffley [39] use their own way of mapping.

A wide literature is available on the comparison of CMMI with other approaches such as ISO 9001, TSP, SPICE, Agile/Lean Development, Six Sigma [56], PMBOK, and IEEE software engineering standards [57]. A huge library of SPI materials, which include several mappings, is the Software Engineering Information Repository maintained by SEI [57].

In part 3 of the PrIME whitepapers [26], granularity of quality approaches are discussed in brief, highlighting that not all the mappings provide information on granularity. Relying only on mappings could lead an organization to satisfy the requirements of an approach, but in the same time may fail at the audit of a finer grained quality approach. Understanding the granularity of quality approaches can

<table>
<thead>
<tr>
<th>Problem</th>
<th>S/W</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handling differences of quality approaches</td>
<td>S</td>
<td>Common structure, granularity, terminology, size, and complexity are achieved.</td>
</tr>
<tr>
<td>Repeatability and documentation</td>
<td>W</td>
<td>There is no guidance or documentation on how the integration is performed and how to perform new integrations.</td>
</tr>
<tr>
<td>Traceability</td>
<td>–</td>
<td>In the case of iCMM and Enterprise SPICE, traceability is achieved via a mapping table; in case of CMMI (as no mapping table included into the model), traceability is questionable.</td>
</tr>
<tr>
<td>Changeability</td>
<td>W</td>
<td>There is no information on how to include new quality approaches or new versions of existing ones into an integrated quality approach.</td>
</tr>
<tr>
<td>Completeness</td>
<td>–</td>
<td>There is no information on how complete are the integrated quality approaches (there is some information in case mapping tables are provided). Because the community accepts these models, we consider them complete enough.</td>
</tr>
<tr>
<td>Appraisal support</td>
<td>S</td>
<td>Because multimodel approaches often replace the source quality approaches, one appraisal is enough to satisfy all the needed requirements.</td>
</tr>
</tbody>
</table>
thus be crucial. These whitepapers highlight (besides the compliance in assessments) the importance of traceability of processes back to the process requirement sources and the change management of derived processes.

One of the most widely known mappings of CMMI is presented in [49]. These authors describe a detailed mapping of CMMI-v1.1 and ISO 9001:2000 requirements, comparing each ISO 9001:2000 requirement to the CMMI specific and generic practices. In CMMI, a practice is the description of an activity that is considered important in achieving an associated goal [5]. This mapping is very well applicable at companies, which already have an ISO 9001 quality management system, and try to move towards CMMI process improvement. In [50], a mapping of CMMI to ISO 9001, ISO 15288, ISO 12207, and ISO 20000 is described.

Also, software applications are available to support mappings of quality approaches, for example the Appraisal Assistant. The most recent (Beta 3) version of this software application facilitates the appraisal of multiple constellations, versions and extensions of CMMI, People CMM, an extension of iCMM, SPICE and Automotive SPICE [58]. Another example of such a software application is the Capability Adviser in the automotive industry [48]. The International Software Consulting Network makes efforts to provide software for automotive companies to support an Integrated Automotive & Safety SPICE Assessment Approach. The software application also contains cross-references to ISO 9001[48,59].

6.3.1. Strengths. One of the main strengths of quality approach mapping is traceability. Mappings provide concrete, traceable information back to the source approaches. Another strength of mapping is that it can act as a basis for multimodel appraisals (e.g. multimodel appraisal software such as Appraisal Assistant or Capability Adviser are based on mappings) [48,58,59].

6.3.2. Weaknesses. Mappings are specific solutions for two selected quality approaches, for example a mapping of ISO 9001-CMMI or CMMI-SixSigma. There is no mechanism provided to (automatically) reflect changes of source approaches. Additionally, most of the current mappings provide only the result of mapping without providing general guidance on how to perform the mapping process and how to extend current mappings to further quality approaches.

Because quality approaches are described textually, mappings are usually performed in a subjective manner, for example in many cases, the level of overlapping can be argued. One disadvantage of quality approach mapping is that the complexity and amount of the work increases extremely with the number of quality approaches included. When a new quality approach is included, new mappings are needed to all quality approaches. Table IV summarizes characteristics of mappings.

Summarizing this section, we can state that each multimodel initiative we identified could be clearly positioned in one of our three categories. The discussions and the positioning also made clear the strengths and weaknesses of the investigated multimodel initiatives.

7. ANALYSIS

In this chapter, we describe criteria (7.1) for multimodel solutions. Subsequently, we discuss our findings related to the current initiatives identified (7.2).

7.1. Criteria for multimodel solutions

Here we summarize the criteria identified during the review of multimodel initiatives:

Handling the differences among quality approaches

Differences among quality approaches exist (in terminology, granularity, structure, content, size, and complexity). As we have shown in previous sections, not all the initiatives handle, nor document the handling of these differences. In order to assure the “goodness” of results, a multimodel solution should handle these differences in quality approaches.

Repeatability and clear documentation

As we summarized in Tables II, III, and IV, one common weakness of the current initiatives is the lack of clear documentation and repeatability of multimodel process. In order to assure that the
outputs are valid and repeatable, a transparent and clear documentation of the solution is needed, describing how multimodel results (outputs) are created from inputs.

Traceability of multimodel results

Traceability of the multimodel results back to source quality approaches is crucial when the changeability, adaptability, or appraisal support of results need to be guaranteed. It also plays an important role in assuring the validity of the solution. Although in some of the current solutions traceability is assured by mapping, many of current initiatives do not provide clear traceability back to source quality approaches. The result of a multimodel solution should clearly be traceable back to source quality approaches.

Adaptability and expandability of multimodel results

When a new quality approach is released, it may have huge change effects on the multimodel results and a company’s processes. This could also happen when a new version of already used quality approach is released. In order to emphasize the importance of the changes occurring in quality approaches, we divide changeability into two criteria, respectively, adaptability (in case that a new version of an existing approach appears) and expandability (in case that a new quality approach appears).

Completeness of multimodel results

There should be a clear indication on the coverage of source quality approaches. The completeness of multimodel results should be proven and sufficient for users.

Appraisal support

Some of the current initiatives provide multiple appraisal support, others do not. In order to assure the conformance to source quality approaches, results of a multimodel solution should be appraisable based on multiple (source) quality approaches.

7.2. Findings regarding multimodel initiatives

A significant effort has been spent on the multimodel problem by different researchers, organizations, and practical process engineers, and they have achieved considerable results. Here we summarize the findings related to current multimodel initiatives:

1. Current initiatives can be categorized into three different categories:
   • Quality approach harmonization is delivered by standardization organizations. Harmonized characteristics of quality approaches help companies to understand and implement the selected
standards. As a result of the commonalities of these standards, they can be used easier than more different/less harmonized ones.

• **Quality approach integration** has advantages when an organization decides to choose a particular integrated approach, instead of looking for mappings of source approaches or creating an integration of source approaches on its own. In this way, the company will save resources, which would be spent on the integration or mapping. It is for example easier to use Enterprise SPICE than to use its separate sources.

• **Quality approach mapping** is useful in case when a company tries to use two different models or standards with different terminologies, contents, and structures. Users of mappings can understand how certain terms and requirements are represented in another quality approach, which they are also going to use.

• In order to clarify the taxonomy, we can say that a mapping is an addition to quality approaches (it does not change the source quality approaches), integration is the replacement of quality approaches (it incorporates source quality approaches), whereas harmonization is the modification of quality approaches (in order to achieve common characteristics such as structure or terminology).

2. No current multimodel initiative fulfills all the criteria that we identified. Therefore, we conclude that there is a serious need for a general multimodel solution.

### 8. THREATS TO VALIDITY

8.1. **Literature search**

We tried to perform a comprehensive literature search within the field of multimodel software process improvement. However, there might be other sources pointing to this field, which include different terminology, or are present in different databases we have not checked.

8.2. **Multimodel software process improvement problems**

Besides the problems that we found in implementing a multimodel solution in an organization, other problems might become important as well. For instance, we could also refer to implementation-related problems such as: abstraction, understandability, accuracy, predictiveness, inexpensiveness, and others mentioned by [42], or to people-related problems, such as: integrated teaming or multimodel trainings [25].

8.3. **Multimodel software process improvement initiatives and initiative categories**

As we analyzed the current literature, we found that harmonization, integration, and mapping are very often used, but not usually clearly defined (see word occurrences in [36]). Therefore, we tried to define them and use as a basis for our categories. New categories may arise when different solution will be developed and used in practice. (e.g. some formal initiatives already exist, but they are still not widespread, e.g. [60]).

8.4. **Multimodel software process improvement criteria**

We tried to discover problems mentioned in literature and tailor the criteria based on these problems. The detailed list of criteria can be and probably will be extended/refined as current problems tend to be solved or new problems and initiatives arise.

### 9. CONCLUSION

Many organizations struggle with the application of multiple software quality approaches. The problem is, in particular, caused by the amount and variety of software quality approaches that is available and has been introduced over the years. In this paper, we showed that classifications and taxonomies for software quality approaches only support organizations to some extent, that is to
CRITERIA FOR MULTIMODEL SPI SOLUTIONS

characterize, compare, and choose from approaches. However, no final solution is offered for the simultaneous usage of multiple software quality approaches in organizations. Regarding the problems of MSPI, we discovered respectively problems caused by differences in quality approaches, which are the inputs of MSPI solutions, problems of documentation and repeatability of the MSPI process, and problems connected to the quality of multimodel results.

Regarding the current initiatives for solving the problem of using multiple quality approaches, we derived three categories. These are: quality approach harmonization, quality approach integration, and quality approach mapping. Based on an analysis of the strengths and weaknesses of current initiatives in these three categories, we derived criteria for multimodel software process improvement solutions. These are: criteria for handling the differences of inputs of MSPI solutions (in terminology, structure, granularity, content, size, and complexity), criteria for documentation and repeatability of the MSPI process, and finally criteria related to the quality of multimodel results or outputs (such as adaptability, expandability, completeness, traceability, and appraisal support). We could conclude that currently, none of the initiatives fulfill all the criteria, and therefore no generally applicable solution exists. However, with the identified criteria, a basis is provided for the development of multimodel solutions.

ACKNOWLEDGEMENT

The following projects contributed to the development of this paper: “Automated workflow system for the quality control of software developments” (project id: GOP-1.1.1-08/1-2008-002), the project “Software quality assurance service-package for open document format applications” (project id: TECH_08_A2-SZOMIN08), and the project “New Hungary Development Plan” (project id: TAMOP-4.2.1/B-09/1/KMR-2010-0002). The authors would like to acknowledge the support of SQI – Hungarian Software Quality Consulting Institute, and the projects mentioned. We also thank Katalin Balla for the useful comments.

REFERENCES


40. DMO. +SAFE, V1.2: A Safety Extension to CMMI – DEV, V1.2. 2007; Available from: http://www.sei.cmu.edu/reports/07mt06.pdf [29 June 2010].
54. FAA. Integrated Capability Maturity Model® (FAA-iCMM®) version 1.0. 1997

AUTHORS’ BIOGRAPHIES

Zádor Dániel Kelemen (1980) obtained his Master’s Degree in Information Technology at Budapest University of Technology and Economics in 2006. At present, he is a software process improvement consultant at SQI – Hungarian Software Quality Consulting Institute Ltd. Besides consultancy work, he participates in process and service assessments, in formal CMMI-based SCAMPI A appraisals and different R&D projects in the field of software quality and process improvement. He is a PhD student at Eindhoven University of Technology; his research focuses on multimodel software process improvement. Since 2006, he participates in teaching software quality management and software testing at Budapest University of Technology and Economics.

Professor Dr Rob J. Kusters (1957) obtained his Master’s Degree in Econometrics at the Catholic University of Brabant in 1982 and his PhD in Operations Management at Eindhoven University of Technology in 1988. He is professor of “ICT and Business Processes” at the Dutch Open University in Heerlen where he is responsible for the Master’s Program, “Business Process Management, and IT”. He is also an Associate Professor of “IT Enabled Business Process Redesign” at Eindhoven University of Technology where he is responsible of a section of the program in management engineering. He published over 90 papers in international journals and conference proceedings and co-authored six books. Research focuses on project and process performance, enterprise modeling, software quality, and software management.

Dr Ir Jos J. M. Trienekens (1952) is an Associate Professor at Eindhoven University of Technology in the area of ICT systems development. He is responsible for a research program on ICT-driven business performance and is an associate member of the research school BETA at TUE, which focuses at information technology and operations management issues. Jos Trienekens published over the last 10 years various books, papers in international journals and conference proceedings. He joined several international conferences as PC member and member of organizing committees. He also has experience as project partner in several European projects (ESPRIT/ESSI).