A Taxonomy Analysis for Multi-Model Process Improvement from The Context of Software Engineering Processes and Services

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Abstract

The industrial and research communities in Software Engineering have shown great interest in Software Process Improvement initiatives. There are variety of process improvement that addresses the process improvement practices for software processes and services. Organizations initially started with single model implementation and progresses for more process improvement certification by adopting multi-model as their improvement needs become increasing crucial. The software development organizations and quality departments leverage these models and frameworks to better address process improvement challenges. These frameworks differ in variety of aspects and making them difficult to compare objectively. This paper discusses on the multi-model process improvement and the integration approach. The main integration issue is the interoperability of the frameworks which may results in inefficiency of the development of the integrated framework. In relation to this, architectures for multi-model are investigated. We propose taxonomy for the multiple software process frameworks to support the understanding and comparison of diverse software quality frameworks. The research outcome is expected to identify the structural relationships among the frameworks and resolve the interoperability issues. The results derived from the taxonomy include characteristics and categories of attributes which are tailored to the discipline-specific framework and applied to three selected frameworks. The result of taxonomy analysis will be used as input for Delphi research approach.

Keywords: Software Process Improvement, Multi-Model, Taxonomy

1. Introduction

The industrial and research communities in Software Engineering have shown increasing interest in Software Process Improvement. There are variety of process improvement that addresses the process improvement practices for software processes and services. Organizations initially started with single model and progresses for more process improvement certification by adopting multi-model as their improvement needs become increasing crucial. The software development organizations and departments leverage these models and frameworks to better address process improvement challenges. These frameworks differ in variety of aspects and making them difficult to compare objectively. This paper discusses on the multi-model process improvement frameworks. Concurrent and multi-model adoptions of software process improvement frameworks have been widely practiced by the software/IT organizations. The software development companies adopt these frameworks to improve product quality. The combination practice of different software process improvement frameworks is increasing. This practice promotes better address process improvement challenges. As much as possible, the software development organization should select the best integration approach, in order to ensure proper integration of these models. Depending on the organization and project goal, the adoption of software process improvement frameworks maybe in single or multiple modes. The frameworks differ in various aspects and direction. Due to this issue, we conclude that the frameworks are difficult to be compared, interpreted and understood. We support this issue by determining the architectures for the frameworks. Another issue or problem that arises is finding an appropriate method to perform the comparison, which we decide to use the taxonomy analysis approach.

This paper investigates the issues in an integrated framework for software process improvement practices and unifies the theories in process definition and establishment. The proposed integrated and unified framework contains a set of formal descriptions for software process improvement frameworks. Architectures for software process improvement frameworks will be discussed. The most important
issue in the integration process is the interoperability of the frameworks. Accurate integration approach ensures efficiency in the integration process. Thus, common interoperability issues, omissions, differences and gaps will be identified for use in the development of new integrated framework.

The goal of this paper is to derive the comparison of software engineering process improvement framework in a convenient and systematic way by using taxonomy approach. Taxonomy for software engineering process framework is used to support the understanding and comparison of diverse software quality frameworks. As a result of this research work, the structural relationships among the frameworks will be derived. The taxonomy comparison generates a set of characteristics and categories of attributes tailored to the discipline-specific framework. We further refine the research approach by adopting the Delphi study to be applied on experts in this field.

The rationale of the organizations embarking into quality initiatives is due to the need to achieve competence in the processes and to better manage their organization’s businesses. The second reason is to increase customer satisfaction in the software products and services. Finally, organizations need to be able to achieve competitive advantage in the software industry. The adoption of the quality initiatives depends on the goals of the organization and it is achievable through the implementation of software engineering process frameworks.

In this paper we focus on the issues of the integrated framework towards the adoption of multi-model process improvement for software processes and services. The structure of the paper is as follows: section 2 explains the recent researches in software process improvement. Section 3 discusses about the research approach. The comparison method and taxonomy of software engineering process frameworks are discussed. Section 4 describes about the results and discussion. The paper concluded with discussion of the taxonomy analysis and Delphi study.

2. Related research work

Software process improvement efforts receive consistent attention by the software development organisations. The organizations’ aim on achieving high competitive advantage and customer satisfaction, increase product and service quality and cost reduction pushes the need to adopt the software process improvement frameworks and best practices. These frameworks help in improving the organizations quality system. Despite the adoption of single quality initiative, there are also organizations that practice multiple adoptions. There are many different quality and process improvement approaches are adopted in the industry. The need to strengthen and improvise certain software engineering process requires the usage of multiple quality initiatives. Some software organizations that practices quality invest on adoption of these frameworks to improve their software processes, products and services.

Research works on quality has begun since 1931 by Shewart. Recent works on software engineering processes, quality and process improvements have been discussed by many researchers and software engineers [1-3]. Early research and works on quality and process improvement frameworks have been performed by the following researchers and quality experts: Control chart and statistical quality control by Shewart [4]; Plan-Do-Check-Action Cycle by Deming [6]; Quality control by Juran [7]; Total Quality Control (TQC) by Ishikawa [8]; Concept on zero defect by Crosby [9]; Managing the software process, Personal Software Process (PSP), Team Software Process (TSP) by Humphrey [10]; Capability Maturity Model for Software (SW-CMM) by Pauluk, Weber, Curtis and Chiassis [11]; and Capability Maturity Model (CMM) by Pauluk, Weber, Curtis and Chiassis [12].

Among the successful international software process improvement frameworks are Capability Maturity Model for Software (SW-CMM) [11], Capability Maturity Model (CMM) [12], Capability Maturity Model Integration (CMMI) [13-15], BOOTSTRAP [16], AMI approach [17], Trillium [18], IDEAL, Iterative Quality Improvement Paradigm (QIP) [20], and Six Sigma. Some software process improvement frameworks are developed to improve development processes and some frameworks focus on services [21, 22]. ISO 9001 [23] define general requirements for an organization and they can be used for any industry type. Thus, ISO 9001 is not software-specific. The guidelines on applying ISO 9001 to computer systems are defined in [24]. Another example of the standard is ISO 9000 [25]. ISO/IEC 12207 [26] is software-specific. ISO/IEC 15504 [27, 39] is used as a standard for automotive, software and other domains.
There are many literatures comparing the frameworks available. Various comparison methods have been adopted. The mostly used method is the framework mapping. Several works by software engineering practitioners and researchers have used this technique. The effort to harmonize the many different software process improvement frameworks that existed was discussed in [5, 9, 19, 28]. Rout and Tuffley [28] presented about harmonizing two frameworks: CMMI and ISO/IEC 15504. Moore [29] reported on the existence of different quality initiatives. Tingey [30] performed comparison on CMM, ISO 9000 and the Malcolm Bridge National Quality Award. El Emam, Drouin and Melo [31] have mapped between two frameworks: SPICE and ISO 9000 standard. Haase [32] discussed about the comparison on assessment concepts. Some comparisons have been performed on CMMI to other frameworks such as ISO 9001, Team Software Process (TSP), SPICE and IEEE software engineering standards. Upon completing the framework mapping approach by deriving the taxonomy analysis, Delphi study is performed to investigate the current practice in the industry by seeking opinion from the experts.

The reason of the proposed integrated framework for software process improvement is supported by recent researches which focus on performing harmonization and mapping. Recent research works on the multiple usages of software process improvement frameworks have been conducted by [28-30]. This paper will be focusing on unification of selected frameworks. Due to the difficulty in implementing multiple frameworks that may differ in focus direction, composition structure, detail level, terminology and granularity, a multi-model solution may help to resolve the issue.


CMMI framework provides process improvement path for organizations [13-15]. CMMI gives description of specific goals and practices that should be attained by an organisation in order to achieve a level of capability and maturity. CMMI has progressed to CMMI v1.3. The current CMMI v1.3 has three constellations: development, acquisition and services. Researches related to CMMI have been conducted by Kasse, Kulpa and Johnson [33,34].

The frameworks for IT services such as IT Service Management (ISO/IEC 20000) and CMMI–SVC have been developed by some organizations. Hochstein, Tamm and Brenner [36] identified the issues on services management with respect to the benefit, cost and success factors. ISO/IEC 20000 is the international standard for IT Service Management, which consists of ISO/IEC 20000-1 and ISO/IEC 20000-2 [21,22]. The current versions have progressed to ISO/IEC 20000-1:2012, ISO/IEC 20000-2:2011 and ISO/IEC 20000-4:2010.

2.2. Delphi Study

Delphi study is named after the ancient Greek oracle at Delphi who forecast future to those who sought for advice. RAND Corporation used Delphi in technology forecasting studies. Since then, it has become a popular and well accepted technique to engage opinion from people with expertise. Some researchers have modified the Delphi technique to suit their research purpose.

3. Research approach

The research approach is shown in Figure 1. The first step is based on the theoretical literature by performing a critical review process based on the available literatures. The second step focuses on analyzing the architectures for multi-model process improvement frameworks. Among the architecture attributes include contents, components, size, structures of the existing multiple software process
improvement frameworks. The next steps are the taxonomy analysis of the multiple frameworks and the application to the PIFs. Finally, the taxonomy result is used as input to the Delphi study.

The proposed taxonomy is used to identify the characteristic and properties of various software process improvement frameworks. The result will be used as input foundation for the integrated and unified framework of software process improvement. The similarities and differences among the PIFs should clarify the integration and unification issues. The proposed taxonomy will be applied to the following process improvement frameworks with relations to software engineering and Information Technology service management: ISO/IEC 15504, Capability Maturity Model Integration – Development (CMMI-DEV), and ISO/IEC 20000.

We discuss on comparison of software engineering process improvement frameworks. Many organizations are also involved in a situation to use more than one framework, rather than a single framework. The organization understands that every framework have their own strength and direction. Based on our discussion above, we suggest the following comparison method: attribute mapping and framework mapping. Framework mapping comparison is performed on existing framework by analysing the content and focus of the frameworks. Attribute mapping comparison is performed in taxonomy by defining list of attributes presented in table format. In addition, the output from the taxonomy is used as input to the Delphi Study which uses expert panel from the software and IT industry focusing on their adoption of related best practices.

3.1. Analysis of the architectures for multi-model process improvement: Identifying the software engineering processes and services in PIFs

This section discusses on the analysis performed on the architectures of multi-model process improvement. We analyze and review three frameworks: ISO/IEC 15504, CMMI-DEV and ISO/IEC 20000, by identifying the software engineering processes and services. Firstly, we discuss the ISO/IEC 15504 that describes the quality standard from the view of software life cycle. ISO/IEC 15504 contains three process categories: Primary, Organizational and Supporting. The framework defines process performance indicators or Base Practices (BP). Each of the 48 processes are structured in 9 process groups as shown in Figure 2.

The following Table 1 indicates the structure of ISO/IEC 15504 showing the process groups, processes, number of processes and base practices (BP).
Secondly, we discuss on Capability Maturity Model Integration – Development (CMMI-DEV). The structure of CMMI-DEV is presented in Table 2 indicating the maturity levels for stage representation and categories for continuous representation.

<table>
<thead>
<tr>
<th>Reps.</th>
<th>Levels &amp; categories</th>
<th>Process areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staged</td>
<td>1. Initial</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>2. Managed</td>
<td>Configuration Mgt (CM), Measurement &amp; Analysis (MA), Project Monitoring &amp; Control (PMC), Project Planning (PP), Process &amp; Product Quality Assurance (PPQA), Req. Mgt (REQM), Supplier Agreement Mgt (SAM)</td>
</tr>
<tr>
<td></td>
<td>3. Defined</td>
<td>Decision Analysis &amp; Resolution (DAR), Integrated Project Mgt (IPM), Organizational Process Definition (OPD), Organizational Process Focus (OPF), Organizational Training (OT), Product Integration (PI), Req. Development (RD), Risk Mgt (RSKM), Technical Solution (TS), Validation (VAL), Verification (VER)</td>
</tr>
<tr>
<td></td>
<td>4. Quantitatively Managed</td>
<td>Quantitative Project Mgt (QPM), Org. Process Performance (OPP)</td>
</tr>
<tr>
<td></td>
<td>5. Optimizing</td>
<td>Causal Analysis &amp; Resolution (CAR), Org. Innovation &amp; Deployment (OID)</td>
</tr>
<tr>
<td></td>
<td>Proc. Mgt</td>
<td>OID, OPP, OPD, OPF, OT</td>
</tr>
<tr>
<td></td>
<td>Project Mgt</td>
<td>QPM, IPM, RSKM, PMC, PP, SAM</td>
</tr>
<tr>
<td></td>
<td>Engineering Mgt</td>
<td>PI, RD, TS, VAL, VER, REQM</td>
</tr>
<tr>
<td></td>
<td>Support</td>
<td>CAR, DAR, CM, MA, PPQA</td>
</tr>
</tbody>
</table>

CMMI provides staged and continuous representations (reps.). The former contains five maturity levels: Initial, Managed, Defined, Quantitatively Managed and Optimizing. The latter allows an organization to perform improvement work for a selected process [15]. It contains the following categories: Process Management (5 process areas (PAs)), Project Management (6 PAs), Engineering (6 PAs) and Support (5 PAs) as shown in Figure 3.
Finally, ISO/IEC 20000 is the third framework that is analyzed in this research. The process categories and processes are listed in Table 3 below. The structure refers to ISO/IEC 20000-1:2005 on the service management processes. Apart from that, another two processes included in ISO/IEC 20000-1:2005 are: Planning and implementing service management; and Planning and implementing new or changed services.

**Table 3. ISO/IEC 20000-1:2005 structure**

<table>
<thead>
<tr>
<th>Process categories</th>
<th>Processes</th>
<th>No. of processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service delivery processes</td>
<td>Capacity Mgt, Service Continuity &amp; Availability Mgt, Service Level Mgt, Service Reporting, Information Security Mgt, Budgeting &amp; Accounting for IT Services</td>
<td>6</td>
</tr>
<tr>
<td>Relationship processes</td>
<td>Supplier Mgt, Business Relationship Mgt</td>
<td>2</td>
</tr>
<tr>
<td>Resolution processes</td>
<td>Problem Mgt, Incident Mgt</td>
<td>2</td>
</tr>
<tr>
<td>Control processes</td>
<td>Change Mgt, Configuration Mgt</td>
<td>2</td>
</tr>
<tr>
<td>Release processes</td>
<td>Release Mgt</td>
<td>1</td>
</tr>
</tbody>
</table>

4. Results and discussion

The results obtained from the critical review process of PIFs are identification of relevant characteristics and properties from the taxonomy analysis. The findings from the taxonomy analysis will be used as input for Delphi study.

4.1. Taxonomy Analysis

The taxonomy analysis is performed on several improvement frameworks by defining related attributes. Three categories of process taxonomy are listed in Table 4 with some modifications [37]. This research uses mapping comparison method by selecting and determining several attributes for the taxonomy based on the frameworks selected. The taxonomy of selected software process improvement frameworks in Table 4 indicates and clarifies the mapping of the models structure. ISO/IEC 15504 works towards automotive, software, space and medical systems. CMMI works towards various domains several domains such as software, acquisition and services. ISO/IEC 20000 is focusing on service management.

ISO/IEC 15504 is a two dimensional process reference model (PRM) which contains process dimension and capability dimension. The process dimension defines the processes which are divided into the following life cycle processes: primary, organizational and supporting. The process dimension contains processes and each process is defined in terms of its purpose and outcomes. ISO/IEC 15504 contains six capability levels (CLs) with process attributes are assigned at each level. Capability levels define the aspect of process capability which states the achievements to be implemented. The six capability levels and their process attributes are stated as follows: incomplete process (level 0) - none, performed process (level 1) – process performance, managed (level 2) – performance management and work product management, established (level 3) – process definition and process deployment, predictable (4) – process measurement and process control and optimizing (level 5) – process innovation and process control.

CMMI defines five maturity levels (MLs) from initial (level 1), managed (level 2), defined (level 3), quantitatively managed (4) and optimizing (level 5). Each ML consists of a group of process areas which forms a basis for the next process improvement stage as indicated in Table 1. Capability dimension defines six capability levels from incomplete process (level 0), performed process (level 1), managed (level 2), defined (level 3), quantitatively managed (4) and optimizing (level 5). CMMI rating
elements are the specific and generic goals. The rating of goals is performed based on the evidence recorded against each specific and generic practice. Practices are indicators of process performance and capability.

Taxonomy attributes such as process, practice, origin, discipline and work orientation, improvement paradigm, improvement entity, process capability scale, certification and qualification schemes and structural component also varies among the frameworks as stated in Table 4.

### Table 4. Taxonomy of multi-model process improvement

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Description</th>
<th>ISO/IEC 15504 (SPICE)</th>
<th>CMMI-DEV</th>
<th>ISO/IEC 20000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>A set of sequential practices which are functionally logical and reusable.</td>
<td>Processes</td>
<td>Key Process Areas (KPA)</td>
<td>Processes</td>
</tr>
<tr>
<td>Practice</td>
<td>An activity or a state in a process or software process which performs a specific task or a set of logical tasks.</td>
<td>Base Practices</td>
<td>Specific Practices (SPs) and Generic Practices (GPs)</td>
<td>Activity</td>
</tr>
<tr>
<td>Origin</td>
<td>Geographic origin/spread.</td>
<td>Europe</td>
<td>U.S.</td>
<td>Europe</td>
</tr>
<tr>
<td>Discipline &amp; Work</td>
<td>The direction and focus of the improvement framework or also known as improvement focus.</td>
<td>Process assessment &amp; development, improvement &amp; capability determination for a variety of domains</td>
<td>Information Technology</td>
<td>Information Technology</td>
</tr>
<tr>
<td>Orientation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improvement Paradigm</td>
<td>El Emam and Goldenson [38] determines two types of general paradigm for software process improvement, the analytic paradigm and benchmarking paradigm.</td>
<td>Benchmark paradigm</td>
<td>Benchmark paradigm</td>
<td>Non-benchmark paradigm</td>
</tr>
<tr>
<td>Improvement Entity</td>
<td>The primary target for the improvement frameworks such as the organization, enterprise, project, engagement, team or individual.</td>
<td>Organization</td>
<td>Organization, Project, Division</td>
<td>Enterprise, Organization, Individual</td>
</tr>
<tr>
<td>Process Capability Scale</td>
<td>The rating scale is categorized as binary, point scale, organizational maturity, process capability and organizational capability.</td>
<td>Capability level (0-5)</td>
<td>Uses ordinal scale for measuring</td>
<td>None</td>
</tr>
<tr>
<td>Certification/Qualification Schemes</td>
<td>Rating elements: Specific &amp; generic goals (SGs &amp; GGs) which depends on SPs &amp; GPs.</td>
<td>Outcomes &amp; achievements of processes</td>
<td>Organization</td>
<td>Organization</td>
</tr>
<tr>
<td>Structural component</td>
<td>Certification of the improvement framework at individual level or organization level.</td>
<td>Organization</td>
<td>Organization</td>
<td>Organization</td>
</tr>
<tr>
<td></td>
<td>The internal structure that builds up the process improvement frameworks</td>
<td>9 process groups/categories, 3 lifecycle processes and 48 processes</td>
<td>2 representations: 5 processes: 5 stages &amp; continuous; 22 process areas and categories &amp; 13 processes</td>
<td>In service mgt processes: 5 processes</td>
</tr>
</tbody>
</table>

The result of comparison determines the specific and generic practices of CMMI that are mapped to outcomes and achievements of ISO/IEC 15504 and ISO/IEC 20000. The taxonomy comparison among the frameworks indicates the interoperability issues which occur when organizations tend to adopt more than one framework. For instance in the case of development and services frameworks adopted using the ISO/IEC 15504, CMMI and ISO/IEC 20000. The interoperability issues require interfaces among these frameworks to be unified and integrated. The frameworks should have an identical structure thus requires modification, addition or deletion of certain processes and definitions. Thus, integrated multi-model frameworks solution requires identification and prioritization of selected process areas. Considering ISO/IEC 15504 and CMMI-DEV are in similar development domain, and ISO/IEC 20000 in a different services domain, further process selection is required to resolve the interoperability issues.
4.2. Planning for the Delphi Study

Delphi study is a method for structuring group communication process to deal with a complex problem [39]. The aim of employing a Delphi technique is to achieve consensus performed through iteration process [40]. Group interaction in research is important since a person’s understanding of a particular issue also requires support of view by listening to others.

The Delphi study plan is designed as follows. The Delphi study is performed with the goal to further investigate the issues on multi-model process improvement adoption using the result from taxonomy analysis. Data collection is conducted by using data from framework mapping – taxonomy analysis. Panelists are selected from industry that practices process improvement frameworks from the domain software engineering development processes and services. Interviews are scheduled at the agreed timeline by ensuring the anonymity among the participants. The numbers of Delphi rounds are decided and set of questions are distributed to the panels. Data analysis is performed to analyze the Delphi result by using statistical formulas. Upon completion and analysis of Delphi rounds, the results are distributed to the expert panel for review.

5. Conclusion

Various software process improvement frameworks have been reviewed as basis to develop an integrated framework. In order to support the understanding of multi-model process improvement frameworks, we adopted the taxonomy analysis approach. Researches on the use of taxonomy as the method for comparing the frameworks have been explored based on attribute mapping. The results from the taxonomy derived are essential for the development of integrated framework of process improvement for software and services. This taxonomy supports the understanding of the characteristics and definition of structural relationships of the improvement frameworks resolution of the frameworks’ interoperability issues. Upon understanding of the structure of the process improvement frameworks we select Delphi study to strengthen the methodology of this research by investigating further on multi-model process improvement practice. The Delphi plan has been elaborated. The key benefit of Delphi study is the recognition and acknowledgement of contribution of each participant, the anonymity feature, iteration with controlled feedback and input from expert that can facilitate in achieving consensus.

6. References

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