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A reference model for software product line capability assessment

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Abstract

The Software Product Line (SPL) approach receives more attention due to the observed benefits, such as cost reduction, quality improvements, and reduced delivery time. Although organizations are aware of its potential benefits, they face some challenges while creating a clear road map to adopt this approach. Capability maturity models are developed to guide organizations by providing an extensive road map for improvement. Accordingly, we developed a capability maturity model, entitled SPL Capability Maturity Model (SPL-CMM), to improve an organization's SPL capabilities by enabling the assessment of SPL-specific processes and providing a guideline for process improvement. SPL-CMM, developed based on SPICE-ISO/IEC 330xx standard, has two dimensions of process and capability. The process dimension consists of 16 SPL-specific processes defined under four process areas: business, architecture, technical, and organization, and the capability dimension has six capability and maturity levels from levels 0 to 5. It is a structured approach assisted by adequate measures with guidance on actions for improvement. A case study was conducted to check the applicability and usefulness of the proposed approach in a software company. The case study results show that SPL-CMM is applicable for identifying the current state of the SPL process capability and the gaps for process improvement to the next level.

KEYWORDS

assessment model, maturity model, reference model, software process improvement, software product line

1 | INTRODUCTION

The Software Product Line (SPL) concept, described as "a set of software-intensive systems sharing a common, managed set of features that satisfy the specific needs of a particular market segment and developed from a common set of core assets in a prescribed way,"[1] is receiving an increasing amount of attention from software development organizations due to promising results in cost reduction, quality improvements, and reduced delivery time.[1] It was observed that using SPL provides a reduction of 50% in time to market and defect density,[2] increasing effectiveness in the inspection by around 66%, and decreasing effort to find a defect by around 36%.[3] Modular product design and exploiting commonality and reuse with approaches like product platforms and product families are utilized to tackle high production and distribution costs arising from high product variety in software organizations.[4] Configurable software products that can be produced by designing the variabilities and variation points of a core software provide reusability, making developers efficiently integrate services related to the needs of their applications.[3,5,6]

Although SPL has a significant disruptive impact on the software development industry, the number of organizations that fully utilize this approach is limited. Although most software organizations are aware of the potential benefits of it, many of them do not have a clear path to redesign their existing software development processes in line with the SPL approach. They face challenges in coordinating and managing this adoption.[7] Therefore, there is a need for assistance and guidance in the provision of a clear road map for improvement of the SPL approach in software organizations.[8–12]

Structural approaches, such as process capability maturity models and standards, are developed to assist organizations by providing extensive guidance for improvement. They provide a road map for implementing the vital practices for the processes performed in the organization[13] as a result of determining the current process capability level based on the assessment results. There are some well-accepted process capability maturity models and standards, such as Capability Maturity Model Integration (CMMI)[14] and Software Process Improvement and Capability Determination (SPICE), published as the standard of ISO/IEC TR 15504[15–18] which is revised as the standard of ISO 330xx.[19–21] CMMI and SPICE are used as evaluative and comparative basis for process assessment and improvement. The observed benefits of these models and standards, such as cost savings, more involved employees, improved and predictable quality, and increased productivity, generating a consistency of process capture and use,[22] lead to the adaptation of the same approach to domains other than software development such as Medical,[23] Automotive,[24] Government,[25] Open data,[26,27] Data Science,[28–30] Big Data,[31] Digital Transformation,[32,33] and Industry 4.0.[34] Although researchers are attempting to develop a prescribed and systematic way of improving SPL processes,[35] there are a limited number of studies related to measuring SPL process capability maturity in the literature,[36–40] and none of the existing studies is developed based on a well-known process capability maturity model or standard.

To satisfy this gap, the purpose of this study is to develop and validate a reference model for assessing the SPL capability maturity level of an organization, which is entitled, SPL Capability Maturity Model (SPL-CMM), based on SPICE in order to assist software organizations that wish to adopt SPL approach. SPL-CMM aims to fulfill four high-level requirements:

- enabling each software development organization to evaluate its SPL capability maturity level in detail;
- identifying the current state of their SPL capability maturity;
- generating a road map for improving the SPL capability maturity of the organization; and
- providing a benchmark with other software development organizations evaluated with the same model.

The developed model, SPL-CMM, consists of two dimensions, process and capability. The process dimension covers 16 SPL engineering processes defined under four main process areas of Business, Architecture, Technical, and Organization. The capability dimension includes capability levels from levels 0 to 5. After providing the development of SPL-CMM, the usefulness and adequacy of the proposed approach are checked by conducting a case study in this research.

This paper is divided into five sections: Section 2 provides a review of the background and related studies, Section 3 describes the structure and components of SPL-CMM, followed by the case study of SPL-CMM application for validation purposes, and the last section describes the overall findings, achievements, and possible directions for future work.

2 | RELATED STUDIES

Brief theoretical background information about SPL, capability maturity models, and existing maturity models developed in the SPL domain is given in this section.

2.1 | Background

2.1.1 | Software product line

SPL practices are designed to manage software products by aiming to maximize commonalities among software products. These commonalities are embodied in artifacts, which are entitled core assets. Software is developed from these core assets. Application engineering aims to develop different software products by configuring the related common parts and implementing product-specific extensions when it is necessary.[41] Although the commonality seems to be at the core of the SPL approach, variations are as crucial as the commonalities from the point of marketing and customer. Exploiting commonality does not always result in cost reductions and customer satisfaction.[42–44] There are always market expectations regarding product differentiations based on customer needs. Therefore, management is a critical feature in SPLs; every reuse does not mean the existence of an SPL. As described in Clements and Northrop[45] "in an SPL approach, the reuse is planned, enabled, and enforced—the opposite of opportunistic." As in product platforms, SPLs also should have targeted specific market segments. It should be structured; otherwise, it may lead to an unmaintainable codebase.

The frontier research on SPL engineering and software product families established the consortium of the European Strategic Programme on Research in Information Technology and Information Technology for European Advancement.[46] There were two projects in European Strategic Programme on Research in Information Technology, namely, Architectural Reasoning for Embedded Software[47] and product-line realization and assessment in industrial settings.[48]

The ISO Standard, ISO/IEC 26550,[49] includes the reference architecture for Software and Systems Product Lines. The architecture consists of domain engineering, application engineering, technical management, and organizational management aspects. The standard aims to provide SPL Scoping guidelines.

2.1.2 | Process capability maturity models and standards

After realizing the importance of business processes in delivering high-quality products, process improvement is defined as "a structured approach to performance improvement that centers on the disciplined design and careful execution of a company's end-to-end business process."[50] It provides benefits, such as product quality, efficiency, and satisfaction level of customers and employees.[13] To provide process improvement in a standardized way, process capability maturity assessment models and standards, which represent process capability maturity levels or stages, are developed. Process capability level refers to "how far an organization has progressed towards achieving continuous improvement in any specific area."[51] They provide a road map for implementing the critical practices to move to the next capability level.[13]

The first process capability maturity model, revised to CMMI,[14] was developed by the Software Engineering Institute. It has six maturity levels and 21 software development processes. Associations between SPL practice areas and CMMI process areas are mapped in the study.[42] Another well-known generic software process capability maturity standard is SPICE, also known as ISO/IEC TR 15504. The first maturity family was presented under the ISO/IEC 15504-x family in 1998. Later, in 2015, the standards were revised by ISO/IEC 330xx family.[19] There are still some ISO/IEC 15504 standards that are being actively used, but all these are also being revised into ISO/IEC 330xx family. The standard establishes a structured assessment framework for the generic software development processes and related business management functions. It enables process assessment and determination of process capabilities.[52] As a result of the process assessment, a road map to improve the process capability level to the next level is achieved. Although they are widely accepted, they aim to improve software development processes. Thus, CMMI and SPICE are not sufficient to evaluate SPL capability maturity as a whole, and they need to be customized/modified to assess SPL process capability maturity. Although SPL practice areas are mapped with CMMI process areas in the literature by Jones (2002),[53] it does not provide SPL process definitions.

2.2 | Existing assessment, capability, and maturity models for SPL domain

There are a limited number of assessment and capability maturity models for evaluating the SPL capability maturity of the organizations in the literature. Related studies, such as SPL Framework,[36] Product Line Software Engineering,[37] In Maturity And Evolution In SPLs,[38] Software Product Line Engineering Maturity Model for Small and Medium-Sized Organizations,[39] and Family Evaluation Framework,[40] are reviewed in Table 1.

In summary, although there is a limited number of frameworks and models developed for assessing the SPL capability maturity of a software organization, none of them is developed based on a well-established process capability maturity model or standard, and their main purpose is not to improve the SPL processes. None of the existing SPL capability maturity assessment frameworks gives full details for the application or provides an action plan for enabling SPL capability maturity level improvement. Moreover, the validation and usefulness of these models are scarce. According to ISO/IEC 33004:2015 standard,[59] the assessment result of a capability maturity model should be complete, clear, unambiguous, objective, impartial, consistent, repeatable, comparable, and representative. As discussed, none of the existing models satisfies all of these criteria. By taking all of these into consideration, it can be asserted that there is a lack of research in this domain. For this reason, this study aims to develop a process capability maturity model for the SPL domain based on SPICE, called SPL-CMM, that fills this research gap. The reasons for selecting SPICE as a basis of the developed Process Capability Maturity Model for SPL domain, SPL-CMM, are that it has a well-defined and commonly accepted structure, and it is adaptable to address the needs of various fields. The next section provides information about the model.

3 | SOFTWARE PRODUCT LINE CAPABILITY MATURITY MODEL

3.1 | The development of SPL-CMM

The development of SPL-CMM is methodologically grounded in design science research, which has a solution-oriented approach to design solutions for domain problems.[60] This approach provides a suitable grounding for this research because the development of a capability maturity

TABLE 1 Existing assessment, capability, and maturity models for software product line (SPL) domain.

Source	Dimensions	Discussion
SPL Framework[36]	• Core asset development • Product development • Management	Although this framework provides quite detailed and structured guidance for the utilization and improvement of the SPLs, it neither provides an assessment methodology nor checks the capability maturity of the practices.
Product Line Software Engineering (PuLSE)[37]	• Deployment phases • Technical components • Support components	It provides a PuLSE-specific maturity evaluation method. Although the assessment provides useful insight while utilizing PuLSE, it is not developed based on a well-established assessment framework.
In Maturity and Evolution in SPLs[38]	• Evolutionary existing products • Evolutionary new products • Revolutionary existing products • Revolutionary new products	The model presents how SPLs evolve and which maturity levels they pass through, but the paper does not present a methodology or a guideline for assessing it.
Software Product Line Engineering Maturity Model for Small and Medium-Sized Organizations[39]	• Business • Domain engineering • Application engineering • Evolution maturity areas	The model seeks to present a methodology to assess the maturity of an SPL in small and medium-sized organizations. Adoption and process improvement of SPLs are addressed in the model, which has two types of elements, process areas and example actions. Additionally, four levels of maturity are defined. Although this model presents a valuable framework for small and medium-sized organizations, the generalizability to a large organization is missing, although it is necessary.[10]
Family Evaluation Framework (FEF)[40,46]	• Business • Process • Architecture • Organization	It is the most prominent measurement framework in the literature; the assessment is done based on a structured survey, but the application of FEF is not straightforward, and it is unclear how to best elicit the information needed to assess a level.[54] The model does not comply with a process capability maturity model or standard, such as CMMI or SPICE.[55] There is no consistency between the same levels of different aspects, and an overall evaluation framework is also missing.[54]
Software product line engineering maturity model[35,56–58]	• Business • Process • Architecture • Organization	The model is developed based on the FEF. A set of four maturity evaluation frameworks are developed for business,[56] architecture,[35] process, and organization[58] dimensions. Five maturity levels and their corresponding attributes are defined for the assessment. Because it is not developed based on a well-established standard for maturity assessment, it lacks comprehensiveness, objectiveness, and repeatability. Moreover, it does not mainly aim to process improvement in SPL processes.

Abbreviations: CMMI, Capability Maturity Model Integration; SPICE, Software Process Improvement and Capability Determination.

model for the SPL domain is a significant domain problem that requires improving capabilities of the software development organizations to improve their efficiency and stay competitive. Design science research aims to develop and evaluate "artifacts" to get over the problems of existing capabilities.[61] Capability maturity models are the reference models[52] and, thus, artifacts that show "an anticipated, desired, or typical evolution path."[62]

The maturity model development framework proposed by De Bruin et al.[63] developed based on design science research is used as the methodological grounding of the development of SPL-CMM. This framework consists of six steps: scope, design, populate, test, deploy, and maintain, for developing a capability maturity model in a structured way as shown in Figure 1. At the scope phase, the focus of the model was determined as a domain-specific model for the SPL domain for the organizations which try to adopt the SPL approach to obtain efficiency improvement in software development processes. At the design phase, the method of application was determined as conducting evaluations by an assessment team headed by a certified practitioner, as described in the literature,[21] because the model is developed based on SPICE. At the populate phase, the capability dimension was adapted from SPICE, whereas the process dimension was developed by utilizing an iterative approach. A comprehensive literature review and interviews with expert practitioners in the SPL domain were conducted at the first iteration, the collected data were iteratively discussed with a group of domain experts to determine processes and process areas to reach a consensus, and the last version was achieved at the end of the third iteration. The standard of ISO/IEC: 33004,[59] which gives the requirements of a capability maturity model, was followed during the design phase. At the test phase, a qualitative case study method was used to check the reliability and validity of the model. At the last phase, the maintain phase, the model is available to be used now. At the end of the development process, the model given in the next section was achieved.

3.2 | The structure of the SPL-CMM

SPL-CMM is developed to provide the base for improving the SPL engineering processes. It pursues a structured and standardized approach by assessing relevant SPL processes to perform improvement initiatives in a consistent, repeatable manner, assessed by adequate metrics with guidance on what to do for improvement in SPL.

SPL-CMM, developed based on SPICE, consists of two dimensions, process and capability, as seen in Figure 2. The process dimension includes 16 SPL-specific processes defined under four main process areas of Technical, Architecture, Business, and Organization. SPL Process Reference Model, including process definitions for the SPL engineering domain, is developed based on ISO 33000.[19] The capability dimension, adapted from ISO 330xx, has six capability and maturity levels from "Level 0: Incomplete" to "Level 5: Innovating" as well as related Process Attributes (PAs) which represent measurable characteristics necessary to improve the process. These levels and related PAs are applicable to all processes.

3.2.1 | Process dimension of SPL-CMM

SPL Process Reference Model covers process definitions of 16 critical SPL-specific processes classified under four process areas. The process areas and processes are given in Figure 3. The process definitions include measurable objectives of a process: Process Purpose, Process Outcomes, Base Practices, and Work Products, as defined in the ISO/IEC 33004:2015 Information technology-Process assessment-Requirements for process reference, process assessment, and maturity models.[59]

- The purpose defines the desired goal of the process;
- The outcomes are the achieved results when the process is performed;
- The base practices are the expected actions and enablers that will result in the outcomes; and
- The work products are the inputs and outputs of the processes, such as plans, documents, and reports.

SPL Process Reference Model, including developed process definitions, is developed. The SPL processes capability level can be assessed based on ISO 330xx owing to these developed process definitions which are used for the Level 1 capability assessments focusing on checking if the process is performed.

3.2.2 | The capability dimension of SPL-CMM

The capability dimension, applicable to any process, is adapted from SPICE-ISO/IEC 33020: Process measurement framework for the assessment of process capability[21] which has six levels from "Level 0: Incomplete" to "Level 5: Innovating." The capability levels indicate the following:

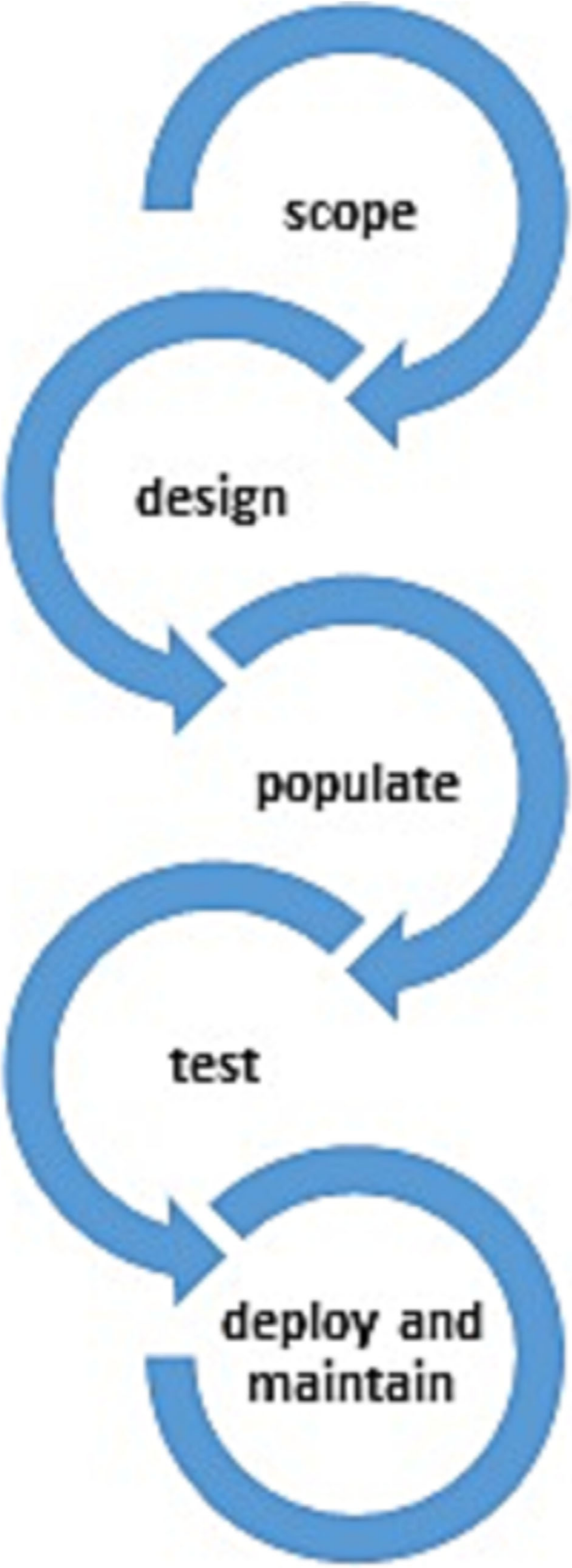

FIGURE 1 The Software Product Line Capability Maturity Model development steps adapted by De Bruin et al.[63]

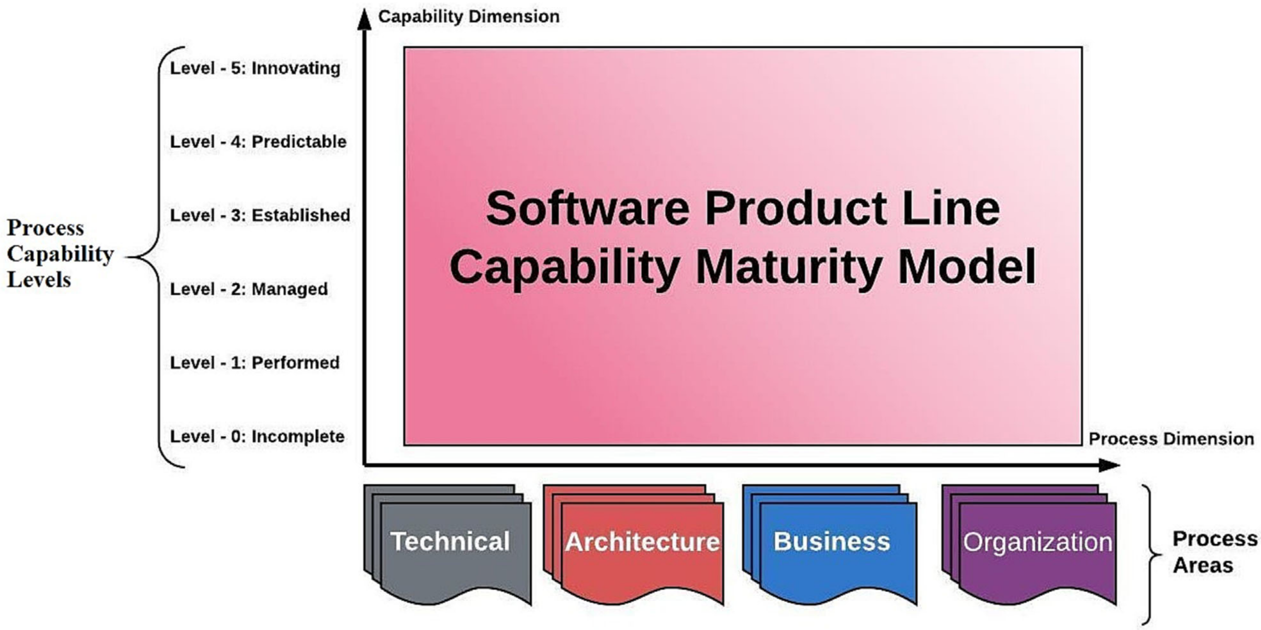

FIGURE 2 Software Product Line Capability Maturity Model structure.

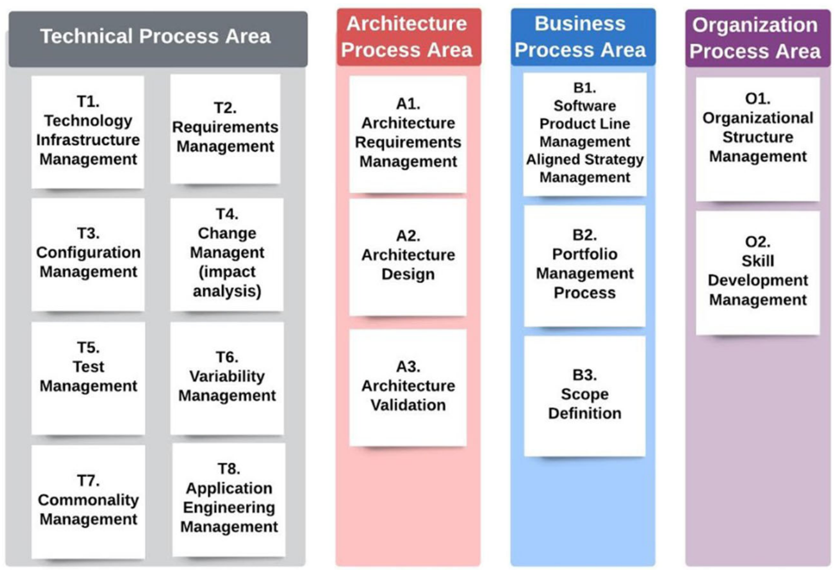

FIGURE 3 Software Product Line Process Reference Model Structure.

- Level 0—Incomplete: The process is not performed to make it to its purpose or is not even defined.
- Level 1—Performed: The process is implemented, but these implementations are not always consistent, although it achieves its purpose.
- Level 2—Managed: The performed process is planned, monitored, and adjusted to achieve its purpose.
- Level 3—Established: The organization is adjusted and defined in the way they perform the process.
- Level 4—Predictable: The process is managed and performed in a way that the variation of its outcome is reduced and limited.
- Level 5—Innovating: The quantitative data are used, and the process is relentlessly improved to meet its goals.

The measure of capability is based upon a set of PAs, as seen in Figure 4. Each capability level is said to be achieved when its PAs are fulfilled. Level 0 does not have a PA because it defines the lack of it. Level 1 has one PA to be achieved, whereas the rest of the levels have two PAs each.

The measure of capability level is based on rating a set of PAs. For instance, it is necessary to rate PA 1.1 (Process performance attribute) to determine if the process has achieved capability level 1. Each PA is measured by an ordinal rating of fully achieved (86% to 100% of achievement),

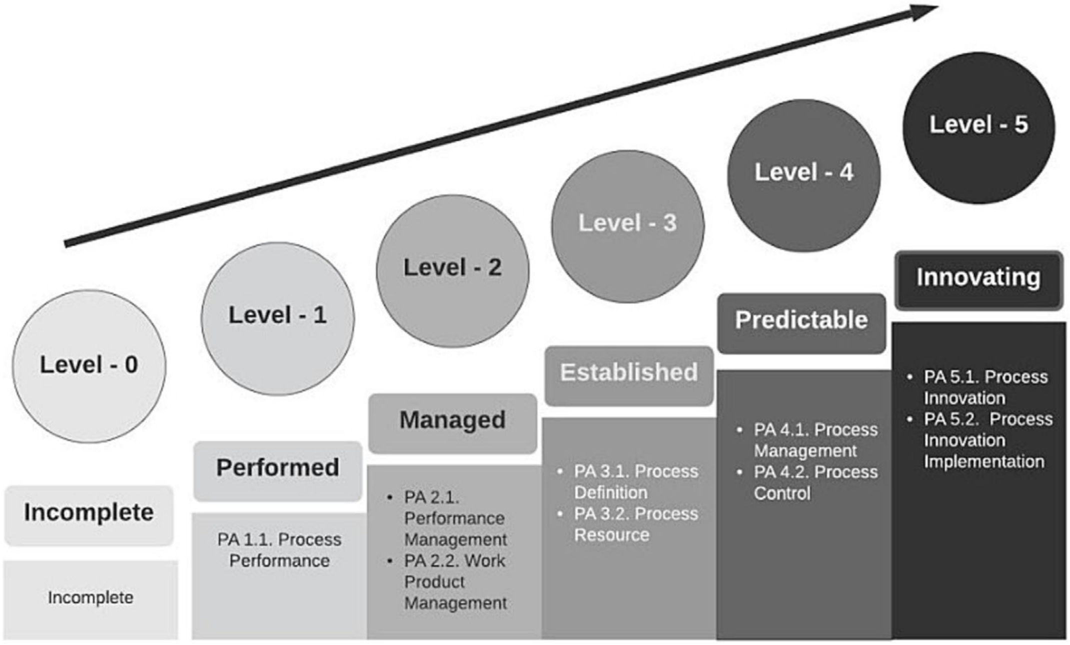

FIGURE 4 Capability levels as adapted from Software Process Improvement and Capability Determination.[21]

largely achieved (51% to 85% of achievement), partially achieved (16% to 50% of achievement), or not achieved (1% to 15% of achievement), which represents the extent of achievement of the PAs. A process is measured to be at a specific capability level if it fully or largely achieves the PAs of that level and fully achieves all the PAs of the lower levels. In other words, the ratings of PAs defined at the level need to be fully achieved or largely achieved, and all of the lower level PAs should be fully achieved, as stated in ISO 33003.[64]

3.3 | The assessment process of SPL capability maturity level

The assessments are to be conducted according to ISO/IEC 33002:2015-Information technology-Process assessment-Requirements for Performing Process Assessments[65] and ISO ISO/IEC TR 33014 Information Technology- Process Assessment- Guide Process Improvement.[66] The assessment plan and assessment report documents describe the details of assessment activities. The collected information is used to provide a view of the current state of the SPL-specific processes.

The assessment process of SPL process capability maturity, depicted in Figure 5, consists of five steps. An organization's business goals are examined in the first step to check if there is a necessity for improvement in SPL in the organization and initiating an SPL capability maturity improvement project in the organization. Step 2 covers the activities for constructing the assessment team and planning the assessment. The assessment plan, including the schedule and the required resources for the assessment, is released at the end of this step. The assessment is done in Step 3 by conducting interviews with key stakeholders of the related SPL-specific processes and by analyzing pieces of evidence, like documents and e-mails. The objective data should be collected systematically, and they should be validated in terms of consistency, comprehensiveness, objectivity, and sufficiency. Then, PAs are rated based on the validated data, following determining the corresponding process capability level. The gap analysis to improve the process capability level to the next level is performed, and the improvement opportunities are prioritized. All evidence, ratings, and improvement opportunities are documented in the assessment report. The following step, Step 4, covers preparing the action plan based on the findings given in the assessment report as well as existing resources the organization has got. The action plan, including activities, responsible people, milestones, and deliverables, is produced at the end of this step. The last step includes implementing this action plan and confirming improvements.

4 | CASE STUDY

To assess the reliability and validity of the SPL-CMM, the case study approach, which is defined as "the most common qualitative method used in information systems,"[67] is used in this study. It is a highly suitable method to seek answers to the research questions and come up with a solution. The case study is conducted according to the template presented by Yin.[68] The data in multiple variation types, such as documents, interviews,

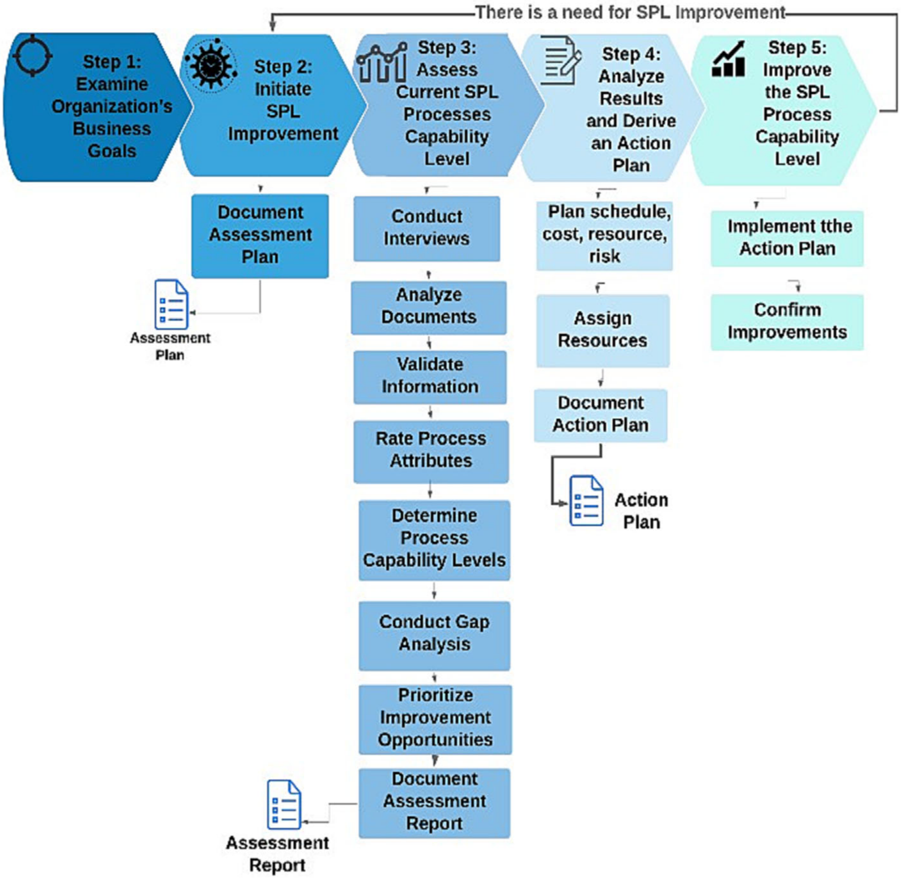

FIGURE 5 The assessment process of Software Product Line (SPL) process capability maturity level.

direct observation, participant observation, and physical artifacts, are collected on the organizations' own site, and inductive data analysis is conducted.

- The **design type** is in the form of a case study for the process capability maturity assessment of 16 SPL processes performed in one organization.
- The **objective of the study** is to examine how applicable and useful is the presented model, SPL-CMM. The model aims to determine the capability level of identified processes by rating PAs as Not Achieved (N.A.), Partially Achieved (P.A), Largely Achieved (L.A), and Fully Achieved (F.A.), as defined in Figure 4. This measurement process provides to deal with the effects of subjectivity and reduces uncertainty in the results. It also aims to provide a guideline and a road map for SPL-specific process improvement.
- The **measure used in the research** is the capability level of the SPL-specific processes.
- The **case selection strategy** is to select the organization for the assessment. It is an upside that we know the processes of the organization. In this manner, it is easier to identify weaknesses and strengths.
- **Case study research questions**: The research questions of the case study are the following:
- RQ1: How suitable is it to use the SPL-CMM with the purpose of identifying the current SPL-specific process capability level, identifying gaps, and providing a road map for SPL process improvement?
- RQ2: What are the strengths and weaknesses of the SPL-CMM?
- **Field procedure, data collection, and limitations**: ISO/IEC 33002[65] is followed to ensure performing assessment, consisting of activities for assessment planning, data collection, ratings, and reporting assessment, in a standardized manner.

The objectivity of the judgment: SPL-CMM has a hierarchical bottom-up approach for rating and explicit indicators in order to overcome the effects of subjectivity and reduce uncertainty in the results. As a result of rating Base Practices and Generic Practices as Not Achieved, Partially Achieved, Largely Achieved, and Fully Achieved, corresponding PAs are rated with the same rating scale. After then, process capability levels are determined based on the ratings of PAs. Moreover, the necessity of preparing an assessment report, including pieces of evidence, reduces subjectivity.

4.1 | Design of the case study

The case study was designed to cover the following activities:

- **Preparation:** Development of the data collection templates and preparing semistructured interview questions and the post-assessment survey questions to be used for collecting feedback.
- **Case selection and planning:** Selection of the organization to be able to observe all patterns of SPL processes, managing the interactions with the case organization about the assessment plan.
- **Assessments and data collection**: Assessing SPL process capability maturity level and collecting data via semistructured interviews and investigating evidence, like documents, e-mail records, tools used, and metrics collected.
- **Analysis:** Analyzing interview records, investigating the evidence, and analyzing them to develop the assessment reports.
- **Validation of the findings**: Sharing the assessment results and discussing with the interviewees to receive their feedback.

4.2 | Case study implementation

The case organization is a company operating in the semiconductor industry whose headquarters are in the Netherlands. More than 2000 software developers work for the company. The SPL methodology is utilized in product software derivation, and each product family has its own SPL. Software integration and software configuration management units are established for each family to maintain the SPL.

Step 1: Examine business goals: There was an organizational strategy for the improvement of SPL capability maturity of the organization. Thus, the initiation of the SPL capability maturity Improvement project was decided in the organization.

Step 2: Initiate SPL improvement: The assessment team was constructed, and the assessment plan was produced and approved by the organizations.

Step 3: Assess current SPL capability maturity level: The assessments were conducted by visiting the organization on three consecutive days. During these visits, 4-h semistructured interviews were held with the stakeholders of the SPL-CMM processes. The motive of these interviews is to gather evidence about the process's capabilities.

For the Level 1 assessment, the developed SPL Process Reference Model, including SPL-specific process definitions, was used. We checked if the outcomes are achieved and if the base practices are performed. For the remaining levels, generic practices and generic practice indicators were checked. The collected data were analyzed and proposed in the assessment report.[69] These capability level assessments were carried out for 16 SPL processes. To show an example, process capability assessment for the change management process is given in the following subsection.

Step 4: Analyze results and derive an action plan: Strong and weak points of the SPL processes of the organization were identified depending on the assessment findings. Improvement opportunities were identified based on the identified weak points of SPL processes. The aim was to make the base practices and generic practices as fully achieved for improving their capability levels to the next levels.

Step 5: Improve the SPL process capability level: Performing activities, such as improvement opportunities in the assessment report, sustaining these improvements, and monitoring them, is a long-lasting step.

The assessment in the company was conducted for the 16 SPL-specific processes identified in SPL-CMM. For the capability assessment, process stakeholders, one cluster architect, two subfunction architects, and one product owner were interviewed, and the process frameworks were investigated. Each of the interviews lasted around an hour. The interviews were conducted on three different days. The notes of the interviews and organization process frameworks and documents were investigated offline in detail. Final assessment scores were identified with this offline investigation.

An example process assessment for the Change Management Process in Technical Process Area is given below to show the assessment procedure. All the detailed assessment results for the 16 SPL-specific processes are presented in Assessment Report[69]; the summary of the overall results is presented in Table 3.

4.2.1 | Example process capability assessment—The change management process

Semistructured interviews with all three software architects working in the company were conducted, and documents were inspected to evaluate the existing capability level of the change management process performed in the organization. The Level 1 assessment was carried out with the focus of checking if the base practices, indicated in the process definition of the Change Management Process, are performed according to the corresponding PA 1.1. Process Performance Attribute. Inspected evidence were the documents and tools used for the change management process, such as process framework booklets and guidelines, mission and vision statements, internal wikis, and tooling guidelines. Generic Practices and Generic practice indicators defined in ISO/IEC 15504-5[18] were used to assess PAs from Levels 2 to 5.

As a result of interviews and inspection of the evidence, it was determined that the change management process is performed as follows: There is a change management portal available to all stakeholders. The portal is used to store and monitor all related information, including stakeholders. Some of the functionalities of the portal are to monitor the life cycle of the change request, including data of the requester, status of the change request, owner of the change, investigator, developer, dates, and details of the change request. Moreover, software impact analysis is conducted and documented for all change requests. There exist template documents for such analyses. All the affected stakeholders, components, interfaces, regression and progression effects, validation, and verification objectives are addressed in this document. This impact analysis is reviewed by the stakeholders, who can be other developers, product owners, related design architects, and industrialization engineers. After this analysis, the change is approved or rejected. If approved, the change is implemented, tested, and deployed. The change management process is also supported by review, waiver, and issue analysis processes of the software process framework. Process audience, inputs, outputs, process owner, controlling processes, process indicators, and process risks are all identified if any. Process flow diagrams are also provided for the stakeholders. The change management infrastructure provides quantitative measures such as the number of requests and change durations; however, objectives for these measures are not set. The analysis of these data is also performed on an ad hoc basis. Therefore, standard analysis procedures and techniques are not yet established or communicated through the organization.

As a result of the assessment, the process capability level of the change management process was found as Level 3, with the rationale given in Table 2, based on the collected and validated evidence. The assessment results are given in Tables A1–A4.

The road map for process improvement for an example process of T4—Change management

Capability level improvement of the process means the transition to capability Level 4 from Level 3 by improving PA 4.1 and PA 4.2 from partially achieved to largely or fully achieved. It covers improving the rating of generic practices of Level 4. The road map for process improvement of T4, Change Management Process, including the transition to fully satisfying the requirements of Level 4, is as follows:

- Quantitative process measurement objectives should be identified and established.
- Quantitative product measurement objectives should be identified and established.
- Related information and data for the objectives should be identified and collected.
- Appropriate analysis methods should be investigated and chosen for the data analysis.
- The analysis method should be defined and communicated with stakeholders.
- The collected data should be analyzed, and corrective actions should be identified and applied.
- Objectives and boundaries should be adjusted according to analysis results.

4.2.2 | SPL-CMM assessment results

All the processes were assessed as described for the T4-change management process. Assessment details are given in the assessment report.[69] As a result of the assessment, the achievement status of PAs and related capability levels for the 16 SPL specific processes, given in Table 2, are achieved. The PAs which were not assessed are marked with a dash. As seen in Table 3, although the capability level of the SPL process of T5-test management was determined at Level 4, it was Level 3 for the rest of them. It can be concluded that the organization gives importance to the reliability and availability of the systems produced. This is because the cost of system downtime is enormous; therefore, the test process is significantly matured to prevent failures and bugs.

4.3 | Analysis of the model's applicability

After determining the process capability levels for 16 SPL processes and achieving guidelines for improvement, they were shared and discussed with four key stakeholders in a meeting. Three of these are software architects, and one is a project manager. During these discussions, we questioned if the SPL-CMM model is useful and adequate. A small questionnaire as given in Table 4, was also utilized to get some feedback after the meeting. The first two questions of the questionnaire were rated on a scale of 1 to 5, meaning *completely disagree*, *disagree*, *neutral*, *agree*, and *completely agree*, respectively; the other two questions were open ended.

The resulting median of the responses was calculated to be 4 for questions 1 and 2. For the usefulness, the assessment was found useful by the respondents, and it was stated that it is definitely useful to have a structured way to drive the improvements. It was also agreed that applying these suggestions should help with process improvement. They said that there are no missing process items, and they have no suggestions for the third open-ended question.

TABLE 2 T4 change management process capability assessment summary result.

Capability level	Process attribute	Rating result	Capability level of the process
Level 1	PA 1.1 Process performance attribute	F.A.	Level 3
Level 2	PA 2.1 Performance management attribute	F.A.	
	PA 2.2 Work product management attribute	F.A.	
Level 3	PA 3.1 Process definition attribute	F.A.	
	PA 3.2 Process deployment attribute	F.A.	
Level 4	PA 4.1 Process measurement attribute	P.A.	
	PA 4.2 Process control attribute	P.A.	
Level 5	PA 5.1 Process innovation	—	
	PA 5.2 Continuous innovation implementation	—	

Abbreviations: F.A., fully achieved; P.A., partially achieved.

TABLE 3 Overall assessment results.

	Capability level	Level 1	Level 2		Level 3		Level 4		Level 5		
Process area	Process	PA 1.1	PA 2.1	PA 2.2	PA 3.1	PA 3.2	PA 4.1	PA 4.2	PA 5.1	PA 5.2	Process capability level
Business	B1. SPL management aligned strategy development	F.A.	F.A.	F.A.	F.A.	F.A.	P.A.	P.A.	—	—	Level 3
	B2. Portfolio management	F.A.	F.A.	F.A.	F.A.	F.A.	P.A.	P.A.	—	—	Level 3
	B3. Scope definition	F.A.	F.A.	F.A.	F.A.	F.A.	P.A.	P.A.	—	—	Level 3
Organization	O1. Organizational structure management	F.A.	F.A.	F.A.	F.A.	F.A.	P.A.	P.A.	—	—	Level 3
	O2. Skill development	F.A.	F.A.	F.A.	F.A.	F.A.	P.A.	P.A.	—	—	Level 3
Architecture	A1. Architecture requirements management	F.A.	F.A.	F.A.	F.A.	F.A.	P.A.	P.A.	—	—	Level 3
	A2. Architecture design	F.A.	F.A.	F.A.	F.A.	F.A.	P.A.	P.A.	—	—	Level 3
	A3. Architecture validation verification	F.A.	F.A.	F.A.	F.A.	F.A.	P.A.	P.A.	—	—	Level 3
Technical	T1. Infrastructure management	F.A.	F.A.	F.A.	F.A.	F.A.	P.A.	P.A.	—	—	Level 3
	T2. Configuration management	F.A.	F.A.	F.A.	F.A.	F.A.	P.A.	P.A.	—	—	Level 3
	T3. Requirements management	F.A.	F.A.	F.A.	F.A.	F.A.	P.A.	P.A.	—	—	Level 3
	T4. Change management	F.A.	F.A.	F.A.	F.A.	F.A.	P.A.	P.A.	—	—	Level 3
	T5. Test management	F.A.	F.A.	F.A.	F.A.	F.A.	L.A	L.A	—	—	Level 4
	T6. Commonality management	F.A.	F.A.	F.A.	L.A	L.A	P.A.	P.A.	—	—	Level 3
	T7. Variability management	F.A.	F.A.	F.A.	L.A	L.A	P.A.	P.A.	—	—	Level 3
	T8. Application engineering management	F.A.	F.A.	F.A.	F.A.	F.A.	P.A.	P.A.	—	—	Level 3

Abbreviations: F.A., fully achieved; L.A., largely achieved; P.A., partially achieved; PA, process attributes; SPL, software product line.

4.4 | Mitigation of threats to validity

For construct validity, the case study constructs should be well-structured and objective. To ensure this, multiple stakeholders in different roles were interviewed. Beyond the respondents, various sources like the process framework of the organization, role definitions, and other documents were investigated. The interviews were recorded and transcribed; Base Practices (BPs), generic practices, and PAs were rated objectively using the 4-point ordinal scale of SPICE, including N.A., P.A., L.A., and F.A., and the results were evaluated objectively.

TABLE 4 Interview results.

Question	Survey type	Response
Q1) Are measuring the process capability and obtaining a guideline for improvement useful?	5 points Likert scale	Median: 4
Q2) Do you think that applying these suggestions will improve the process performance?	5 points Likert scale	Median: 4
Q3) Is there any information you want to add in the process definition of the SPL specific processes? Please write, if any.	Open ended	
Q4) Is there any missing item(s) in the guideline for the improvement list? Please write, if any.	Open ended	

Abbreviation: SPL, software product line.

In order to ensure internal validity, the findings were discussed with the respondents again to eliminate any kind of bias. The data were collected from at least three people in order to triangulate it, and different sources for direct evidence were used to overcome the threats to internal validity.

To mitigate external validity threats, the approach was utilized for 16 different SPL processes to observe its' applicability in different circumstances. It was ensured that the replication logic was executed consistently and resulted in similar findings and conclusions. However, performing the case study in one organization limits the generalizability of the results. To ensure reliability, the case study protocol by Yin[68] was followed in a structured way for the case study, and the assessment methodology defined in SPL-CMM in detail was also followed.

5 | DISCUSSION

Based on the collected feedback, it can be concluded that the assessment and the resulting guideline for the SPL process capability improvement are useful. It is also agreed that applying these suggestions will help the organization to improve these SPL processes. Respondents also agree that the process definitions and the guideline are adequate. No additional remarks were made in that manner.

Based on the results of the case study, the answers to our research questions are found out to be

- RQ1: How suitable is it to use the SPL-CMM with the purpose of identifying the current SPL-specific process capability level and how well it provides a road map for process improvement?

Based on the case study results and the opinions of the respondents on the results, it can be concluded that the SPL-CMM can be used to identify the process capability level and provide a road map for SPL process improvement.

- RQ2: What are the strengths and weaknesses of the SPL-CMM?

The strengths of the SPL-CMM can be stated below:

- SPL-CMM pursues to provide a structured and standardized approach by assessing the SPL-specific processes. The motive is to be able to perform improvement initiatives in a consistent and repeatable way, supported by adequate measures with guidance for improvement.
- SPL-CMM succeeds in identifying process capabilities and defects of processes at various levels. SPL-CMM also achieves to provide a road map for process improvement. The process owners' and stakeholders' answers verify that they agree with the results and the road map. They also agree that having a road map to guide the organization on what they need to do for process capability improvement is valuable and helpful.

The weaknesses/limitations of the study are identified as follows:

- The case study was performed in one company; however, SPL process assessments in different organizations are needed to improve the reliability and generalizability of the results. Accordingly, as an extension of this study, we conducted a case study in an organization in the defense industry to verify the application and usability of the SPL-CMM.[70]
- We could observe the capability levels until Level 4. However, Level 5 could not be observed. Because Level 4 is not fully achieved by any of the processes, we could not perform any Level 5 assessment. Evaluation of Level 5 will be useful to further prove and improve the completeness of the model.

6 | CONCLUSION

To provide a useful, applicable, and complete capability maturity assessment, we have developed SPL-CMM based on ISO 330xx, which is a well-known software process improvement standard. We customized ISO 330xx by developing SPL-PRM, including 16 SPL-specific process definitions under four main process areas: business, organization, technical, and architecture. To assess the reliability and validity of the model, we conducted a case study in one software organization. As part of the case study, the capability levels of 16 SPL processes performed in one organization were assessed, and a road map for improving the processes to the next capability levels was derived. Following sharing the results with process owners in meetings, follow-up interviews were conducted to collect feedback about the assessment results. Lastly, the collected feedback is analyzed in the study. According to these findings, it is asserted that the SPL-CMM approach has been found useful and adequate.

The contributions of this study are as follows:

- The main contribution is developing a capability maturity model for the SPL domain. It consists of the SPL process reference model, including 16 SPL-specific process definitions, and a measurement framework that provides objective ratings. SPL-CMM presents a basis for SPL process improvement by aiming to provide a structured and standardized approach for assessing SPL processes. It is designed in such a way that it provides improvement initiatives in a repeatable and consistent manner. In the existing literature, no such approach has been presented yet.
- Another contribution is checking the applicability of the SPL-CMM with a case study. The case study results indicated that the SPL-CMM succeeds in identifying process capabilities and defects of processes at various levels. SPL-CMM also achieves to provide a road map for process improvement. It is approved that these suggestions identified in the guideline will help the organization improve the process performance by the process owners.
- The last contribution is improving the applicability of ISO/IEC 330xx in the SPL domain. It is also supported by the ISO/IEC 330xx community itself to apply the standards to different domains.

The improvement opportunities regarding SPL-CMM as a future study are as follows: developing an SPL process capability maturity self-assessment method covering the complete set of questions aligned with SPL-CMM; publishing the model and collecting new assessment data from different organizations and benchmarking the data; developing a tool to support the SPL-CMM assessment activities; and performing more case studies in different organizations.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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APPENDIX A

TABLE A1 T4 change management process capability assessment—Level 1.

Base practices	Evidence	Achievement	Result
T4.BP1: Develop a change management strategy	The strategy, way of working, steps, and documentation requirements are all defined in the software process framework guideline.	Fully achieved	The rating of PA 1.1. Process Performance Attribute is fully achieved.
T4.BP2: Establish a change management framework to record and track the change request	A change management framework and infrastructure is established. It is governed by a change management portal available to all stakeholders. The life cycle of the request is monitored.	Fully achieved	
T4.BP3: Analyze and document the impact of the change	Software impact analysis is conducted and documented for all of the change requests. There exist template documents for such analyses.	Fully achieved	
T4.BP4: Identify validation and verification needs and regression effects	In the impact analysis document, affected stakeholders, components, interfaces, regression and progression effects, validation, and verification objectives are addressed.	Fully achieved	
T4.BP5: Implement changes when approved	After the impact analyses, the change is approved or rejected. If approved, the change is implemented, tested, and deployed.	Fully achieved	

TABLE A2 T4 change management process capability assessment—Level 2.

Generic practice	Evidence	Achievement	Result
GP 2.1.1: Identify the objectives	Process performance objectives are defined in reference and guide books and software process framework.	Fully achieved	The rating of PA 2.1 Performance management attribute is fully achieved.
GP 2.1.2: Plan and monitor the performance	Process performance is planned by the process owners and monitored by the software architects, process owners, and other stakeholders.	Fully achieved	
GP 2.1.3: Adjust the performance of the process	The process is monitored and adjusted by the owners and all stakeholders whenever it is required.	Fully achieved	
GP 2.1.4: Define responsibilities and authorities	Responsibilities and authorities are defined and structured.	Fully achieved	
GP 2.1.5: Identify and make available resources	Resources are identified in yearly and long-term plans documents. Responsible employees to manage the process are identified in the project plan. Actions are performed by the staff.	Fully achieved	
GP 2.1.6: Manage the interfaces	The stakeholders are identified, and corresponding responsibilities are assigned. Contact point responsibilities among the stakeholders are identified. The responsible stakeholder assures communications among the involving parties.	Fully achieved	
GP 2.2.1: Define the requirements for the work products	Templates are released to ensure the work products adhere to the requirements. The subprocesses also define the requirements and act as a guideline.	Fully achieved	The rating of PA 2.2 Work product management attribute is fully achieved.
GP 2.2.2: Define the requirements for documentation and control	A third-party documentation management system is utilized. Documentation process and templates are released, reviewed, and waivered. Dependencies between work products are identified.	Fully achieved	
GP 2.2.3: Identify, document, and control the work products	The work products are documented and stored in the document management tool. The documents must adhere to templates released for consistency. A change control mechanism is also established for work products. Change requests, change review, revision status, and change acceptance of the work products are recorded.	Fully achieved	
GP 2.2.4: Review and adjust work products	Change management, review, and waiver activities are performed in accordance with planned arrangements. In case of a need, new documents and templates for the work products are added or current document templates are updated.	Fully achieved	

TABLE A3 T4 change management process capability assessment—Level 3.

Generic practices	Evidence	Achievement	Result
GP 3.1.1: Define the standard process	There is a software process framework that has a standard definition of all software development processes performed in the organization, including the change management process.	Fully achieved	The rating of PA 3.1 Process definition attribute is fully achieved.
GP 3.1.2: Determine the sequence and interaction	The software process framework is structured, including the relationships, layers, sequence, and interactions of the processes, which are defined.	Fully achieved	
GP 3.1.3: Identify the roles and competencies	Roles, competencies, and owners are identified and structured.	Fully achieved	
GP 3.1.4: Identify the required infrastructure and work environment	Infrastructure needs and the structure are defined and provided.	Fully achieved	
GP 3.1.5: Determine suitable methods	Methods are defined, reviewed, and followed.	Fully achieved	
GP 3.2.1: Deploy a defined process	Software process framework processes are defined, documented, and deployed. The stakeholders are communicated.	Fully achieved	The rating of PA 3.2 Process deployment attribute is fully achieved.
GP 3.2.2: Assign and communicate roles, responsibilities, and authorities	The roles and responsibilities of process owners, software architects, and other stakeholders are defined and assigned.	Fully achieved	
GP 3.2.3: Ensure necessary competencies for performing the defined process	Necessary competencies and competency owners are identified for the process.	Fully achieved	
GP 3.2.4: Provide resources and information	Necessary resources and information are available, and the communication process is established.	Fully achieved	
GP 3.2.5: Provide adequate process infrastructure to support the performance of the defined process	Infrastructure is provided, used, and maintained. The human resource is assigned to manage the maintenance of the infrastructure of change management. The contact point makes sure the third party maintains, updates, or modifies the tool according to new requirements.	Fully achieved	
GP 3.2.6: Collect and analyze data about the performance of the process	Data required to understand process performance, such as change requests, change reviews, review comments, reviewers, review status, priorities, and cycle time of the changes, are regularly collected, monitored, and analyzed to ensure it works efficiently.	Fully achieved	

TABLE A4 T4 change management process capability assessment—Level 4.

Generic practices	Evidence	Achievement	Result
GP 4.1.1: Identify process information needs	Process needs are defined in the software process framework guidelines.	Fully achieved	The rating of PA 4.1 Process measurement attribute is partially achieved.
GP 4.1.2: Derive process measurement objectives	Process measurement metrics are defined in the software process framework document, but objectives are set on the department level.	Partially achieved	
GP 4.1.3: Establish quantitative objectives	Although there are objectives for the department level, quantitative objectives for the change management process are not established.	Partially achieved	
GP 4.1.4: Identify product and process measures	Detailed measures for supporting monitoring, analysis, and verification needs of the process are established, but methods to create derived measurement results from base measures are not defined.	Partially achieved	
GP 4.1.5: Collect product and process measurement results	Some results are monitored, and some statistical data are available. However, creating measurement results and analysis of them are not performed within the defined frequency.	Partially achieved	
GP 4.1.6: Use the results of the defined measurement	Analysis of the measurements is usually ad hoc. There are no statistical or similar techniques to be used to quantitatively understand the process performance.	Not achieved	
GP 4.2.1: Determine analysis and control techniques	Some formal quantitative analysis and control mechanism is available, but this practice is applied mostly ad hoc.	Partially achieved	The rating of PA 4.2 Process control attribute is partially achieved.
GP 4.2.2: Define parameters	The parameters are mostly available for the departmental levels instead of the process.	Partially achieved	
GP 4.2.3: Analyze process and product measurement results	The process is analyzed by process owners and stakeholders but mostly ad hoc.	Partially achieved	
GP 4.2.4: Identify and implement corrective actions	Lessons learned are used for corrective actions.	Partially achieved	
GP 4.2.5: Reestablish control limits	Quantitative control limits are missing.	Not achieved	