A Maturity Model for the Implementation of Software Process Improvement

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Abstract
The Capability Maturity Model (CMM) focuses on process to achieve quality software. However, little attention has been paid to the effective implementation of this model which has resulted in limited success for many software process improvement (SPI) efforts. We believe that the importance of SPI implementation demands that it be recognised as a complex process in its own right and that organizations should determine their SPI implementation maturity through an organized set of activities. We have adapted a CMM perspective and developed a maturity model for SPI implementation in order to guide organizations in improving their SPI implementation processes. In order to design this maturity model we have extended the concept of critical success factors (CSFs). We have analysed CSFs using 50 references (published experience reports, case studies and papers). This maturity model helps organizations to improve their SPI implementation processes.

Keywords: Software process improvement, CMM

1. Introduction

Improving the quality of software process is a key information system issue. Efforts put into quality improvement will ultimately produce high quality software, reduce cost and time and increase productivity [6, 45, 62]. SPI models such as the Capability Maturity Model (CMM) [41] (and more recently CMMI) and standards such as ISO's SPICE [28] focus on process to achieve quality software. Little attention has been paid to the effective implementation of these models and standards [21] which has resulted in limited success for many SPI efforts. Studies show that 67% of SPI managers want guidance on how to implement SPI activities, rather what SPI activities to implement [25]. We believe that the importance of SPI implementation demands that it be recognised as a complex process in its own right and that organizations should determine their SPI implementation maturity through an organized set of activities. Therefore, aim of this research paper is to provide a maturity model for the implementation of SPI programmes.

In order to design this maturity model we have extended the concept of CSFs [52]. The concept of CSFs was introduced by Rockart [52], as a mechanism to identify the information needs of chief executive officers. CSFs are defined as those few key areas where things must go right for a business to grow [52]. If the management does not pay attention to these areas the organizational performance will suffer. The CSFs method has been applied to different areas of IT and management and different studies have confirmed the value of the CSF approach [27, 32, 33, 46, 53, 57]. We have analysed the literature (i.e. case studies, technical reports and journal's papers as shown in Appendix A) about factors that have a positive or negative impact on the implementation of a SPI program and develop a list of critical factors.

In this paper we focus, in particular, on two research questions:

- RQ1. What factors, as identified in the literature, have a positive impact on implementing SPI?
- RQ2. What factors, as identified in the literature, have a negative impact on implementing SPI?

This paper is organised as follows. Section 2 provides background. Section 3 describes the study design. Sections 4 describe the CSFs and CBs as identified by the literature. A maturity model for SPI implementation is described in Section 5. Section 6 concludes this paper.

2. Background

A number of studies have investigated factors that positively or negatively impact SPI, e.g. [21, 14, 16, 48]. Factors affecting SPI, as identified by these studies, are summarised in Table 1.

A survey of 138 individuals in 56 software organizations [21] identified the factors necessary for implementing a successful SPI programme. Authors have identified a number of factors associated with successful SPI programmes. In this study factors associated with unsuccessful SPI programmes are also identified [21].

A review of 56 software organizations that have either implemented an ISO 9000 quality system or that have conducted a CMM-based process improvement initiative [14] determined ten factors that affect organizational change in SPI [14].

El Emam et al. [16] has conducted a study in order to investigate some of the important success factors and barriers for SPI. They have used data from 14 companies involved in the SPICE trials in order to identify which of the factors are most strongly related to the success of SPI efforts and which factors have no impact.

A questionnaire survey of UK companies [48] identified the key success factors that can impact on SPI implementation. The results show that the four factors that practitioners considered had a major impact on successfully implementing SPI. These factors are: reviews, standards and procedures, training and mentoring and experienced staff. The authors have also identified 4 further factors (internal leadership, inspections, executive support and internal process ownership) that the more mature companies considered had a major impact on successfully implementing SPI.

Table 1. Factors affecting SPI, as identified by the literature (Adapted from [48])

Factors	[21]	[16]	[14]	[48]
Senior management commitment	Y	Y	Y	Y
Clear and relevant SPI goals	Y	Y	Y	
Staff involvement	Y	Y	Y	
Staff time and resources	Y	Y		
SPI people highly respected	Y	Y		
Assignment of responsibility of SPI	Y	Y		
Creating process action teams		Y	Y	
Encouraging communication			Y	
Tailoring improvement initiatives			Y	
Managing the SPI project			Y	
Providing enhanced understanding			Y	
Stabilising changed processes			Y	
Unfreezing the organization			Y	
Reviews/inspections				Y
Standards and procedures				Y
Internal leadership				Y
Process ownership				Y
Training and mentoring				Y
Experienced staff				Y

The work we report in this paper complements work previously done by [14, 16, 21, 48]. Little attention is paid to the improvement of SPI implementation process in the literature. We believe that only identification of factors are not sufficient for the improvement of SPI implementation process but a holistic approach is required in order to successfully implement SPI programmes. We have designed a maturity model that provides a very practical structure with which to improve SPI implementation process. The basis of this framework is what we have found in the SPI literature.

3. Study Design

We use the frequency analysis technique and measure the occurrence of key factors in a survey of literature. We note the occurrence of a key factor in each article. By comparing the occurrences of a key factor in a number of articles against occurrences of other key factors in the same articles, we calculate the relative importance of each factor. For example, a percentage of x for factor y means that factor y is mentioned in x% of the literature, i.e. if a factor is mentioned in 10 out of 20 articles, it has an importance of 50 % for comparison purposes. In this way we compared and ranked the factors. Finally, conclusions are drawn regarding the factors that are critical in the literature.

We have analysed 50 references (published experience reports, case studies and papers) that document organizations' experiences of attempting to improve their software processes. We have also identified barriers [21, 58] that can undermine the implementation of SPI. The literature we have analysed appeared to be of well-known organizations. Appendix A summarises published experience reports, case studies and papers organized according to the companies. We consider these to be important publications because the 34 organizations include all the five organizations that have been awarded the IEEE Computer Society Award for Process Achievement.

4. Findings

Tables 2 and 3 show the CSFs and critical barriers cited in the literature and the frequency with which they occurred. The percentage shows the proportion of literature that cited a particular CSF.

4.1. CSFs identified during 1991-todate

Table 2 shows the list of CSFs cited in the literature. CSFs are listed in order of their importance. The results suggest that in practitioners' opinion sponsorship can play a vital role in the implementation of SPI programs.

Table 2. Success factors

Success Factors	Occurrence in literature (n=47)	
	Freq.	%
Senior management commitment	31	66
Staff involvement	24	51
Training and mentoring	23	49
Staff time and resources	18	38
Creating process action teams	15	31
Reviews	13	28
Experienced staff	13	28
Clear and relevant SPI goals	12	26
Assignment of responsibility of SPI	12	26
Process ownership	11	23
Encouraging communication and collaboration or sharing best practices	10	21
Tailoring improvement initiatives	7	15
Reward schemes	7	15
Managing the SPI project	7	15
Providing enhanced understanding	7	15
Internal leadership	6	13
SPI people highly/well respected	5	11
Standards and procedures	4	9

It also shows that practitioners consider their involvement, training and mentoring imperative for the successful implementation of SPI programs. The results show that staff time and resources and creating process action teams are also important factors. A quarter of the literature cited reviews, experienced staff, clear and relevant SPI goals and assigning of responsibilities as CSFs. Other factors are less cited in the literature.

4.2. Critical barriers identified during 1991-todate

Our aim of identifying critical barriers [21, 58] is to understand the nature of issues that undermine the SPI implementation programmes. Table 3 shows the list of critical barriers cited in the literature.

The results show that most of the practitioners consider lack of resources a major critical barrier for the implementation of SPI. The results also suggest that in practitioners' opinion time pressure and inexperienced staff can undermine the success of SPI implementation programs. It shows that practitioners do not want organizational politics and staff turnover during the implementation of SPI programs.

Table 3. Barriers

Barriers	Occurrence in literature (n=14)	
	Freq.	%
Lack of resources	7	50
Time pressure	5	36
Inexperienced staff/lack of knowledge	5	36
Organizational politics	4	29
SPI gets in the way of real work	4	29
Staff turnover	4	29
Lack of support	3	21
Changing the mindset of management and technical staff	2	14
Paperwork required	1	7
Negative/Bad experience	1	7
Inertia	1	7

5. A SPI implementation maturity model

We have adapted a CMM [41] (and more recently CMMI) perspective and developed a maturity model for SPI implementation in order to guide organizations to improve their SPI implementation processes. The structure of our maturity model is built upon the following elements:

- Maturity stage dimension
- CSFs dimension

5.1. Maturity stage dimension

The CMM [41] is structured into five maturity levels ranging from level 1 to 5. For SPI implementation maturity model several adjustments to this stage structure are necessary to take account of SPI implementation characteristics:

- We have adopted stage 1 directly from CMM. This is the stage where the SPI implementation process is chaotic and few processes are defined.
- Different studies emphasise the importance of awareness for the implementation of SPI programmes [36, 44, 60]. SPI implementation is the process of adoption of new practices in the organization. It is therefore very important to promote awareness activities of SPI and to share knowledge among different practitioners. These awareness activities include high-level sessions for practitioners to fully understand the benefits of SPI. Awareness activities also cover a series of working sessions of practitioners in order to define the goals and organisational strategy. Therefore, stage 2 of our maturity model is called aware.
- Stage 3 and stage 4 of the maturity model are adopted from CMM. Stage 3 is the stage where SPI implementation processes are documented, standardized, and integrated into a standard implementation process for the organization. Stage 4 is the stage where organizations establish structures for continuous improvement.

Maturity stages of SPI maturity model are shown in Table 4.

Table 4: Maturity stage dimension

Maturity Stage	Description
1 – Initial	The implementation of SPI is not planned and changes randomly. This maturity level can be best described as one of chaotic processes.
2 – Aware	Awareness to SPI implementation process has been gained.
3 – Defined	This stage focuses on the systematic structure and definition of SPI implementation process.
4 – Optimising	The focus of this stage lies on establishing structures or continuous improvement.

5.2. CSFs dimension

The CMM consists of 18 key process areas (KPAs) categorized across the five maturity levels. We believe that successful SPI implementation process should be viewed in terms of CSFs rather than KPAs. This is because:

- Different studies have confirmed the value of the CSF approach in the field of information technology [14, 16, 21, 32, 33, 48, 53]. A review of the CSF research literature reveals that the concept has not been employed to any great degree in research on the topic of SPI implementation. Therefore, we believe that CSFs approach can also be useful in the implementation of SPI.
- Implementation of SPI programmes require real life experiences where one learns from mistakes and continuously improves the implementation process.

CSFs are often identified after the successful completion of certain activities. Hence these factors are near-to real life experiences.

Keeping in view the above facts we have identified different CSFs and critical barriers from the literature. We use the frequency analysis technique and calculate the relative importance of each factor (see tables 2 and 3). As CSFs are a small number of important issues on which management should focus their attention [52], so we have only considered top 50% of the success factors and barriers as CSFs and critical barriers for the SPI implementation.

The 18 KPAs of CMM can be split into three categories [18]. We have adopted this approach and categorised CSFs and critical barriers into three categories, i.e. awareness, organizational and engineering. The three categories with the corresponding CSFs and critical barriers are shown in Table 5. The basis of this categorisation is the perceived coherence between the CSFs and critical barriers identified. It should also be pointed out that these factors and barriers are not necessarily mutually exclusive and there may be a certain degree of overlap among them.

Table 5: Categories of CSFs and Critical barriers

Category	CSFs	Critical Barriers
Awareness	Senior management commitment, Training and mentoring, Staff involvement	Org. politics
Organizational	Creating process action teams, Experienced staff, Staff time and resources, Clear and relevant SPI goals, Assignment of responsibility of SPI	Time pressure, Inexperienced staff, SPI gets in the way of real work, Staff turnover
Engineering	Reviews	

In order to divide these categories of CSFs and critical barriers among different stages of maturity model, we have used the perception of KPA division among different maturity levels of CMM. The awareness category can be directly linked to maturity stage 2, i.e. aware of the maturity model. While organizational category can be linked to maturity stage 3, i.e. defined, because the focus in this stage is on the systematic structure and definition of SPI implementation process. Focus in stage 4 of the maturity model is on continuous improvement; therefore engineering category is linked with this stage. We also believe that these factor categories may overlap and one should continuously monitor previously implemented category. Thus, we called current category as "front-end category" and previously implemented category as "back-end category". The final division of factors' categories among four maturity levels of maturity model is shown in Table 6.

Table 6: CSFs dimension

Maturity Stage	Front-end category	Back-end category	Quality
4 - Optimising	Engineering	Awareness, Organizational	
3 – Defined	Organizational	Awareness	
2 – Aware	Awareness		
1- Initial			Risk

6. Conclusion and Future research

In this paper a new model is presented that has the potential to help companies to improve their SPI implementation processes. However, this model is in very initial stage and need further improvement and evaluation. As for each KPA in CMM, a number of key practices are defined that, when collectively addressed, accomplish the goals of the KPA. So one of the possible improvements in our model is to identify goals and practices for each CSF and critical barrier.

Multiple case studies will be conducted in order to test and evaluate this model and to highlight areas where this model has deficiencies. To progress on this model, a research project at faculty of IT, University of Technology Sydney, is currently being carried out in co-operation with SPI practitioners. The final shape of our model is shown in Figure 1.

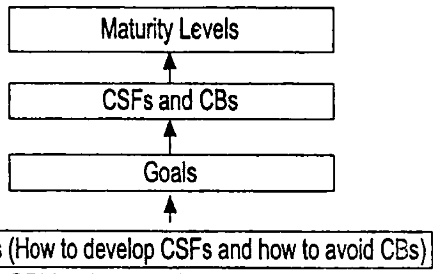

Figure 1. SPI implementation maturity model

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Appendix A: Organizations covered in our study

Organization	References	Organization	References
Advanced information services	(Ferguson et al., 1999) [17]	Ogden Air Logistics Centre	(Paul and Webb 1995) [42]
AVX Ltd	(Sweeney and Bustard, 1997) [55]	Oklahoma City Air Logistics Centre	(Butler, 1997) [7], (Butler, 1995) [6], (Herbsleb et al., 1994) [24]
Boeing's Space Transportation Systems	(Yamamura, 1999) [63], (Yamamura and Wigle 1997) [62]	Raytheon	(Dion 1992) [12], (Dion 1993) [13]
Bull HN	(Herbsleb et al, 1994) [24]	Rolls-Royce	(Nolan, 1999) [38]
Corning Information Services	(Johnson 1994) [29]	Sacramento Air Logistics Centre	(Westaway, 1995) [59]
Eastman Kodak Comp.	(Wiegers, 1998) [58]	Schlumberger	(Wohlwend and Rosenbaum 1993) [61], (Herbsleb et al, 1994) [24]
Fastrak Training Inc.	(Quann, 1997) [47]	SEI	(Goldenson and Herbsleb, 1995) [21], (Herbsleb and Goldenson, 1996) [25], (Paulk, 1998) [43], (Paulk, 1999) [44]
High-Tech Measurement	(Kautz and Nielsen, 2000) [31]	Siemens	(Paulish and Carleton 1994) [39]
Hughes	(Humphery et al. 1991) [26], (Herbsleb et al, 1994) [24], (Willis et al., 1998) [60]	SINTEF Telecom and Informatics	(Dyba, 2000) [15]
Lucent Technologies	(Moitra, 1998) [37]	Space Shuttle Software Project	(Paulk et al., 1994) [41], (Curtis, 2000) [9], (Billings et al., 1994) [5]
MITRE Corporation	(Florence, 2001) [19]	Sybase	(Macfarlane, 1996) [36]
Motorola	(Diaz and Sligo, 1997) [11], (Fitzgerald and O'Kane, 1999) [18]	Tata Consulting Services	(Curtis, 2000) [9]
Master Systems	(Rifkin, 2001) [51]	Texas Instruments	(Herbsleb et al, 1994) [24]
NASA SEL	(Basili et al., 2002) [4]	Telcordia Technologies	(Pitterman, 2000) [45], (Curtis, 2000) [9]
Network Products	(Kautz and Nielsen, 2000) [31]	Trident Data Systems	(Reel, 1999) [50]
Nokia	(Kaltio and Kinnula, 2000) [30]	University of Hertfordshire	(Baddoo et al., 2000) [1], (Baddoo and Hall, 2002) [2], (Baddoo and Hall, 2003) [3], (Rainer and Hall, 2002) [48], (Rainer and Hall, 2002) [49], (Hall et al, 2002) [22], (Hall et al., 2002) [23]
Oerlikon Aerospace	(Laporte and Trudel, 1998) [35]	Xerox	(Fowler et al., 1999) [20]