A framework for guiding the design of effective implementation strategies for software process improvement

Mahmood Niazi, David Wilson and Didar Zowghi
Faculty of Information Technology, University of Technology Sydney, NSW 2007, Australia
Email: {mkniazi, davidw, didar}@it.uts.edu.au

Abstract

Software process improvement (SPI) models such as the Capability Maturity Model (CMM) and standards such as ISO's SPICE focus on processes to achieve quality software. Little attention has been paid to the effective implementation of these models and standards which has resulted in limited success for many SPI efforts. 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 extended the concept of critical success factors (CSFs) and developed a SPI implementation framework. This framework has three components - SPI implementation plan, SPI implementation roadmap, and SPI implementation model. This framework provides advice to SPI practitioners when designing effective SPI implementation strategies.

1. Introduction

Software quality in the past several years has received much attention in both academia and business. This attention is due to the role software plays in modern-day business and, to some extent, modern-day lives. Customer satisfaction has also become the motto of many software organizations. Efforts put into quality improvement will ultimately produce high quality software, reduce cost and time and increase productivity [3, 22, 32]. SPI models such as the Capability Maturity Model (CMM) [20] (and more recently CMMI) and standards such as ISO's SPICE [14] focus on process to achieve quality software. Little attention has been paid to the effective implementation of these models and standards [10]. Studies show that 67% of SPI managers want guidance on how to implement SPI activities, rather than what SPI activities actually implement [11]. 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. Despite the importance of the SPI implementation process, little work has been done on developing ways in which to effectively implement a SPI programme. In this paper we provide a framework to guide practitioners when designing effective SPI implementation strategies.

In order to design this SPI implementation framework we have extended the concept of CSFs [26]. The CSFs concept has been applied to different areas of IT and management and different studies have confirmed the value of the CSF approach [13, 15, 16, 23, 27, 28]. We have analysed the literature (i.e. case studies, technical reports and journal's papers) about factors that have a positive or negative impact on the implementation of a SPI program and developed a list of critical factors. We have also conducted preliminary interviews with 10 SPI practitioners in order to establish their SPI implementation experiences and concerns. Our framework provides advice to SPI practitioners in designing appropriate SPI implementation strategies.

In this paper we focus, in particular, on four 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?
RQ3. Do factors that have positive impact on implementing SPI change in different periods of time?
RQ4. What are the necessary phases/steps for the implementation of SPI programmes?

This paper is organised as follows. Section 2 describes the background. In Section 3 a framework for SPI implementation is described in detail. Section 4 provides the conclusion.

2. Background

Improvement in the software process has been going on for several decades. The software organizations have been struggling with a questionable quality image for a long time. The software quality has become more critical as software pervades our day-to-day lives. The ability to deliver quality software within budget and schedule continues to elude most software organizations. The state of affairs is sometimes referred to as the software crisis.

The search for solutions to these problems has continued for many years and software organizations are now realizing that their fundamental problem is the inability to manage the software process [3, 22, 31]. Therefore, SPI has become a popular approach to delivering improvements in software products. SPI provides organizations with a powerful means of assessing their current capabilities for developing software systems and in so doing, identifying their strengths and weaknesses [12].

In the last few years we have seen technical quality initiatives such as CASE tools and organizational initiatives such as CMM (and more recently CMMI) in order to improve software processes. We suggest that whether a

quality initiative is technical or organizational, ineffective implementation can significantly affect the success of SPI efforts.

A number of studies have investigated factors that positively or negatively impact SPI [10, 7, 8, 25]. Factors affecting SPI, as identified by these studies, are summarised in Table 1.

Factors	[10]	[8]	[7]	[25]
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/well 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

Table 1. Factors affecting SPI (Adapted from [25])

The work we report in this paper complements work previously done by [7, 8, 10, 25]. However, little attention is paid to the improvement of SPI implementation process in the literature. We believe that the identification of factors is alone not sufficient for the improvement of SPI implementation processes but a holistic approach is required in order to successfully implement SPI programmes. We have designed a framework that provides a very practical structure with which to implement SPI programmes. The basis of this framework is what we have found in the literature as well as the findings from our empirical study of SPI in practice.

3. SPI implementation Framework

The framework proposed for SPI implementation comprises three components:

- SPI implementation plan
- SPI implementation roadmap
- SPI implementation model

3.1. SPI implementation plan

The objective of this component is to provide practitioners with sufficient knowledge about the nature of issues that play a positive or negative role in the implementation of SPI programmes and to assist them in effectively planning SPI implementation strategies. We have analysed 50 published experience reports, case studies and papers in order to identify factors that can play a positive or negative role in the implementation of SPI programmes. We analysed the factors using historical study over the period of 12 years. The literature we have analysed appeared to be of well-known organizations. Organizations covered in our study are shown in Appendix A. 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.

We identified 5 factors (senior management commitment, staff involvement, staff time and resources, training and mentoring, and creating process action teams) that generally considered critical for successfully implementing SPI. We also identified 6 barriers (lack of resources, time pressure, inexperienced staff/lack of knowledge, organizational politics, staff turnover and SPI gets in the way of real work) that can undermine the implementing of SPI. We found (using chi-square test) that the CSFs for the implementation of SPI do not change significantly in different periods of time.

3.1.1 Findings

In this section we discuss the results relating to RQ1, RQ2 and RQ3. This section shows the CSFs and critical barriers (CBs) cited in the literature and the frequency with which they occurred. The percentage shows the proportion of literature that cited a particular CSF.

- **CSFs identified during 1991-to date**

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

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

Table 2. CSFs (1990-to date)

- **CBs identified during 1991-to date**

Our aim of identifying CBs [10, 29] is to understand the nature of issues that undermine the SPI implementation

programmes. Table 3 shows the list of CBs cited in the literature.

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

Table 3. CBs (1991-to date)

It shows 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.

- **CSFs in different periods of time**

In order to answer RQ3, we have divided the literature into different years. The column chart is shown in Appendix B where the top five CSFs are shown in different years. It shows that there are more similarities than differences between the CSFs during different years of time. We suggest that by identifying both similarities and differences, practitioners can improve the SPI implementation process. Focusing on similar CSFs during different periods of time may offer SPI practitioners cost-effective opportunities in order to improve the SPI implementation process. This is because a small number of CSFs can be implemented that have wide effect on the success of SPI implementation process.

Our results show that all these studies recognise the contribution of senior management commitment, staff involvement, staff time and resources, training and mentoring, and creating process action teams. Appendix B shows that senior management commitment and staff involvement are the most stable factors in different periods of time. While training and mentoring, staff time and resources and creating process action teams are less stable factors. It shows that CSFs for the implementation of SPI do not change significantly in different periods of time. Our results suggest that organizations should focus on these CSFs in order to successfully implement SPI programmes because we have more confidence that a factor does indeed have an impact on SPI implementation if it is critical in different periods of time.

3.2. SPI implementation roadmap

The objective of this component is to provide a maturity model for SPI implementation in order to guide organizations in improving their SPI implementation processes.

3.2.1 A SPI implementation maturity model

We have adapted a CMM [20] 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

- **Maturity stage dimension**

The CMM [20] 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 [19, 21, 30]. 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 series of working sessions for practitioners to fully understand the benefits of SPI. Therefore, stage 2 of our maturity model is called aware.
- Stage 3 and stage 4 of the implementation 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 implementation model are shown in Table 4.

Maturity Stage	Description
1 – Initial	The implementation of SPI is not planned and changes randomly.
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.

Table 4: Maturity stage dimension

- **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 [7, 8, 10, 15, 16, 25, 27]. A review of the CSF 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 CBs from the literature. We used frequency analysis technique and calculated 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 [26], we have only considered top 50% of the success factors and barriers as CSFs and CBs for the SPI implementation.

The 18 KPAs of CMM can be split into three categories [9]. We have adopted this approach and categorised CSFs and CBs into three categories, i.e. awareness, organizational and engineering. The three categories with the corresponding CSFs and CBs are shown in Table 5. The basis of this categorisation is the perceived coherence between the CSFs and CBs 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.

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

Table 5: Categories of CSFs and CBs

In order to divide these categories 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 the 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. The 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 categories. Thus, we called the current category "front-end category" and the previously implemented category "back-end category". The final division of factors' categories among four maturity levels of implementation model is shown in Table 6.

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

Table 6: CSFs dimension

3.3 SPI implementation model

The objective of this component is to empirically explore the viewpoints and experiences of practitioners regarding SPI implementation and to develop a model in order to guide practitioners for effectively implementing SPI programmes. In this section we discuss the results relating to RQ4.

In this section we report on our recent empirical study which explored the experiences and perceptions of practitioners about SPI implementation. We went to 8 companies and conducted interviews of practitioners with the specific aim of:

1. Establishing what their typical SPI implementation experiences are
2. Identifying their major concerns about SPI implementation
3. Exploring different phases/steps necessary for the implementation of SPI programmes?

3.3.1 The Companies

Eight Australian companies participated in this study. All of the 8 companies responded to a request for participants which was posted via the email. Although we do not claim this is a statistically representative sample, this study does cover companies from very small software house to very large multinational companies and a wide range of application areas. It is further important to acknowledge that the data was collected from companies who were tackling real issues on a daily basis; therefore we have high confidence in the accuracy and validity of data [1]. Of the 8 companies in this study, two were CMM level-2, one was planning to use CMM, one was ISO 9001 certified, three had implemented internal formal quality assurance programmes while one claimed assessment against AS3563.

3.3.2 Methodology

We have conducted in-depth interviews with 10 practitioners in order to identify the phases/steps necessary for the implementation of SPI programmes. Each interview lasted approximately 45-90 minutes. All the interviews were tape recorded and then transcribed. The content analysis technique [17] was used in order to analyse each

interview. Ten practitioners voluntarily participated in this study. By volunteering to participate they have become self-selecting sample. The target population in this research was the software producing companies and practitioners. The extent, to which the sample of participants in a research adequately represents the target population, gives the results validity [17].

Self-sampling as opposed to random sampling though more practical is often prone to bias. In this research because the sample of companies form an original self-selected group (that is software producing companies), it is important to ensure that one particular group is not over represented [5]. This research addresses the issue of over representation by using a sample of companies of varying complexities, size, nature of business, type of applications etc [1, 25].

It is further important to acknowledge that the practitioners sampled within companies are representative of practitioners in organisations as a whole. In this research, one to two practitioners from each organisation self-selected to participate. The sample of practitioners researched includes developers, business analysts, technical directors, project managers and senior management.

3.3.3 Findings

Using the content analysis of the recorded interviews, we have identified six stages for the implementation of SPI programmes.

- Awareness: Practitioners felt the need for awareness of SPI programmes in order to fully understand the benefits of SPI. Practitioners said that as SPI implementation is the process of adoption of new practices in the organization, it is very important to conduct high-level sessions for practitioners in order to provide them sufficient knowledge of SPI. Different studies have also revealed the importance of awareness for the implementation of SPI programmes [19, 21, 30].
- Learning: Learning appears as an important factor for SPI implementation success. For learning, practitioners emphasized training in SPI skills in order to achieve mastery of its use. Different studies have also confirmed training as an important factor for the implementation of SPI programmes [2, 4, 6, 9, 19, 21, 24].
- Pilot implementation: Practitioners advised to first implement SPI programs at a low level and see how successful it is within a particular department. This is also important for practitioners in order to judge their SPI skills in this pilot implementation. This is the phase where practitioners can decide about how much resources, training and commitment is required in order to implement SPI practices across the organization.
- SPI implementation action plan: Practitioners stressed the need for proper planning and management. They said after pilot implementation a proper plan with activities, schedule, allocated resources, budget and milestone should be designed. This plan should be based on the results and experiences of pilot implementation. Often, SPI projects have no specified requirements, project plan, or schedule [7]. It was recommended by the practitioners to treat SPI as a real project that it must be managed just as any other project.
- Implementation across the organization: After proper planning and using the pilot implementation experience, practitioners suggested to implement SPI practices in other areas/departments of the organization. It is also important to give reference of pilot implementation to different departments in order to get support and confidence.
- Maintenance: The important theme in maintenance is to continuously monitor previously implemented SPI activities. Practitioners suggested continuing awareness and training programmes since often practitioners switch jobs. Also SPI efforts do not have long lasting effects because practitioners often slide back to their old habits [7]. It is therefore very important to continuously provide them with feedback, guidance, motivation and reinforcement to stay involved in the improvement effort [7, 18, 26].

4. Conclusion

In this paper a new framework is presented that has the potential to help companies to improve their SPI implementation processes. This framework has three components and provides a very practical structure with which to implement SPI programmes. In order to design this framework we have extended the concept of CSFs. However, this framework is in very initial stage and need further improvement and evaluation. Multiple case studies will be conducted in order to test and evaluate this framework and to highlight areas where this framework has deficiencies. To progress on this framework, a research project at faculty of IT, University of Technology Sydney, is currently being carried out in co-operation with SPI practitioners.

5. References

[1] Baddoo Nathan and Hall Tracy, Motivators of SPI: An analysis of practitioner's views, *Journal of Systems and Software*, 62, pp85-96, 2002.

[2] Billings C, Clifton J, Kolkhorst B, Lee E and Wingert WB, Journey to a mature software process, *IBM Systems Journal*, 33(1), pp46-61, 1994.

[3] Butler Kelly, The economics benefits of SPI, *Crosstalk*, July, pp14-17, 1995.

[4] Butler Kelly, Process lessons learned while reaching Level 4, *CrossTalk*, May, pp1-6, 1997.

[5] Coolican H, Research Methods and Statistics in Psychology", Hodder and Stoughton, London, 1999.

[6] Dion *Raymond*, Process improvement and the corporate balance sheet, *IEEE Software*, 10(4), pp28-35, 1993.

[7] Dirk Stelzer and Werner Mellis, Success factors of organizational change in SPI, *(SPI) and practice*, 4(4), 1999.

[8] El Emam, K., Fusaro, P. and Smith, B., Success factors and barriers for SPI. Better software practice for business benefit: Principles and experience, *IEEE Computer Society,* 1999.

[9] Fitzgerald Brian and O'Kane Tom, A longitudinal study of SPI, *IEEE Software,* May/June, pp37-45, 1999.

[10] Goldenson, D. R. and Herbsleb, J. D., After the appraisal: A systematic survey of Process Improvement, Its benefits, And Factors That Influence success, *CMU/SEI-95-TR-009*, Software Engineering Institute USA, 1995.

[11] Herbsleb, J. D and Goldenson, D. R., A systematic survey of CMM experience and results, *18th international conference on software engineering (ICSE-18)*, Germany, March, 1996.

[12] Humphery W.S., *Managing the software process*, Addison-Wesley, 1989.
[13] Huotari Maija_leena and Wilson T.D., Determining organizational information needs: the CSFs approach, *Information research*, 6(3), 2001.
[14] ISO/IEC 15504, Information technology – Software process assessment, *Technical report – Type 2*, 1998.
[15] Khandelwal V. and Ferguson J., CSFs and the growth of IT in selected geographic regions, *Proceedings of the 32nd Hawaii International Conference on System Sciences*, 1999.
[16] Khandelwal V. and Natarajan R., Quality IT management in Australia: CSFs for 2002, *CIT/1/2002*, University of Western Sydney, 2002.
[17] Krippendorf. K, "Content Analysis: An introduction to its Methodologies", sage London, 1980.
[18] Lapasaar M., Kalja A., Varkoi T., Jaakkola H., Key factors of a regional (SPI) programme, *Portland International Conference on Management of Engineering & Technology (PICMET)*, 2001.
[19] Macfarlane Malcolm, Eating the elephant one bite at a time: Effective Implementation of ISO 9001/TickIT, *Executive Digest - The ISO 9000 Quality Management System*, August, 1996.
[20] Paulk Mark, Curtis Bill, Chrissis Mary and Weber Charles, Capability Maturity Model for software, Version 1.1, *CMU/SEI-93-TR-24*, Software Engineering Institute USA, 1993.
[21] Paulk Mark, Practices of high maturity organizations, *SEPG Conference*, pp8-11, 1999.
[22] Pitterman Bill, Telcordia Technologies: The journey to high maturity, *IEEE Software* July/August, pp89-96, 2000.
[23] Pellow A. and Wilson T.D., The management information requirements of heads of university departments: a CSFs approach, *Journal of Information Science*, 19, pp425-437, 1993.
[24] Quann Eileen Steets, My boss needs to hear this: How management can support SPI, *CrossTalk*, May, 1997.
[25] Rainer Austen and Hall Tracy, Key success factors for implementing SPI: a maturity-based analysis, *Journal of Systems & Software*, 62, pp71-84, 2002.
[26] Rockart, J.F., Chief executives define their own data needs, *Harvard Business Review*, 2, 81-93, 1979.
[27] Somers M. Toni and Nelson Klara, The impact of CSFs across the stages of Enterprise Resource Planning Implementations, *Proceedings of the 34nd Hawaii International Conference on System Sciences*, 2001.
[28] Tyran C. and George J., The implementation of expert systems: A survey of successful implementation, Database, Winter, pp5-15, 1993.
[29] Weigers, K. E., SPI: Eight traps to avoid, *CrossTalk* September: pp9-12, 1998.
[30] Willis R.R., Rova R.M., Scott M.D., Johnson M.I., Ryskowski J.F., Moon J.A., Shumate K.C. and Winfield T.O. Hughes aircraft's widespread deployment of a continuously improving software process, *Technical report, CMU/SEI-98-TR-006*, 1998.
[31] Yamamura George and Wigle Gary, SEI CMM Level 5: For the right reasons, *Crosstalk*, 1997.
[32] Yamamura George, Software process satisfied employees, *IEEE Software*, September/October, pp83-85, 1999.

Appendix A: Organizations covered in our study

- Advanced information services
- AVX Ltd
- Boeing's Space Transportation Systems
- Bull HN
- Corning Information Services
- Eastman Kodak Comp.
- Fastrak Training Inc.
- High-Tech Measurement
- Hughes
- Lucent Technologies
- MITRE Corporation
- Master Systems
- NASA SEL
- Network Products
- Nokia
- Oerlikon Aerospace
- Ogden Air Logistics Centre
- Oklahoma City Air Logistics Centre
- Raytheon
- Rolls-Royce
- Sacramento Air Logistics Centre
- Schlumberger
- SEI
- Siemens
- SINTEF Telecom and Informatics
- Space Shuttle Software Project
- Sybase
- Tata Consulting Services
- Texas Instruments
- Telcordia Technologies
- Trident Data Systems
- University of Hertfordshire
- Xerox

Note: References to these organizations are available from authors

Appendix B: CSFs in different periods of time