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SPIIMM: Toward a Model for Software Process Improvement Implementation and Management in Global Software Development

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ABSTRACT Software development organizations are globalizing their activities by adopting the phenomenon of global software development (GSD), mainly due to the significant return on investment it offers. Various challenges are associated with the software process improvement (SPI). The aim of this paper is to develop a software process improvement implementation and management model (SPIIMM) that can assist GSD organizations in assessing and improving their SPI activities. A thorough systematic literature review (SLR) study was performed to identify the critical success factors (CSFs), critical barriers (CBs), and the relevant practices of SPI. An empirical study of the industry was conducted with 111 SPI experts using a survey questionnaire to verify the outcomes of the SLR. The final CSFs and CBs were categorized into five maturity levels based on the implementation maturity model, the software outsourcing vendor readiness model, and capability maturity model integration. Each maturity level consisted of different CSFs and CBs to assess and improve the SPI-related maturity level of an organization. Three case studies were conducted to evaluate the effectiveness of the proposed model. The results revealed that SPIIMM can provide a robust framework to assess and improve SPI activities in GSD organizations.

INDEX TERMS Software process improvement, global software development, success factors, barriers, practices, systematic literature review.

I. INTRODUCTION

Global software development (GSD) is a phenomenon in which software development activities are conducted across geographical, cultural, and temporal boundaries [1].

This geographically distributed approach to software development has been around since the 1970s, before the term GSD was coined. Through "contract programming" a small module of a software system would be contracted out to a third party [2]. A majority of software development organizations took to contract programming, due to a lack of resources, low budgets, limited time available for development activities, and rising costs [3]. The current GSD trend was introduced in the 1990s by software firms in the U.S. [4]. The continued improvement in information and communications technologies has since made it easy to develop software projects without regard for geographical boundaries [5].

The economic benefits offered by GSD projects are the most important factors motivating firms to adopt this type of development [5]. Conchuir *et al.* [6] suggested that GSD is a good choice because of the business profits it yields for development firms. It also provides high-quality productivity, low development cost and time, access to skillful workers, and addresses the demands of the international market [7].

Due to the distributed nature of GSD, the quality of software products becomes an important issue. Several large-scale GSD projects have yielded unsatisfactory results that have served as a blow to the industry [8]. The survey of Fitzgerald and Russo [9] highlighted this issue, reporting that 31.1% of the GSD projects they considered had ended before completion. They also revealed that only 16.2% of projects had been completed within the allocated time and budget. Attarzadeh and Ow [10] considered the quality of GSD projects a serious challenge to the software industry.

Research has been conducted into software quality issues for many years, and GSD organizations have recognized that the failure to effectively direct the software development process is one of the main causes of project failure [11].

In the CHOAS report released by the Standish Group the failure rate of the software projects considered was found to increase from 17% [12] to 19% in 2015 [13]. These issues are often seen as related to problems in software quality. The Department of Trade and Industry in the UK commissioned two reports on software quality [14], aimed at managing and controlling quality-related challenges by motivating software firms to obtain standards certification, such as ISO 9000. However, the ISO certification scheme has created disenchantment in the business community. Most small- and medium-sized enterprises are concerned about the budget required to achieve and sustain ISO 9000 certification. Researchers and practitioners have thus been investigating alternative ways managing and controlling software quality challenges. A basic inability to successfully manage the software process has been identified [15]–[17].

A number of techniques have been proposed to manage and control the software process, primarily software process improvement (SPI). Yamamura [18] defined SPI as "the discipline of defining, characterizing, improving, and measuring software management, better product innovation, faster cycle time, greater product quality, and reduced development costs simultaneously."

Various process improvement models and standards have been developed to assist software development organizations effectively manage their processes. Capability maturity model integration (CMMI) is one such model, and consists of structured and methodical practices for process evaluation and improvement [19]. The International Organization for Standardization (ISO) has also developed standards and recommendations for SPI. For example, ISO 9000 is used to assess the quality of the deployed software systems in an organization [20], while ISO/IEC 15504 is used for process improvement under the software process improvement and capability determination (SPICE) [21]. SPICE was developed to test and advertise process improvement standards and models [21]. The ISO/IEC 15504 standard has since evolved into a more advanced set of process assessment and improvement standards, the ISO/IEC 330XX family, which covers the assessment of processes deployed in an organization, including their maintenance, change management, delivery, and improvement [62]. These models and techniques can assist an organization to develop a quality product, reduce development cost and time, and promote user satisfaction [15]–[17], [22]

However, process improvement models and standards in the context of GSD have not been extensively developed, and hence process improvement efforts have had limited success [23]. Most organizations currently adopt GSD to gain various benefits, so it is important that process improvement experts have a deep understanding and knowledge of SPI programs in a distributed environment [23]–[25]. In the GSD environment the challenges faced by process improvement teams are quite different from other areas [23]. The implementation of SPI activities is considerably more complex in the GSD environment than in collocated development [23]. The literature on SPI has not examined the distributed nature of GSD organizations in sufficient detail [24], [25].

Little research has been conducted to develop standards, models, and frameworks that could assist organizations to efficiently assess and execute SPI activities in the GSD environment. We propose a model that can assist SPI practitioners to successfully quantify, evaluate, and improve their process improvement programs.

II. MOTIVATION

SPI has a long tradition in software engineering and information systems research [15], [22], [23], [26], [27]. Niazi *et al.* [24] reported that most of the literature has focused on SPI in the context of collocated software development. However, most organizations are currently in the process of adopting GSD. In spite of the different process improvement models and techniques proposed, the success rate of SPI projects in distributed development is very low [28], [29].

Khan *et al.* [30] suggested that process improvement deployment is a long-term approach that requires sufficient time and resources. However, the provision of the required resources and time is not a guarantee of the successful execution of SPI activities. Niazi [31] reported a 70% failure rate in their study of SPI implementation programs, and a fundamental cause was the lack of consideration of specific issues affecting SPI [28].

Ngwenyama and Nielsen [32] argued that with regard to GSD, geographical dispersion results in physical separation among practitioners and managerial staff, the temporal distance can reduce opportunities for direct communication, and the cultural distance affects the understanding and appreciation of the activities and efforts of the distributed teams. Issues affecting GSD are thus more complex than in collocated development. Ngwenyama and Nielsen [32] mentioned that process models such as CMM, CMMI, and ISO/IEC 15504 operated successfully in collocated software development environments, but do not explicitly address the distributed nature of software development. Similarly, Richardson *et al.* [33] suggested that the social issues regarding process improvement in GSD must be managed along with the technical challenges. In their systematic mapping study of SPI in GSD, O'Leary *et al.* [34] concluded that the literature consists of numerous SPI proposals and experience reports, but few studies have examined standards and models for SPI in GSD. The deployment of SPI standards and models such as CMMI and ISO/IEC 15504 were found to have been critically discussed in the domain of GSD.

In addition to financial benefits, GSD improves the entire development lifecycle [28]. This change highlights the importance of SPI programs in the GSD environment. The arrangement and successful execution of SPI activities in a distributed environment require significant time and resources [23].

The geographically distributed nature of GSD projects makes it challenging for team members to communicate and coordinate while implementing an SPI program. In a distributed environment, the deployment of process improvement activities becomes more pronounced [24]. Niazi *et al.* [24] further reported that it is challenging for GSD team members to develop SPI practices, maintain strong relationships among dispersed organizations, mitigate the temporal distance, and overcome cultural challenges. SPI practitioners must have a deep understanding and knowledge of different aspects of the process improvement program [23].

To summarize, regardless of the significance of SPI implementation, a technique is urgently required for process improvement practitioners to competently assess and manage SPI implementation initiatives in the GSD environment.

III. RESEARCH QUESTIONS AND RESEARCH CONTRIBUTION

The main aim of this study is to experimentally investigate the views and opinions of SPI experts and develop a model that can help the GSD industry successfully implement process improvement programs.

The model is based on the process improvement literature, an empirical study of the industry, and factors that can influence the deployment of SPI programs in GSD.

The following six research questions have been addressed by our research work:

RQ1. What are the success factors, as identified in the literature and in practice, which GSD organizations need to address to have a positive impact on SPI implementation?

RQ2. What are the barriers, as identified in the literature and in practice, within GSD that can have a negative impact on SPI implementation?

RQ3. Are there differences between the success factors identified in the literature and those in practice?

RQ4. Are there differences between the barriers identified in the literature and those in practice?

RQ5. How can a practically robust software process improvement implementation and management model (SPIIMM) be developed?

RQ6. How can the effectiveness of SPIIMM in the real-world GSD industry be assessed?

The primary focus of this work is the development of SPIIMM for the assessment and implementation of process improvement activities in the GSD industry. SPIIMM can help SPI practitioners identify, analyze, and address challenges related to SPI implementation, by suggesting best practices. This research project is original and significant. No study to date has addressed software process improvement implementation challenges by developing an SPI implementation management model in the context of GSD.

IV. RESEARCH METHODOLOGY

The selected research methods consist of a systematic literature review (SLR), a survey questionnaire, and a case study. The details are as follows:

- In the first phase, the SLR approach was used to identify success factors, barriers, and implementation practices from the literature.
- In the second phase, a survey approach was used to empirically confirm the findings of the SLR and identify additional success factors, barriers, and practices in addition to those reported in the first phase.
- The SPIIMM was developed based on the inputs from the SLR and the questionnaire survey.
- In the last phase, industrial case studies were conducted to assess the performance of SPIIMM in a real-world environment.

A. DATA COLLECTION AND ANALYSIS

The data collection method must be clearly described and justified as it has a significant effect on the analysis process [35], [36]. We used an SLR and a questionnaire survey to collect data from the literature and practitioners. These approaches are best for the type of data analyzed and reported in the study [35]–[37].

B. SYSTEMATIC LITERATURE REVIEW (SLR)

The SLR was conducted to extract critical success factors, barriers, and implementation practices from the literature. Rockart [38] defined SLR as a method of systematically collecting, analyzing, and reporting data from the literature of a specific research area and questions of interest [38]. The SLR technique was used to search for the most relevant literature by applying explicit inclusion and exclusion criteria for primary studies [38].

We followed the guidelines provided by Rockart [38] to conduct our SLR study. The approach consists of three main phases: planning, conducting, and reporting the review. A thorough discussion of the SLR study conducted for this research project can be found in our previously published articles [25], [63], [64].

C. EMPIRICAL DATA COLLECTION

The broad array of empirical research techniques and methods enables researchers to select the most appropriate for their research problems. Kitchenham and Charters [39] claimed that the selection of empirical research methods should be based on type of data, available resources, control over the selected approach, and the capability to operate variables of interest.

Based on the findings of the SLR, we developed an online survey questionnaire to investigate the success factors, barriers, and practices of SPI in the context of GSD. The survey questionnaire provided the opportunity to obtain data from a large group of people [40]. Information was collected regarding attitudes, which is difficult using observational research methods [40], [41].

The survey questionnaire was based on the success factors and barriers identified during the SLR study as discussed in our published research articles [25], [63], [64]. A sample of the survey questionnaire used to assess the critical success factors is available through the link http://tinyurl.com/hyyhc83.

1) PRETESTING OF THE SURVEY QUESTIONNAIRE

Pretesting the survey instrument is important, to assess the validity of its content by measuring the significant variables [42]. In this study, questionnaire pretesting was conducted with five experts in the field of empirical software engineering at the Department of Computer Science, City University of Hong Kong. The survey questionnaire was finalized after final review feedback, and minor corrections were made in the final version of the instrument.

2) POPULATION AND RESPONDENTS

Rea and Parker [43] define population as "a set of elements regarding which researchers want to make an inference." Selecting the proper sample size from the targeted population is important as collecting the data from the entire population is extremely difficult [43]. As the context of this empirical study was GSD, we needed to collect data from a diverse range of SPI experts engaged in GSD projects worldwide.

3) SAMPLING DESIGN

We selected the simple random technique to design the survey sample. The simple random approach is preferred for quantitative research [39]. In random sampling, each variable of the target population has an equal chance of selection in the sample [39]. Borrego *et al.* [44] reported that if the population is large, random sampling is the best method of obtaining a proper sample of the population. It is a proper selection method for the listed members of the population [45]. As the target population of this study was large and consisted of a diverse range of GSD organizations, the random sampling technique was appropriate. The proposed model for this work is intended to be applicable to all GSD organizations with regard to generalization; the simple random sample technique is mainly used in such cases.

4) DATA SOURCES

Based on our experience, and discussions with research colleagues and experts at the City University of Hong Kong, we decided to approach the target population using different online sources. We joined online SPI- and GSD-related groups hosted by LinkedIn (www.linkedin.com) and Facebook (www.facebook.com). These groups provide an opportunity for the SPI and GSD communities across the world to exchange views, ideas, and information related to growing trends. We have also used email to contact SPI and GSD experts. An online request was posted on the groups we joined, and separate emails were sent to specific experts to invite them to participate in the survey.

We contacted 569 participants, of which 111 completed our questionnaire. We manually reviewed all the responses to exclude incomplete entries, but found none. The respondents ranged from software developers to CEOs with expertise in SPI and GSD. The full details of the respondents are given in Appendix 1.

D. EMPIRICAL DATA ANALYSIS

1) FREQUENCY ANALYSIS

Based on the results and analyses in our previous studies [25], [63], [64], we used the frequency analysis technique in this study to report the discussion of the identified factors. The same approach has been used by other researchers for the same type of data [36], [49], [53], [58].

2) CASE STUDY ANALYSIS

We used a case study approach to evaluate the industrial effectiveness of the proposed model (SPIIMM), as this is considered the most effective evaluation technique [46]. Three case studies were conducted in three GSD organizations to evaluate SPIIMM (see Section VI). We also conducted a feedback session with the case study participants to obtain feedback regarding the functionality of the SPIIMM.

We focused on the following criteria in the participants' feedback:

- Ease of use
- User satisfaction
- Structure of SPIIMM

The given criteria could then be used to evaluate and measure the quality and effectiveness of products, and can help to explore areas featuring defects [36]. These criteria were based on studies conducted by researchers in different domains [35], [36], [46], [48], [49], [58].

V. DISCUSSION ON FINDINGS

In this section, we highlight the results of the research questions reported in (Section III). The complete SLR process, including the success factors and barriers, has been discussed in our previous research studies [25], [63], [64]. We conducted a comparative analysis of these success factors and barriers, identified using the SLR and the survey questionnaire.

A. COMPARISON OF SUCCESS FACTORS AND BARRIERS ACROSS SLR AND EMPIRICAL STUDY

To address RQ1 and RQ3, Fig. 1 and Table 1 shows a list of the success factors identified using the SLR and survey questionnaire, respectively.

Fig. 1 and Table 1 present a comparative analysis of the identified success factors. The aim of this comparison is to understand the similarities and differences between the two datasets, i.e., SLR and the empirical study.

We also performed an independent t-test to evaluate the mean difference between the ranks of SLR and the empirical study, as shown in Table 2 and Table 3, respectively.

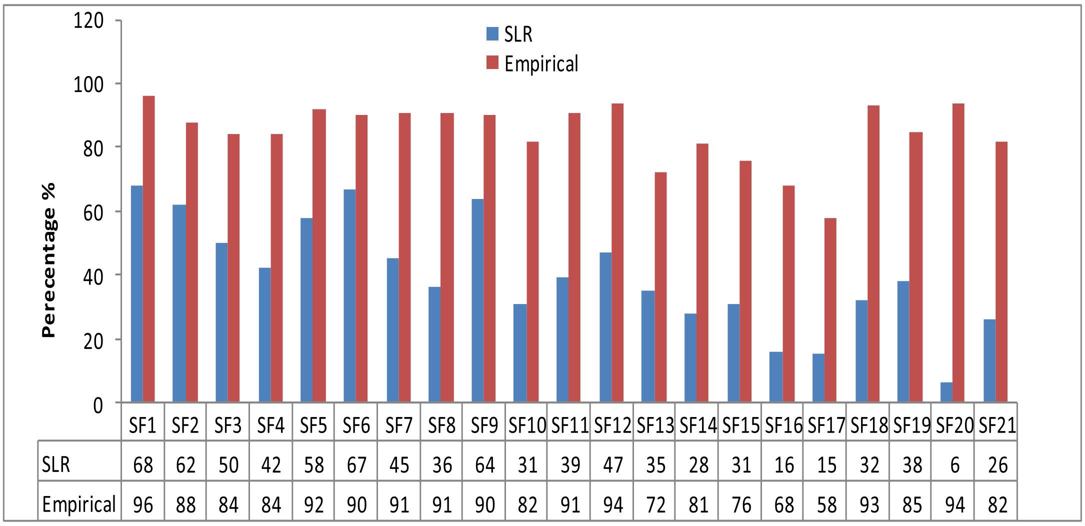

FIGURE 1. Percentage-wise comparisons of success factors identified using SLR and a survey questionnaire.

TABLE 1. Rank wise comparison of success factors across SLR and empirical study.

S. No	Success Factors	Occurrence in SLR (n=91)		Positive occurrence in survey (n=111)		Average Rank
		%	Rank	%	Rank	
SF1	Management commitment	68	1	96	1	1
SF2	Staff involvement	62	4	88	7	6
SF3	Project pilot implementation	50	6	84	9	8
SF4	Information sharing	42	9	84	9	9
SF5	Process improvement expertise	58	5	92	4	5
SF6	Allocation of resources	67	2	90	6	4
SF7	Process improvement awareness	45	8	91	5	7
SF8	Skilled human resources	36	12	91	5	9
SF9	3C (communication, coordination and control)	64	3	90	6	5
SF10	Mutual understanding between team members	31	15	82	10	13
SF11	Continuous organizational support	39	10	91	5	8
SF12	Process improvement leadership	47	7	94	2	5
SF13	Organizational culture	35	13	72	13	13
SF14	Organizational infrastructure	28	16	81	11	14
SF15	Overseas site's response	31	15	76	12	14
SF16	SPI consultancy	16	18	68	14	16
SF17	Joint management Infrastructure	15	19	58	15	17
SF18	Setting process improvement goals	32	14	93	3	9
SF19	Strong relationship between team members	38	11	85	8	10
SF20	Process improvement evaluation	6	20	94	2	11
SF21	Process improvement standards and procedures	26	17	82	10	14

Using Levene's Test, we calculated the significant difference in the ranks for SLR and the empirical study. Levene's Test is considered ideal for two or more groups of variables [63]. Table 3 shows that the results of the t-test were ($t = 2.361$, $p = 0.018 < 0.05$), and a significant difference between the ranks of the success factors was identified. For example, Table 1 shows that the success factor "SF20: process improvement evaluation" was ranked 20 in SLR but 2 in the empirical study. This shows that "SF20: process improvement evaluation" received more attention from practitioners compared to that from the available literature. Similarly, other factors ("SF18: setting process improvement goals," "SF8: skilled human resources," and "SF21: process improvement standards and procedures") featured a considerable variation in their ranks for both SLR and the empirical study. They achieved high ranking in one type of study but little consideration in the other.

In addition to independent t-test analysis, we performed a correlation data analysis test using Spearman's rank-order correlation, which assesses the statistical dependencies between the rankings of two variables [63]. Using this correlation test, we evaluated the significance of similarities between the success factors identified using SLR and the survey study. Table 4 shows that Spearman's correlation

TABLE 2. Group statistics for success factors.

	Group	N	Mean	Std. Deviation	Std. Error Mean
Rank	SLR	21	10.714	5.849	1.276
	Survey	21	7.142	3.718	0.811

TABLE 3. Independent sample T-test for success factors.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2 tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Rank	Equal variances assumed	6.057	0.018	2.361	40	0.023	3.571	1.512	0.514	6.628
	Equal variances not assumed			2.361	33.897	0.024	3.571	1.512	0.497	6.645

TABLE 4. Correlation of success factors ranks across SLR and empirical studies.

			SLR_Rank	Empr_Rank
Spearman's rho	SLR_Rank	Correlation Coefficient	1.000	0.474*
		Sig. (2-tailed)	.	0.030
		N	21	21
	Empr_Rank	Correlation Coefficient	0.474*	1.000
		Sig. (2-tailed)	0.030	.
		N	21	21

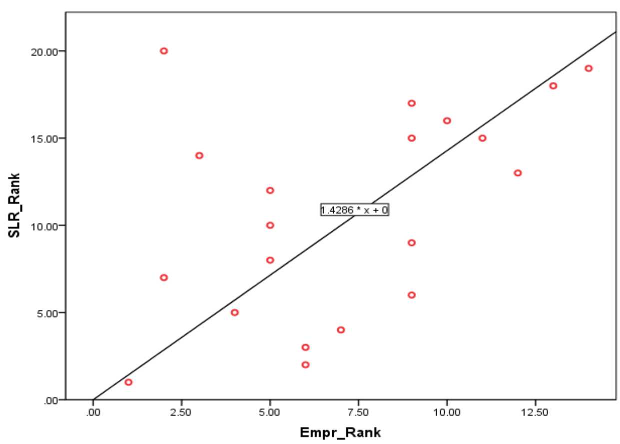

FIGURE 2. Scatterplot of the success factors ranks obtained from SLR and Empirical study.

coefficient was (0.474), with (p = 0.030). The correlation coefficient (0.474) indicated a positive correlation among the ranks obtained from the SLR and empirical data. The significance value (p = 0.030) shows that Spearman's rank-order correlation was statistically significant. These results are presented as a scatter plot in Fig. 2.

To address RQ2 and RQ4, we conducted a thorough SLR in addition to the empirical studies we previously published [25], [63], [64]. The complete results and data analysis of RQ2 and RQ4 are presented in [63]. We have conducted thorough comparative study of barriers identified during SLR and empirical study [63].

B. STRUCTURE OF SPIIMM

The success factors, barriers, and practices identified during SLR and the empirical studies provide the basis for addressing RQ5 and developing the core components of the proposed SPIIMM. The identified success factors, barriers, and practices were structured by following the concepts of the available models, i.e., CMMI [19], [56], IMM [35], and SOVRM [36], to develop SPIIMM. Fig. 3 shows the relationship between the components of SPIIMM. It demonstrates how findings of the SLR and the empirical study assist in developing the three core components of SPIIMM, i.e.,

- SPIIMM factors (CSFs and CBs) component
- SPIIMM maturity levels component
- Practices for CSFs and CBs

1) SPIIMM FACTORS (CSFs AND CBs) COMPONENT

CMMI [19] involves 25 process areas (PAs), which are classified into five maturity levels. In IMM [35] and SOVRM [36], the authors have considered the maturity levels of CMMI in terms of critical success factors (CSFs) and critical barriers (CBs) rather than process areas. The same concept of CSFs and CBs has been used in other research studies [48], [49], [58]. Researchers have identified the

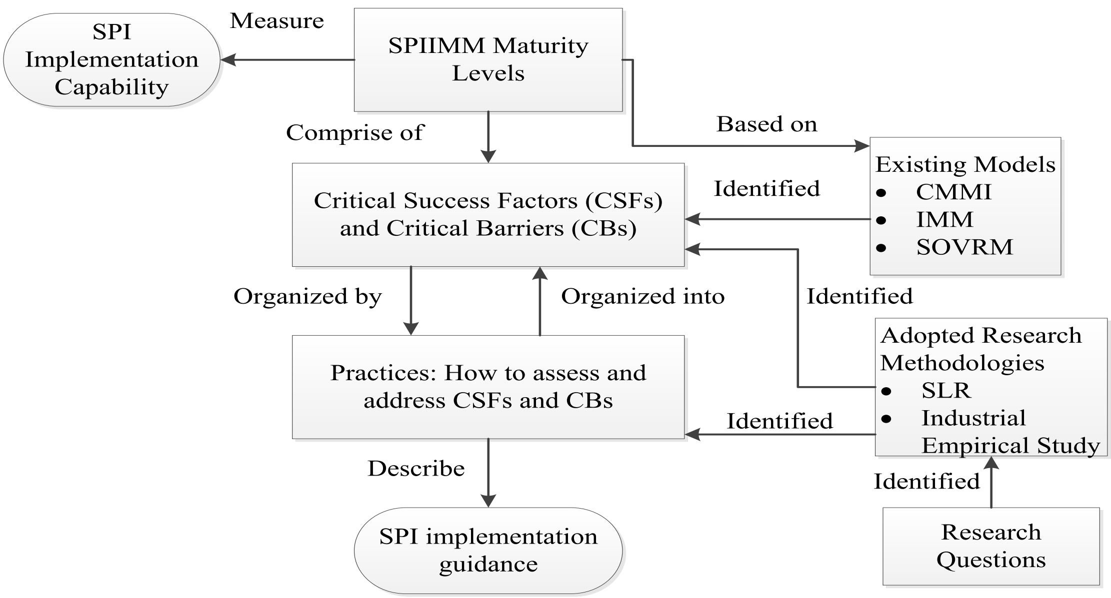

FIGURE 3. Structure of SPIIMM.

significance of CSFs and CBs [36], [48], [52], [57], [58]. Therefore the concept of using CSFs and CBs can be effective in developing SPIIMM.

The concept of critical factors was proposed by Rockart [43] to identify the information needs of the chief executive of a business. Critical factors are based on the concept of factors discussed in the literature of management [51]. Kuhrmann *et al.* [35] highlighted that critical factors present the key areas of process improvement projects. SPI experts should focus on those key areas otherwise they may not achieve the long-term benefits of SPI [35], [36], [43], [52]. Critical factors depend on the positions of the employees in an organization and may differ from person to person. They also depend on the dispersal of the team members across geographical, cultural, and temporal boundaries [35], [43], [52].

The following criteria were used to determine the criticality of a factor:

- If a factor has a frequency ≥50% in both the literature and the empirical study, it was considered critical.

The same criterion has been used by researchers in other domains [25], [36], [53], [54], and to determine the CSFs and CBs for SPI implementation, regardless of significant differences among datasets (i.e., SLR and the empirical study).

We have identified the following CSFs using the above criteria: CSF1: management commitment, CSF2: staff involvement, CSF3: allocation of resources, CSF4: 3Cs (communication, coordination, and control), CSF5: project pilot implementation and CSF6: process improvement expertise.

Similarly, the reported CBs are: CB1: lack of organizational support, CB2: lack of communication, CB3: lack of process improvement knowledge, CB4: lack of formal SPI implementation methodology and CB5: lack of resources. We have reported the detail analysis of CBs in [25] and [63].

2) SPIIMM MATURITY LEVEL COMPONENT

In this research study, a staged representation of CMMI [19], [56] was followed to structure the maturity levels of SPIIMM. CMMI consists of five maturity levels, and each level is based on different PAs. The PAs of CMMI maturity levels contain various real-world practices. The CMMI maturity levels and its categorization are based on different PAs. This leads us to design SPIIMM maturity levels that are composed of different CSFs and CBs. We also identified the real-world practices to address each CSF and CB of a specific maturity level. The CSFs and CBs are briefly discussed in Section V-B1.

For the SPIIMM, we made some alterations in the structure of CMMI maturity levels (Fig. 4):

- Level-1 (Initial): We considered the first level of CMMI as the initial maturity level of SPIIMM [19], [56]. At this level the SPI activities are not formally defined and only few processes are presented. This level has no CSF and CB.
- Level-2 (Commitment): Commitment has been identified as the most significant factor in the SLR study (68%) and the survey questionnaire (96%). The implementation of the SPI program is a long-standing approach and requires the commitment of organizational management, in the sense of participating in SPI activities, providing the adequate resources, time, appropriate infrastructure, and continuous support to successfully execute the process improvement activities. Therefore, based on the results obtained from the SLR and the empirical study, the level-2 of

TABLE 5. SPIIMM maturity levels.

Maturity Levels	CSFs	CBs	Practices
Level-1 (Initial)	Nill	Nill	Nill
Level-2 (Commitment)	CSF1:Management commitment	CB3: Lack of process improvement knowledge	CSF1: Management commitment (Practices are given in Table 15 and Table 17) CB3: Lack of process improvement knowledge (Practices are given in Table 16)
Level-3 (Communication)	CSF2: Staff involvement CSF4: 3Cs (communication, coordination, control)	CB2: Lack of communication	CSF2: Staff involvement (Practices are given in Table 15 and Table 17) CSF4: 3Cs (communication, coordination, control) (Practices are given in Table 15 and Table 17) CB2: Lack of communication (Practices are given in Table 16)
Level-4 (Managed)	CSF3: Allocation of resources CSF5: Project pilot implementation	CB4: Lack of formal SPI implementation methodology CB5: Lack of resources	CSF3: Allocation of resources (Practices are given in Table 15 and Table 17) CSF5: Project pilot implementation (Practices are given in Table 15 and Table 17) CB4: Lack of formal SPI implementation methodology (Practices are given in Table 16) CB5: Lack of resources (Practices are given in Table 16)
Level-5 (Optimizing)	CSF6: Process improvement expertise	CB1:Lack of organizational support	CSF6: Process improvement expertise (Practices are given in Table 15 and Table 17) CB1:Lack of organizational support (Practices are given in Table 16)

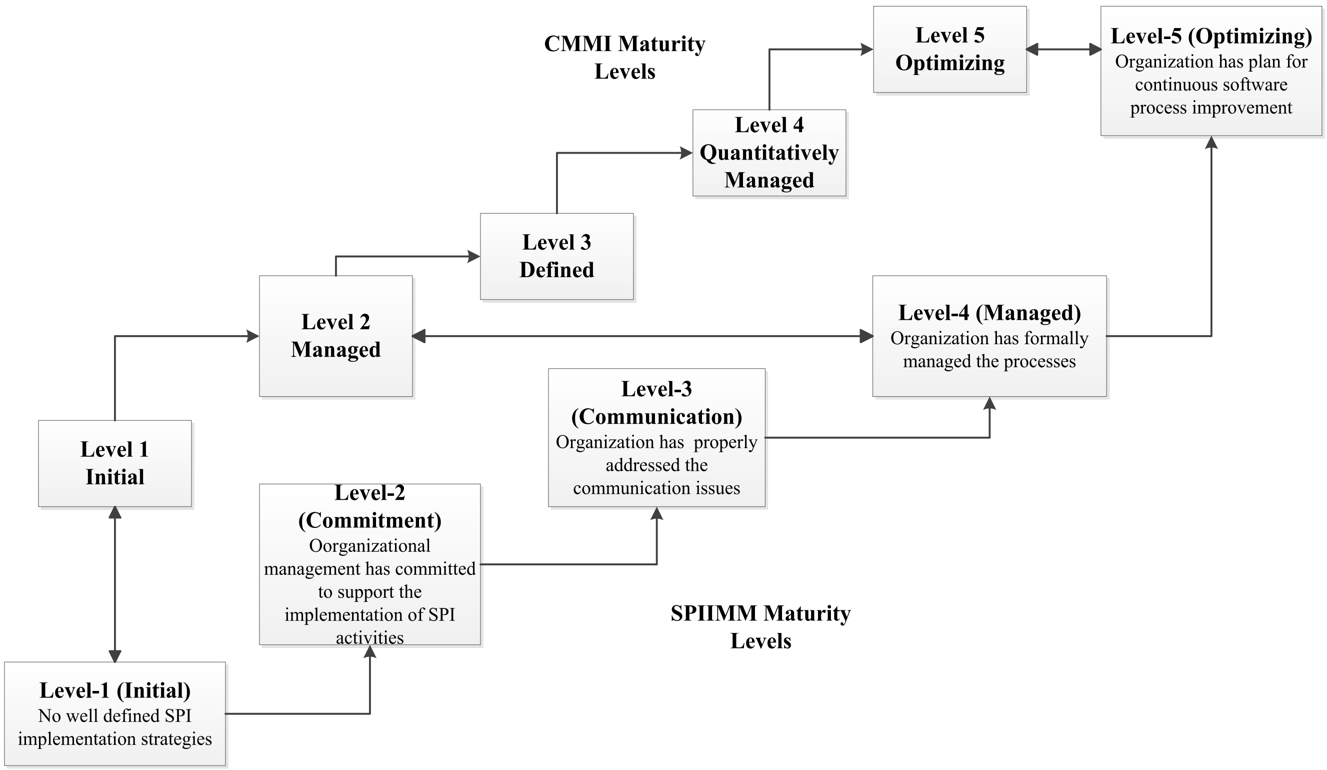

FIGURE 4. Comparison of SPIIMM and CMMI maturity levels.

SPIIMM was considered as "commitment." Organizational management should thus commit to consider the SPI as a real-world project. This level has one CSF and one CB (Table 5).

- Level-3 (Communication): The focus of this level is that the organization has appropriately addressed all the issues related to communication, which has been considered as the maturity level in another study [49], to develop a communication and coordination challenges mitigation model for GSD vendor organizations. Therefore, in this research study the level-3 "Communication" is adopted from [49] as the domain of our work is also based on GSD. Similarly, the 3Cs (communication, coordination, control) have been found to be significant factors in SLR (64%) and the empirical study (90%), as shown in Table 1. Therefore, we have considered ''communication'' as the maturity level because both coordination and control are dependent on communication [40]. Level-3 consists of two CSFs and one CB (Table 5).

- Level-4 (Managed): Level-4 of SPIIMM has been directly selected from CMMI as at this level all the processes are formally managed [19], [48]. The level consists of two CSFs and two CBs (Table 5).
- Level-5 (Optimizing): Optimizing is the final maturity level of SPIIMM and is directly taken from CMMI. At this level the organizations develop a structure for continuous improvement [19], [48]. The level has one CSF and one CB (Table 5).

SPIIMM does not adopt ''level-3: Defined'' and ''level-4: Quantitatively Managed'' of CMMI. In this research work, we found no factor that directly relates to level-3 and level-4 of CMMI.

3) SPIIMM PRACTICES COMPONENT

To address the reported CSFs and CBs, we identified a list of practices using SLR and a survey questionnaire, as discussed in Appendix 2. All the identified practices along their respective CSFs and CBs are reported in Table 5. In Appendix 2, Table 15 consists of those practices identified during the SLR study to address the CSFs, and Table 17 contains the additional new practices that were not found during the SLR study but reported by the survey respondents. In total 45 practices were identified that could address the reported CSFs, as shown in Appendix 2.

Similarly, various practices were identified to address the CBs. The CBs along their respective practices are given in Table 5. We identified 26 practices to address the CBs. In these practices, one additional new practice was mentioned by the survey respondents. The remaining 25 were extracted from the literature and validated for SPI implementation in GSD organizations, using the survey questionnaire approach. The practices are briefly discussed in Appendix 2 (Table 16).

C. SPIIMM ASSESSMENT METHOD

We used the Motorola assessment tool [59] to evaluate the effectiveness of SPIIMM. This tool has been used by other researchers to assess the efficiency of their proposed models [36], [48], [49], [58]. The Motorola assessment instrument has numerous advantages. It is normative and has been tried and tested by Motorola. The instrument is used to evaluate the status of an organization relative to CMM and CMMI, and can indicate the weak areas of an organization that need further attention and improvements [59]. It consists of the following three evaluation dimensions [59].

- **Approach:** The criterion for this dimension is based on the commitment of organizational management to the practice, and also the capability of an organization to implement the practice.
- **Deployment:** The criterion developed for this dimension is the uniform and consistent deployment of practices across all areas of the project.
- **Results:** In this dimension the criterion is about the breadth and consistency of positive results over time and across the project areas.

Each dimension was assigned a score from 0-10 [59]. The scoring criterion for each dimension is discussed in [59].

The following steps of the Motorola instrument have been adopted for SPIIMM assessment [72].

- Step-1: The participant from the SPI implementation team should compute the three-dimensional score of the Motorola instrument for each practice of critical success factors (CSFs) and critical barriers (CBs).
- Step-2: The calculated three-dimensional scores of each practice should be added together and divided by three (3).
- The final calculated score should round to the nearest whole number.
- Step-3: Repeat step-2 for each practice of the identified CSFs and CBs. Add the scores of all the practices together to calculate the final score for specific CSF or CB.
- Step-4: Relating the assessment score to SPIIMM: a score of 7 or above for a specific critical success factor or critical barrier will show that the particular CSF or CB has been effectively implemented [59]. If the score of any CSF or CB is lower than seven then the implementation of that particular CSF or CB is considered weak [59].
- Step-5: To achieve a specific maturity level of SPIIMM, it is vital to address all the CSFs and CBs of that particular maturity level. For example, if the organization want to attain the maturity level-3 of SPIIMM it is must to address all the CSFs and CBs of level 3, i.e., (CSF2: staff involvement), (CSF4: 3C's (communication, coordination, control), and (CB2: lack of communication) and their average score should be seven or above.

In Table 6 the evaluation example of SPIIM is shown by following the above five steps of the Motorola instrument.

The results presented in Table 6 shows that the practices identified for the critical success factor (CSF1: management commitment) have an overall average score of five. This reveals that the success factor (CSF1: management commitment) is not completely addressed, as its average score is less than seven. To assess the SPI maturity level of an organization, it is vital to go through the evaluation of all the practices identified for CSFs and CBS.

VI. ASSESSMENT OF SPIIMM

To address RQ6, we adopted a case study approach to assess the software process improvement implementation and management model (SPIIMM) using the Motorola assessment

TABLE 6. Assessment example of SPIIMM factors using motorola assessment instrument.

CSF1:Management Commitment					
S. No	**Practices**	**Key Activity evaluation dimensions**			**Average Score (Average of the dimension values)**
		Approach (0,2,4,6,8,10)	**Deployment (0,2,4,6,8,10)**	**Results (0,2,4,6,8,10)**	
P1-CSF1	Organizational management commit to support the SPI program.	6	6	8	7
P2-CSF1	Organizational management reserve sufficient resources for SPI activities.	4	2	2	3
P3-CSF1	Regularly observe the activities involved in the SPI program.	6	4	4	5
P4-CSF1	Provide a well establish infrastructure that can motivate the team members to participate in process improvement activities.	4	4	2	3
P5-CSF1	Encourage the efforts of the practitioners involved in process improvement programs.	6	8	8	7
P6-CSF1	Top level management lead the initiation and implementation of the SPI program	8	6	6	7
P7-CSF1	Management encourage and drive the bottom-up staff in SPI activities.	8	6	4	6
P8-CSF1	Organizational management motivate SPI team members and non-SPI staff members to accept the changes of process improvement.	8	8	8	8
P9-CSF1	Users see that the change is of benefit to them as individuals and to the entire organization.	4	2	6	4
P10-CSF1	Tope level management lead the initiation and implementation of the SPI program	2	2	2	2
Total of "average scores" = (add the average score values in the right-most column)					52
Overall score = Total of "average score"/total number of practices = (52/10 = 5.2)					5

tool. A case study approach is considered to be more effective for the assessment and can provide adequate information about real-world industry experience [46]. As SPIIMM is designed to be implemented in the real-world software industry this approach is considered to be more suitable and effective for this research study. The aim of the real-world case study was to examine whether SPIIMM is appropriate for the GSD industry.

A. SPIIMM ASSESSMENT CRITERIA

We used the following criteria to assess the effectiveness of SPIIMM.

- **Ease of use:** The aim of this criterion is to measure how easily experts can use and understand the implementation of SPIIMM.
- **User satisfaction:** The objective of this criterion is to measure the degree of user satisfaction with the outputs of SPIIMM.
- **Structure of SPIIMM**: The objective of this criterion is to assess the key components of SPIIMM and also to provide an overview of the classification of the identified CSFs and CFs across the maturity levels of SPIIMM.

The criteria are based on the literature, and have been used by other researchers [48], [58]. The above criteria are followed to examine those areas where SPIIMM needs further improvements. All the evaluation results of SPIIMM are used to modify its structure and for future study.

B. SPIIMM ASSESSMENT USING CASE STUDIES

Three case studies were conducted in GSD organizations to evaluate the effectiveness of SPIIMM. Organizations were randomly selected for the case studies by visiting their profiles on the social network LinkedIn. We visited their websites for further information and details about their SPI activities. Initially we contacted some of the organizations by sending an invitation letter via email. The sample invitation letter can be found via the link http://tinyurl.com/zu79lv7. Finally, we selected three organizations for the case studies. The selected organizations provided rich descriptions of their process improvement efforts and agreed to release the case study results. We sent a guideline document to each participant of the case study, which consists of a brief introduction of the project and the assessment procedure. The sample guideline document can be found via the link http://tinyurl.com/go2n5ky. The participants from the selected organizations assessed the SPI capabilities of their organization against the maturity levels of SPIIMM.

We also conducted a feedback session with the case study participants to investigate the results and usefulness of SPIIMM (Section VI-G). A questionnaire was developed to

TABLE 7. Assessment results for critical success factor and critical barriers in company A.

Maturity Levels	CSFs and CBs	Final Score	Status in Company A
Level-1 (Initial)	-	-	-
Level-2 (Commitment)	CSF1: Management commitment	7.1	Strong
	CB:3 Lack of process improvement knowledge	7	Strong
Level-3 (Communication)	CSF2: Staff involvement	7.37	Strong
	CSF4: 3Cs (communication, coordination, control)	7.14	Strong
	CB2: Lack of communication	8	Strong
Level-4 (Managed)	CSF3: Allocation of resources	8.83	Strong
	CSF5: Project pilot implementation	2	Weak
	CB5: Lack of resources	7	Strong
	CB4: Lack of formal SPI implementation methodology	9	Strong
Level-5 (Optimizing)	CSF6: Process improvement expertise	5.71	Weak
	CB1: Lack of organizational support	7.8	Strong

structure the feedback session, and can be found via the link (http://tinyurl.com/zyxhf26). The questionnaire consists of three sections, A, B, and C. Section-A provides detailed demographic information about each participant. Section-B contains the evaluation of SPIIMM according to the assessment criterion discussed in Section VI-A. In Section-C, the list of the identified practices for CSFs and CBs is provided to the participant for review and suggestions.

C. PROFILES OF SELECTED ORGANIZATIONS

The selected three organizations are tagged as companies A, B, and C. Due to privacy reasons the original names of the respondent organizations are not disclosed.

1) COMPANY A

Company A is an ISO 9001:2008 certified international company that provides consulting and services related to information technology and electronics. Company A is a large organization with 10000+ employees and its network spans 54 countries worldwide. The participant of this case study is a product process consultant working in the branch of Company A located in Delhi, India.

Company A provides consultancy and technical services in the following main areas.

- Electronics industry
- Machinery and heavy industry
- Chemical industry
- Financial services

2) COMPANY B

Company B is a medium-sized government organization located in Uruguay. It has 200 employees and provides consulting services to software development organizations, in subjects ranging from standards adoption to organizational strategy. Company B assists software development organizations in transforming their development lifecycle to become agile, to achieve ISO certifications, and to streamline their delivery process.

The main areas where Company B provides consultation to software development organizations are as follows.

- Process improvement for software organizations
- Transition to agile development
- Process evaluation
- Quality management system deployment
- ISO 9001 audits

3) COMPANY C

Company C is a small organization located in London, U.K. It offers consulting and training services for software process improvement in the IT and telecommunication sectors. The participant of this case study is a senior project manager and business analyst. Company C helps organizations achieve their strategic business goals by providing consultancy and projects in the following areas.

- Business process redesign and alignment to strategic goals.
- Improving business controls to enhance the effectiveness and efficiency of the management processes.
- Design and management of programs and projects to roll out the new processes and process controls across the organization.
- Providing consultancy with CMMI process improvement strategies, methodology, and Implementation.

D. CASE STUDY RESULTS AT COMPANY A

We used the Motorola assessment instrument [59] discussed in Section V-C to evaluate SPIIMM. According to the assessment criteria, if a specific critical success factor or critical barrier scores greater than seven, it will indicate that those factors have been successfully implemented.

The respondent of Company A assessed the SPI implementation maturity level of his organization for the reported CSFs and CBs of SPIIMM. The summarized results of the case study conducted at Company A are reported in Table 7.

The results in Table 7 illustrate that Company A is at Level-3 of SPIIMM. The company has addressed all CSFs and CBs of Level-2 and Level-3 as the average score of each CSF and CB is ≥ 7.

To achieve a specific maturity level, all the CSFs and CBs of that level should be addressed, and the average score

TABLE 8. Assessment results for critical success factor and critical barriers in company B.

Maturity Levels	CSFs and CBs	Final Score	Status in Company B
Level-1 (Initial)	-	-	-
Level-2 (Commitment)	CSF1: Management commitment	7.7	Strong
	CB:3 Lack of process improvement knowledge	3.8	Weak
Level-3 (Communication)	CSF2: Staff involvement	5.08	Weak
	CSF4: 3C's (communication, coordination, control)	3.42	Weak
	CB2: Lack of communication	7	Strong
Level-4 (Managed)	CSF3: Allocation of resources	7	Strong
	CSF5: Project pilot implementation	10	Strong
	CB5: Lack of resources	6.8	Weak
	CB4: Lack of formal SPI implementation methodology	10	Strong
Level-5 (Optimizing)	CSF6: Process improvement expertise	9	Strong
	CB1: Lack of organizational support	5.2	Weak

TABLE 9. Assessment results for critical success factor and critical barriers in company C.

Maturity Levels	CSFs and CBs	Final Score	Status in Company C
Level-1 (Initial)	-	-	-
Level-2 (Commitment)	CSF1: Management commitment	7.1	Strong
	CB:3 Lack of process improvement knowledge	7.4	Strong
Level-3 (Communication)	CSF2: Staff involvement	7.7	Strong
	CSF4: 3C's (communication, coordination, control)	5.8	Weak
	CB2: Lack of communication	6.8	Weak
Level-4 (Managed)	CSF3: Allocation of resources	7.2	Strong
	CSF5: Project pilot implementation	6.6	Weak
	CB5: Lack of resources	6.2	Weak
	CB4: Lack of formal SPI implementation methodology	7.1	Strong
Level-5 (Optimizing)	CSF6: Process improvement expertise	5.6	Weak
	CB1: Lack of organizational support	5.7	Weak

should be $\geq$7. Therefore, to achieve maturity Level-4, Company A must seriously address the critical success factor (CSF5: project pilot implementation) as its current score is less than 7, meaning that Company A has given less attention to conducting a pilot-based implementation of newly adopted standards and models.

E. CASE STUDY RESULTS AT COMPANY B

The respondent of Company B is an SPI consultant and researcher, and he evaluated the maturity level of the company using SPIIMM. A summary of the results is presented in Table 8.

The results illustrate that Company B stands at Level-1 (Initial) of SPIIMM as one critical barrier, i.e., (CB3: lack of process improvement knowledge), of Level-2 is not fully addressed, as the average final score is $<$7. Company B should thoroughly address this barrier to achieve the maturity Level-2 (Commitment). Similarly, to achieve maturity Level-3 and Level-4, Company B should address the critical success factors and barriers, as it has an average final score lower than 7.

F. CASE STUDY RESULTS AT COMPANY C

The participant of the case study used SPIIMM to assess and measured the SPI related maturity level of Company C. The results presented in Table 9 show that Company C is at maturity level-2 of SPIIMM. CSFs and CBs of levels-2 (Commitment) are strongly addressed as their average evaluation scores are $\geq$7. The management of company C is therefore strongly committed to the implementation of SPI activities.

G. EXPERTS FEEDBACK ON SPIIMM

In addition to the case studies, the experts were requested to evaluate the SPIIMM against the assessment criteria reported in Section VI-A. As discussed, a questionnaire survey was used to conduct the feedback sessions with the three participants of the case studies. Each participant was asked to assess the effectiveness of SPIIMM against the following criteria.

- Ease of use
- User satisfaction
- Structure of SPIIMM

1) EASE OF USE

The results show that the case study participants of SPIIMM were satisfied with respect to the criterion developed for ease of use. The participants were asked questions about the ease of use and their feedback was positive. They agreed with the assessment results of SPIIMM. The summarized results regarding ease of use are presented in Table 10, which

TABLE 10. SPIIMM feedback results (ease of use) of companies A, B and C.

Ease of Use	No of Participants (n=3)								
	Positive (+Ve)				Negative (-Ve)				
	EA	MA	A	EA+MA+A	ED	MD	D	ED+MD+D	NU
Representation of SPIIMM is simple.	2	1	0	3	0	0	0	0	0
SPIIMM need little SPI knowledge to understand it.	2	0	1	3	0	0	0	0	0
It's simple to understand the practices of critical success factors and barriers.	1	0	2	3	0	0	0	0	0
It's simple to understand the Motorola assessment technique.	0	0	3	3					
It's simple to implement SPIIMM for process improvement activities.	0	3	0	3	0	0	0	0	0
It's simple to understand the maturity levels of SPIIMM along their critical success factors and critical barriers.	0	2	1	3	0	0	0	0	0
SPIIMM needs training to fully understand it.	0	0	1	1	0	0	0	0	2
Extremely Agree (EA), Moderately Agree (MA), Agree (A), Neutral (NU), Extremely Disagree (ED), Moderately Disagree (MD), Disagree (D)									

TABLE 11. SPIIMM feedback results (user satisfaction) of companies A, B and C.

User Satisfaction	No of Participants (n=3)								
	Positive (+Ve)				Negative (-Ve)				
	EA	MA	A	EA+MA+A	ED	MD	D	ED+MD+D	NU
SPIIMM is generic in nature and could be installed in different global software development organizations.	0	1	2	3	0	0	0	0	0
SPIIMM could help an organization to understand weak and strong areas of process improvement.	1	1	1	3	0	0	0	0	0
The use of SPIIMM could improve the software process of our organization.	0	0	2	2	0	0	0	0	1
I will prefer to use SPIIMM in my organization.	0	0	3	3	0	0	0	0	0
I am confident with the results of SPIIMM.	1	1	1	3	0	0	0	0	0
The software tool of SPIIMM could facilitate the experts to implement SPI.	0	2	1	3	0	0	0	0	0
SPIIMM is a useful model for global software development organizations.	1	1	1	3	0	0	0	0	0
Extremely Agree (EA), Moderately Agree (MA), Agree (A), Neutral (NU), Extremely Disagree (ED), Moderately Disagree (MD), Disagree (D)									

show that the participants positively agreed with the questions regarding the ease of use of SPIIMM. Two participants were neutral concerning the need of conducting training sessions to completely understand the use of SPIIMM.

2) USER SATISFACTION

All the participants provided positive responses and highlighted that it would be useful to deploy SPIIMM in the software industry, which illustrates that the experts considered SPIIMM useful and elegant for the GSD industry. They were asked to rank the usefulness of SPIIMM for the GSD industry and 100% of the participants gave a satisfactory response, as shown in Table 11. Any type of GSD organization can therefore assess their SPI related activities using SPIIMM and also could deploy it to improve their process improvement program.

The experts responded to the other questions positively, i.e., the generic nature of SPIIMM, reporting the weak and strong areas of the organization related to SPI, and the software tool of SPIIMM.

3) STRUCTURE OF SPIIMM

The feedback questionnaire consists of closed and open-ended questions, to identify any limitations in the structure of SPIIMM. The summarized results of the responses regarding the structure of SPIIMM are reported in Table 12. The participants positively considered the core components of SPIIMM as practical and robust for the GSD industry. The experts also agreed with the five maturity levels of SPIIMM to assess the SPI maturity level of an organization. The maturity levels are thus sufficient and well-defined.

One expert reported additional improvement by moving the critical barrier (CB3: lack of process improvement knowledge) from maturity level-2 (Commitment) to level-4 (Managed). He reported that the management may have a complete understanding and knowledge of the process improvement program but may still not be committed. Similarly, he suggested moving critical barrier (CB5: lack of resources) from level-4 (Managed) to level-2 (Commitment) as lack of sufficient resources can prevent higher management from committing to deploying the SPI program.

One expert recommended moving practice (P3-SF2: Facilitate process improvement team members) from factor (CSF2: staff involvement) to (CSF1: management commitment). He highlighted that providing the core facilities will demonstrate the strong commitment of higher management toward the implementation of the SPI program. One expert suggested rephrasing the practice (P1-CB3: Detail

TABLE 12. SPIIMM feedback results (structure of SPIIMM) of companies A, B and C.

Structure of SPIIMM	No of Participants (n=3)								
	Positive (+Ve)				Negative (-Ve)				
	EA	MA	A	EA+MA+A	ED	MD	D	ED+MD+D	NU
The core components of SPIIMM are self-explanatory and no need of further explanation to be used effectively.	0	0	2	2	0	0	1	1	0
The SPIIMM components are practical and could be used in the GSD industry.	0	0	3	3	0	0	0	0	0
The implementation of SPIIMM could assist an organization to identify issues related to SPI.	2	1	0	3	0	0	0	0	0
The five maturity levels of SPIIMM are enough to assess the SPI maturity level of an organization.	2	0	1	3	0	0	0	0	0
Extremely Agree (EA), Moderately Agree (MA), Agree (A), Neutral (NU), Extremely Disagree (ED), Moderately Disagree (MD), Disagree (D)									

TABLE 13. Modification of SPIIMM structure based on case studies feedback.

Maturity Levels	CSFs	CBs	Practices
Level-1 (Initial)	Nill	Nill	Nill
Level-2 (Commitment)	CSF1:Management commitment	CB5: Lack of resources	CSF1: Management commitment (Practices are given in Table 15 and Table 17) CB5: Lack of resources (Practices are given in Table 16)
Level-3 (Communication)	CSF2: Staff involvement CSF4: 3Cs (communication, coordination, control)	CB2: Lack of communication	CSF2: Staff involvement (Practices are given in Table 15 and Table 17) CSF4: 3Cs (communication, coordination, control) (Practices are given in Table 15 and Table 17) CB2: Lack of communication (Practices are given in Table 16)
Level-4 (Managed)	CSF3: Allocation of resources CSF5: Project pilot implementation	CB4: Lack of formal SPI implementation methodology CB3: Lack of process improvement knowledge	CSF3: Allocation of resources (Practices are given in Table 15 and Table 17) CSF5: Project pilot implementation (Practices are given in Table 15 and Table 17) CB4: Lack of formal SPI implementation methodology (Practices are given in Table 16) CB3: Lack of process improvement knowledge (Practices are given in Table 16)
Level-5 (Optimizing)	CSF6: Process Improvement Expertise	CB1:Lack of organizational support	CSF6: Process improvement expertise (Practices are given in Table 15 and Table 17) CB1:Lack of organizational support (Practices are given in Table 16)

process improvement knowledge) to a meaningful sentence. We therefore updated this practice to (P1-CB3: Team members should have deep and detailed knowledge related to process improvement).

Another expert criticized the adopted Motorola assessment method. He mentioned that the way we have used this method is complex in the case study. He suggested using the Motorola assessment tool when we conduct focus group studies. This could be a valuable suggestion for researchers willing to use the Motorola assessment tool.

H. REVISED SPIIMM

The structure of SPIIMM was revised based on the case studies conducted with the SPI expert. The feedback results of the expert revealed that minor changes in the structure of SPIIMM are necessary. As discussed in Section VI-G3, we moved the critical barrier (CB3: lack of process improvement knowledge) from maturity level-2 (Commitment) to level-4 (Managed). Similarly, one expert recommended moving the critical barrier (CB5: lack of resources) from level-4 (Managed) to level-2 (Commitment). Other small changes were made in the practices of CSFs and CBs by moving practice (P3-SF2: facilitate process improvement team members) from factor (CSF2: staff involvement) to (CSF1: management commitment). The revised structure of SPIIMM is shown in Table 13.

VII. THREATS TO VALIDITY

We have identified some issues in the design of this study. Internal validity refers to the overall evaluation of the results. The outcomes of the pilot study provided an acceptable level of internal validity as the variables considered in this research work were obtained from a detailed literature review and piloting of the questions.

TABLE 14. **Information of empirical study respondents.**

S.No	Job Title	Experience	Country	Primary Business Function	Size	Adopted SPI standards/ models	SPI in operation (Years)
1.	Software Engineer	5	Nigeria	Collocated software development	Medium	Not sure	10
2.	Software Engineer	2	China	Collocated/Global software development	Large	Not sure	4
3.	Researcher	5	China	Collocated software development	Large	Not sure	0
4.	Researcher	8	Pakistan	SPI Consultancy	Medium	CMMILevel-2 (Managed)	3
5.	Researcher	12	China	Software Engineering research	Small	Not sure	2
6.	Researcher	8	Saudi Arabia	Research Institute	Medium	CMMILevel-3 (Defined)	2
7.	Researcher	1	China	Global Software Development	Medium	CMMILevel-4 (Quantitatively Managed)	5
8.	Researcher	18	Pakistan	Collocated software development	Small	CMMILevel-2 (Managed)	5
9.	Senior process executive	>4	India	Global Software Development	Large	CMMILevel-4 (Quantitatively Managed)	4-7
10.	Researcher	4	Pakistan	Research Institute	Medium	Not sure	5
11.	Professor emeritus	46	Norway	SPI research	Large	ISO	10
12.	Researcher	20	Cyprus	Research Institute	Small	No	0
13.	Professor	18	Saudi Arabia	Research	Large	CMMILevel-3 (Defined)	5
14.	Researcher	10	Pakistan	Research	Medium	HEC, Pakistan	10
15.	Researcher	3	Pakistan	Research	Small	Not sure	0
16.	Researcher	4	Pakistan	Research	Medium	Not sure	0
17.	Software Applications Developer	4	China	Telecommunications	Large	CMMILevel-4 (Quantitatively Managed)	4
18.	CEO	5	Pakistan	Global Software Development	Small	Nil	0
19.	CTO	22	Netherlands	Global Software Development	Medium	Nil	0
20.	Software Engineer	1	China	Collocated/Global software development	Medium	CMMILevel-4 (Quantitatively Managed)	2
21.	IT In charge	<1	UAE	Global Software Development	Medium	Nil	0
22.	SPI consultant	40	USA	SPI consulting	Small	Nil	0
23.	Consultant	20	China	Global Software Development	Large	CMMILevel-3 (Defined)	3
24.	Software Developer	3	Nigeria	Collocated Software Development	Medium	ISO	2-3
25.	Researcher	35	UK	Research	Large	Nil	0
26.	Researcher	4	Malaysia	Research	Large	Not sure	0
27.	CEO	5	Pakistan	Global Software Development	Small	CMMILevel-1 (Initial)	<1
28.	Project Manager	4	Pakistan	Collocated/Global software development	Small	CMMILevel-1 (Initial)	1
29.	Professor	7	Pakistan	Research	Large	Not sure	5
30.	Web Developer	2	Pakistan	Collocated/Global software development	Medium	CMMILevel-2 (Managed)	Nil
31.	Software Engineer	3	Pakistan	Collocated software development	Small	CMMILevel-1 (Initial)	2
32.	Research	5	China	Research; Education	Large	Not sure	2
33.	Senior SPI Consultant	42	UK	Consultancy & Training	Small	Provide CMMI Consultancy to other companies	4
34.	Manager	11	Vietnam	Collocated Software Development; BPO, Data Entry, Image Processing	Small	CMMILevel-3 (Defined)	8
35.	Global Process Lead	12	UK	Process Leadership	Large	ISO	6

TABLE 14. **Information of empirical study respondents.** ***(Continued.)***

36.	Interim Manager	27	USA	Interim Management of Software Development	Small	ISO	25
37.	Assistant Vice President	27	China	Finance	Not sure	Self-developed	15
38.	SEO executive	3	Pakistan	Collocated/Global software development	Medium	CMMILevel-1 (Initial)	<1
39.	Professor	15	Denmark	Research	Small	Nil	0
40.	Chief operating officer	9	Pakistan	Global Software Development/web development and design	small	CMMILevel-1 (Initial)	1
41.	Senior web developer	5	Pakistan	Global Software Development	Medium	Not sure	Nil
42.	Software Engineer	2	Pakistan	Collocated/Global software development	Small	CMMILevel-1 (Initial)	<1
43.	Manager	7	Pakistan	Collocated/Global software development	Medium	Not sure	Nil
44.	Senior Executive Consultant	15	USA	Business Function	Large	Other	15
45.	Software Engineer	1	China	Collocated Software Development	Medium	Not sure	Nil
46.	SPI Practitioner	11	India	Collocated Software Development/Consulting services	Medium	Not sure	Nil
47.	Researcher	8	Saudi Arabia	Research	Large	Not Sure	Nil
48.	Software Developer	4	Pakistan	Global software development	Medium	CMMILevel-2 (Managed)	Nil
49.	Process Management Consultant	30+	UK	Consultancy	Large	Multiple	5
50.	VP and CTO, Namcook Analytics LLC	45	USA	Consultancy/Research	Small	CMMILevel-3 (Defined)	15
51.	Professor	30	Colombia	Research	Small	Not Sure	Nil
52.	Professor	8	Pakistan	Global Software Development/Research	Small	Not Sure	Nil
53.	Social Media/Admin Assistant	2	Pakistan	Collocated/Global software development	Small	Not Sure	Nil
54.	iOS Developer	2	Pakistan	Collocated/Global software development	Small	Not Sure	Nil
55.	Professor	23	Norway	Research	Medium	Not Sure	Nil
56.	CMMI Lead Appraiser	30	Germany	Global Software Development	Medium	CMMILevel-2 (Managed)	Nil
57.	Senior Software Project Manager	20	Vietnam	Automotive Software	Small	CMMILevel-3 (Defined)	13
58.	Researcher	25	India	Research	Large	Nil	Nil
59.	Quality Assurance	3	Pakistan	Global Software Development	Medium	CMMILevel-3 (Defined)	3
60.	Chairman and MD	40	India	Collocated Software Development	Small	Not initiated	0
61.	Researcher	<1	Sweden	Research	Small	Not Sure	Nil
62.	Professor	10	Pakistan	Research	Large	Not Sure	Nil
63.	Professor	30	UAE	Global Software Development/ Banking & Insurance	Large	CMMILevel-1 (Initial)	2
64.	Agile Coach / Consultant	7	Malaysia	Consultation / Coaching / Training	Medium	Not Sure	Nil
65.	Senior Developer	2	Pakistan	Collocated Software Development	Small	Not Sure	Nil
66.	Researcher	9	China	Research	Medium	Not Sure	Nil
67.	IT Officer	5	Pakistan	Research/ SAP development	Large	ISO	<1
68.	Software Developer	5	Ghana	Global Software Development	Small	Not Sure	Nil
69.	Researcher	5	Ghana	Research	Large	ISO	8
70.	Consultant	55	USA	Global Software Development	Small	CMMILevel-5 (Optimizing)	20
71.	Professor	14	Pakistan	Research	Large	Not Sure	Nil

TABLE 14. **Information of empirical study respondents.** ***(Continued.)***

72.	Researcher	15	Pakistan	Collocated Software Development/ Global Software Development/ Research	Small	Not Sure	4
73.	Researcher	5	Pakistan	Research	Large	Not Sure	Nil
74.	Lecturer	11	Pakistan	Research	Small	Not Sure	Nil
75.	FOUNDER of Bangalore Software Process Improvement Network (BSPIN)	27	India	Global Software Development	Medium	ISO	3
76.	Web developer	2	Pakistan	Collocated Software Development	Small	Not Sure	0
77.	Professor	8	Spain	Research	Medium	Research Centre	Nil
78.	Manager	17	France	Global Software Development	Medium	ISO	10
79.	Research assistant	7	Saudi Arabia	Research	Not sure	Not Sure	Nil
80.	Process Consultant	30	USA	Project management support	Medium	working on CMMI-SVC	<2
81.	Researcher	2	Pakistan	Global Software Development/ Research	Small	Not Sure	Nil
82.	Lecturer	10	UK	Collocated Software Development	Medium	CMMILevel-2 (Managed)	Nil
83.	SPIIM leader	30	New Zealand	Implementing SPI	Small	CMMILevel-3 (Defined)	20
84.	Software Engineer	14	Brazil	Oil and Gas	Large	ISO	Nil
85.	Professor	25	Denmark	Research	Medium	No process model	Nil
86.	Lecturer	7	South Africa	Research	Large	Not Sure	Nil
87.	Senior VP, Operational Excellence	30	USA	Solutions and Services. Software and Systems engineering and service delivery	Large	CMMILevel-3 (Defined)	20
88.	Web Developer	20	USA	Global Software Development	Small	CMMILevel-1 (Initial)	<1
89.	Product Manager	10	Norway	Collocated Software Development/ Research	Medium	CMMILevel-5 (Optimizing)	5
90.	Software Engineer	4	Pakistan	Global Software Development	Medium	CMMILevel-3 (Defined)	2
91.	Configuration Manager	15	India	Collocated Software Development	Medium	Not Sure	Nil
92.	Project Coordinator / QA Professional	8	UAE	Global Software Development	Large	ISO	5
93.	Assistant Vice President	21	Germany	Global Software Development	Large	CMMILevel-5 (Optimizing)	10
94.	Product Manager	10	Vietnam	Global Software Development	Large	CMMILevel-5 (Optimizing)	5
95.	Professor	41	UK	Research	Large	Not Sure	Nil
96.	Software Engineer	2	Pakistan	Global Software Development	Medium	ISO	Nil
97.	Configuration Manager	15	USA	Collocated Software Development	Medium	Not Sure	Not Sure
98.	Professor	40	Australia	Research	Large	Research Centre	Nil
99.	Software Requirements Analyst	4	Pakistan	Global Software Development	Medium	CMMILevel-1 (Initial)	Nil
100.	Software Engineer	4	Pakistan	Global Software Development	Medium	CMMILevel-3 (Defined)	2
101.	Executive Vice President	21	China	Global Software Development	Large	CMMILevel-5 (Optimizing)	10
102.	Web Developer	5	Pakistan	Collocated Software Development, Global Software Development	Medium	ISO	Nil
103.	Research Associate	5	Spain	Research	Large	Not Sure	Not Sure
104.	Software Engineer	1	Pakistan	Collocated Software Development, Global Software Development	Medium	Not Sure	Not Sure
105.	Senior Mobile Developer	3	Pakistan	Global Software Development	Medium	CMMILevel-1 (Initial)	1
106.	Software Engineer	1.5	Pakistan	Global Software Development	Medium	Not Sure	1
107.	Web Developer	20	Canada	Global Software Development	Small	CMMILevel-1 (Initial)	Nil
108.	Researcher	15	Canada	Research	Medium	Not Sure	4
109.	Researcher	9	Japan	Research	Medium	Not Sure	Not Sure
110.	Agile Coach / Consultant	7	New Zealand	Consultation , Coaching , Training	Medium	Not Sure	Not Sure
111.	Researcher	25	Australia	Research	Large	Nil	Nil

TABLE 15. Identified practices for critical success factors (CSFS) using SLR.

Practice No	CSF1: Management Commitment
P1-CSF1	Organizational management commit to support the SPI program.
P2-CSF1	Organizational management reserve sufficient resources for SPI activities.
P3-CSF1	Regularly observe the activities involved in SPI program.
P4-CSF1	Provide a well establish infrastructure that could motivate the team members to participate in process improvement activities.
P5-CSF1	Encourage the efforts of the practitioners involved in process improvement programs.
CSF2: Staff Involvement	
P1-CSF2	Staff members should adopt the changes made due to the implementation of SPI program.
P2-CSF2	The practitioners should regularly participate in SPI activities because they have deep understanding of the existing processes.
P3-CSF2	Facilitate the SPI practitioners by providing adequate resources to execute the process improvement activities.
P4-CSF2	Regularly assess the efforts of the SPI staff, so that every member feels the sense of responsibility.
P5-CSF2	Organization should establish process teams and forums which could help the staff members to exchange the innovative ideas.
CSF3: Allocation of Resources	
P1-CSF3	Schedule the provision of resources for process improvement activities.
P2-CSF3	Management should have proper plan for the allocation of time and financial resources.
P3-CSF3	Provide all the required technological resources including hardware and software.
P4-CSF3	Provide sufficient time to practitioners in order to complete the SPI program.
P5-CSF3	Management should prepare the detail budget and schedule the allocated human resources.
CSF4: 3C's (Communication, Coordination, Control)	
P1-CSF4	Frequent traveling to the distributed sites increase the degree of communication.
P2-CSF4	Motivate the SPI team members to use the most advanced technological tools to communicate, coordinate and control the process improvement activities.
P3-CSF4	Management should conduct cultural activities for the distributed team members in order to mitigate the cultural barriers.
P4-CSF4	There should be a define plan for proper coordination and control in order alleviate the cultural, geographical and temporal distances.
P5-CSF4	Distributed teams should frequently communicate using video conference meetings, regular rotation of team members and conducting the team building activities.
P6-CSF4	Employ a liaison between the geographically dispersed teams.
CSF5: Project Pilot Implementation	
P1-CSF5	Deploy the implementation of SPI program on experimental bases.
P2-CSF5	Develop criteria for experimental based implementation of SPI program.
P3-CSF5	Use the results of experimental based implementation of SPI program for large-scale execution of process improvement activities.
P4-CSF5	Assess the results of experimental based implementation of SPI program.
P5-CSF5	Allocate sufficient resources to execute the process improvement activities on experimental bases.
CSF6: Process Improvement Expertise	
P1-CSF6	SPI practitioners should have detail knowledge of process improvement standards and models.
P2-CSF6	Conduct regular training sessions to increase the SPI related expertise of practitioners.
P3-CSF6	The SPI team members should have previous process improvement experience, knowledge and necessary skills.
P4-CSF6	Use the previous experience of process improvement projects in global software development.
P5-CSF6	Draw on the expertise of external assessors/consultants as mentors.

External validity refers to the generalization of the outcomes for all other domains [60]. In this research project, we collected the data from a diverse range of SPI experts across different countries. We are confident to generalize our results, because we have found more similarities than differences in our country based comparison of the survey results [63].

One possible threat to external validity is the sample size of the case study. The selected sample size was small (three) so the results of the case study might not be generalized to the real world. However, like similar research studies, we are certain that that our sample size was sufficiently representative [35], [36], [49].

With respect to the questionnaire survey, construct validity represents whether or not the measurement scales denote the attributes being measured. The attributes considered in this study were obtained from an extensive body of literature [23], [28], [30] and through discussion with SPI practitioners. The feedback from practitioners demonstrates that all the selected attributes were related to their work. Another possible limitation of construct validity is that the survey respondents might have interpreted the critical success factors; critical barriers, and practices differently. We were not able to directly verify the views and opinions of the experts so their feedback on the factors may not necessarily be authentic.

In this survey questionnaire, the experts were provided with close-ended questions to rank the identified success factors and barriers of their practices. The close-ended questions limit the survey respondents to only those success factors, barriers, and practices that are provided in the list. We attempted to eliminate this problem by providing an open-ended text box to the respondents so they could provide additional factors in addition to those reported. However, like the researchers of many studies based on experience data [36], [48], [50], [55], we are confident about the findings of the data collected from the SPI practitioners, who have broad experience in SPI-related activities.

TABLE 16. Identified practices for critical barriers (CBs) using SLR.

Practice No	CB1: Lack of organizational support
P1- CB1	Management committed to support SPI team members.
P2- CB1	Organizational management makes the process improvement practices as an important part of the development processes.
P3- CB1	Develop criteria to continuously assess the efforts of SPI team members.
P4- CB1	Management commits to provide adequate resources and training for process improvement activities.
P5- CB1	Management commits to participate in SPI workshops and evaluations meetings.
CB2: Lack of Communication	
P1- CB2	Frequently visit the geographically distributed teams to decrease the communication gap.
P2- CB2	Promote efficient offshore relationship.
P3- CB2	Motivate SPI team members to use the advance tools and techniques for effective communication.
P4- CB2	Arrange training and workshops to understand both the culture of the people participating in distributed process improvement.
P5- CB2	Encourage video conferencing during process improvement implementation, especially when traveling and face to face is difficult.
P6-CB2 (Identified in survey study)	Team members should plan for frequent daily meetings.
CB3: Lack of Process Improvement Knowledge	
P1- CB3	Detail process improvement knowledge.
P2- CB3	Conduct regular training session for team members.
P3- CB3	Establish a mechanism to continuously monitor the progress of each SPI team member.
P4- CB3	Encourage team building activities.
P5- CB3	Promote process improvement awareness among process improvement team members.
CB4: Lack of formal SPI implementation methodology	
P1-CB4	Establish technical infrastructure to implement the process improvement program.
P2-CB4	Use applications of process, implementation or product indicators as an effective management tool for process improvement.
P3-CB4	Promote the awareness of process improvement application tools and standards among team members.
P4-CB4	Adopt standards for the assessment of processes.
P5-CB4	Use of licensed software tools.
CB5: Lack of Resources	
P1-CB5	Project planning done in order to estimate all the required resources.
P2-CB5	Management commits to allocate sufficient time for SPI activities.
P3-CB5	A mechanism developed to avoid time pressure.
P4-CB5	Team members agree to allocate time for SPI activities.
P5-CB5	Strategy should be developed so that SPI activities will not disturb the everyday schedule of the team members.

TABLE 17. Additional practices identified for CSFS using survey.

Additional Practices S. No	CSF1: Management Commitment
P6-CSF1	Top level management should lead the initiation and implementation of SPI program.
P7-CSF1	Management encourage and drive the bottom-up staff in SPI activities.
P8-CSF1	Organizational management motivate SPI team members and non-SPI staff members to accept the changes of process improvement.
P9-CSF1	Users see that the change is of benefit to them as individuals and to the entire organization.
CSF2: Staff Involvement	
P6-CSF2	Employ a team manager on each distributed site that could assist the process improvement teams to manage the SPI activities.
P7-CSF2	Regularly discuss the rationale for process improvement efforts with staff.
P8-CSF2	Explicitly describe the benefits of SPI to both team members and organization.
CSF3: Allocation of Resources	
P6-CSF3	The organization set priorities of what they choose to implement based on resources and budget - they don't have to do everything at once.
CSF4: 3C's (Communication, Coordination, Control)	
P7-CSF4	Frequent planning of interactions between distributed sites: daily stand-up/call improves this largely.
CSF5: Project Pilot Implementation	
P6-CSF5	Publicize and communicate: widely pilot implementation success story.
P7-CSF5	Test earlier, provide examples and reiterate fast.
P8-CSF5	Explicitly discuss the results of the pilot implementation.
CSF6: Process Improvement Expertise	
P6-CSF6	Use consultants to facilitate and guide.
P7-CSF6	The users of the system and the implementation team need to understand the basics of a quality process.

VIII. CONCLUSIONS AND FUTURE WORK

In this study, a software process improvement implementation and management (SPIIMM) is presented that can assist GSD organizations to successfully execute SPI activities. The model was based on the concepts of existing models (i.e., CMMI, IMM, SOVRM) and the phenomena of critical success factors and barriers.

We analyzed the available literature using the SLR approach and extracted the factors that can have a positive or negative impact on SPI implementation in the domain of

GSD [25], [63], [64]. During the SLR study, 21 success factors (positive impact) and 22 barriers (negative impact) were identified. Out of the 21 success factors, 6 were ranked as CSFs based on the criterion of factors having a frequency $\geq 50\%$ in both the literature and the empirical study. Similarly, five barriers were ranked as CBs for SPI implementation in GSD. For the reported CSFs and CBs, we identified 56 practices using the SLR approach. We conducted an industry specific empirical study using the questionnaire survey approach with 111 SPI experts, validate our SLR findings and to identify new success factors, barriers, and practices in addition to those reported. Using the questionnaire survey, we identified an additional 15 practices to address the CSFs and CBs.

The SPIIMM was structured based on the findings of SLR, the empirical study, and existing models. The identified CSFs, CBs, and practices were distributed into five maturity levels of SPIIMM. We conducted three case studies in three organizations, to evaluate the effectiveness of the SPIIMM. The case studies results demonstrate that the SPIIMM is a suitable tool for the GSD organizations to assess their SPI-related maturity levels and to guide an organization to improve their SPI activities to advanced levels.

In future, we will develop a software tool for SPIIMM that can assist an organization in assessing their current SPI maturity level and to identify the most critical success factors and barriers that can affect the SPI program. The tool will also suggest the most suitable practices to address each CSF and CB of a specific maturity level, in order to achieve the next level. The tool will generate a complete report based on the assessment results and the suggestions of practices for CSFs and CBs. We have identified other research gaps in this area, which we plan to address in future studies. We will extend SPIIMM based on the client-vendor based nature of GSD organizations, as currently most researchers focus on the client perspective of GSD organizations [61], [47]. We also plan to highlight the activities involved in each maturity level of SPIIMM.

APPENDIX 1

See Table 14.

APPENDIX 2

See Tables 15–17.

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