IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received December 24, 2020, accepted January 4, 2021, date of publication January 8, 2021, date of current version January 20, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3049904

Blockchain-Based Software Process Improvement (BBSPI): An Approach for SMEs to Perform Process Improvement

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ABSTRACT Progressively, Software development organizations are investing their resources, time and, money on Software Process Improvement (SPI) since it is beneficial in the enhancement of product quality, reduction in development time, and cost of software projects. However, the existing methodologies and approaches are time-consuming and costly and their major focus is on the SPI of Large Scale Enterprises (LSEs) therefore, we are introducing blockchain in SPI to overcome its major issues such as reliance on a central body of standardization for certification, knowledge management, high cost, resource management and change in organizational culture, etc. We have performed an exploratory case study to identify the different barriers of traditional SPI approaches. To overcome the identified issues, we have proposed and implemented a new approach by performing two case studies. The first case study was performed to identify the barriers in traditional SPI approaches and the second case study was performed to validate our proposed approach. We have performed our experiments on 55 representatives of 50 organizations. According to the results of proposed approach 56.4% of the population agreed that the SPI cost will decrease, 61.8% agreed that time of SPI will decrease and 60.3% of the population agreed that BBSPI will decrease resource utilization. Moreover, 69.1% of the population agreed with the fact that proposed BBSPI will make effective knowledge management and 83.3% of the population said that an organization can mature its processes equaliant to the central certification (CMMI, ISO) body by employing proposed BBSPI. Our results affirm that the BBSPI can reduce the time, cost, resources and helps to manage knowledge used to perform SPI. Moreover, results also depict that the BBSPI can be an efficient substitute of central bodies that could help small and medium-sized organizations to conform to common process improvement models by spending less money, time, and resources with effective knowledge management.

INDEX TERMS Blockchain, blockchain-based software engineering, software engineering, software process improvement, capability models, software process improvement models, CMMI, ISO, smart contracts, distributed systems.

I. INTRODUCTION

In Software Development, Software Process is a goal-oriented activity that consists of partially ordered steps that are followed to accomplish an objective or a goal in the context of engineering style software development [1], [2]. A software process in development can be coding, testing, planning, or a packaging process [1]. For better quality, on time, and within budget delivery of a product, these processes can be improved and the activity under which these processes are improved is known as Software Process Improvement (SPI) [3].

It is widely claimed by researchers that the quality of the product is mainly based on the processes which an organization follows to develop the software [4] along with the capability and maturity of these processes [5]. In Software Process Improvement activity, different approaches to process management such as standardization models and expert-based process improvement are used.

At present, mostly SPI is being achieved through the conformance of different standards [6]. These standards include Capability Maturity Model (CMMI) [7], ISO-9000

The associate editor coordinating the review of this manuscript and approving it for publication was Resul Das.

family [8], Lean [9], Initiating, Diagnosing, Establishing, Acting, and Learning Model (IDEAL model), Software Process Improvement and Capability Determination (SPICE) [10], and so on. These standardization models are developed for different goals in different contexts. From the stated models, CMMI is the most extensively used model for the improvement of processes of an organization [11].

Typically, an organization hires an expert known as a process engineer or team of process engineers to improve and manage its organizational processes. These experts investigate the current practices and recommend a collection of changes along with guidelines by benchmarking a state-of-the-art standard for the improvement of their existing practices and procedures. Other than that, the government of the United Kingdom has officially developed a framework that comprises of practices that organizations can follow themselves to improve the software processes [12].

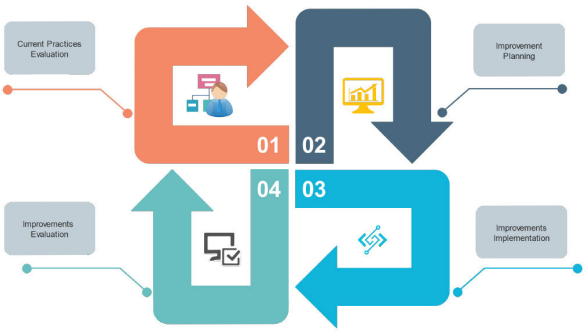

FIGURE 1. Abstract overview of traditional software process improvement.

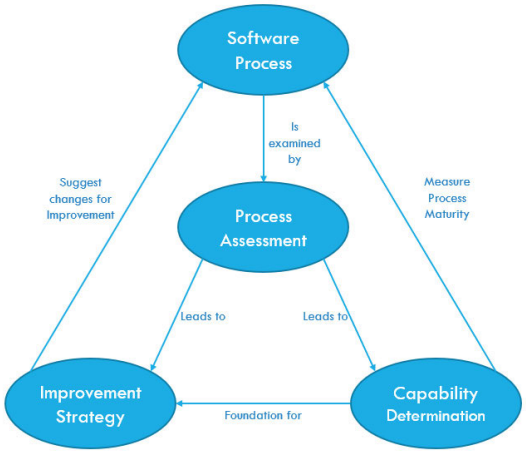

FIGURE 2. Major elements of traditional SPI methodology.

Major elements of traditional software process improvement are shown in Figures 1 and 2. Figure 1 shows an abstract overview of traditional process improvement whereas Figure 2 shows major elements of traditional process improvement according to which software process is assessed by examining it and then by determining its maturity. Typically, process engineers determine this maturity and then develop an improvement strategy that is followed to increase the maturity of the software process. As shown in Figures 1 and 2, traditional process improvement is a continuous process, and it keeps on iterating unless the desired maturity level is not achieved.

Although CMMI and other standards are used to improve the processes of organizations and they provide sufficient guidelines to comply with them, however, many Small and Medium-Sized Enterprises (SMEs) which consist of almost 85% of the industry in different countries such as China, USA, Canada, India, Finland, etc. are unable to get certification from the central governing body of these standards because it costs them a substantial amount of time and money [13]. This cost and time barrier discourages them to perform SPI as they cannot afford to invest that much in SPI due to their restricted budgets.

Apart from that cost, SMEs are supposed to provide training to their technical and non-technical staff for employing those guidelines which could lead to the use of extra resources while doing the SPI process and an organization might need to change its working style to ensure to conform to these standards [14]. Since SPI is an expensive process therefore SMEs cannot afford it because to meet the terms of a standard, they need extra resources (human and technical) and change in the organization's working environment might be obligatory.

Subsequently, knowledge management in the area of SPI is a substantial issue that should be analyzed independently because traditional SPI methods are not good enough for SMEs as these traditional methods are generally engrossed towards Large Scale Enterprises (LSEs). Another drawback of traditional SPI is that almost all of the existing models and techniques rely on the central governing bodies that certify your organization once you have fully conformed to their specified standards.

Therefore, in this research, we are proposing a novel solution which is a more decentralized way that can automate the trust which organizations have in the central bodies of certification. This automation of trust encourages organizations to perform SPI activities and use the best available SPI standards by employing their best practices in the organization to increase the quality of their products by not worrying about the outlined drawbacks of traditional SPI. This research also aims to mature the processes of SMEs equivalent to the maturity of processes of certified organizations of the existing standards. Aside from that, this approach is not engrossed only towards SMEs or LSEs but organizations of any size can use it by spending less money and resources to achieve more.

A. RESEARCH CONTRIBUTION

Major contributions of our work are the following:

1. Proposed a novel blockchain-based approach to perform software process improvement.

2. Through this novel approach we are providing an opportunity to software companies to completely outsource the SPI activity.
3. Conformance to standards such as CMMI, ISO, etc. by spending less money, time, and resources.
4. A substitute for central certification bodies.
5. Our proposed approach offers effective knowledge management for SPI.
6. This approach allows an organization to Implementing SPI activity without changing their organizational culture.

B. RESEARCH MOTIVATION

Usually, Software Process Improvement (SPI) standards like CMMI are followed to ensure the software quality on time and within budget delivery of a product. However, this practice is not common in Very Small Enterprises (VSEs), Small and Medium-Sized Enterprises (SMEs) due to high cost, knowledge management of historical data, and usage of additional resources for conformance to a standardization model. The term blockchain has been coined in the context of software engineering activities to overcome the issues in traditional Software Engineering [15]. We have considered that VSEs and SMEs do not perform SPI and it is a crucial issue of traditional SE and hence, by taking advantage of this new technology we have introduced a blockchain-based SPI approach, which can aid domain experts to ensure the quality and product delivery within time.

C. HYPOTHESIS FORMULATION

Based on the above theoretical foundation we have concluded that there are five major facilitating factors for software process improvement (SPI). These five factors include time, cost, resources, knowledge management, and reliance on central bodies. Further, after examining the literature extensively, we have hypothesized that:

1) NULL HYPOTHESIS: H_0

Traditional SPI approaches are cost-effective, takes fewer resources and time to perform SPI, and offer effective knowledge management because there is no need to change organizational culture to conform to the standard of certification bodies.

2) ALTERNATE HYPOTHESIS H_a

Traditional SPI approaches are not cost-effective, takes excessive resources and time to perform SPI, and provides poor knowledge management because there is a need to change organizational culture to conform to the standard of certification bodies.

The rest of the article is organized as follows: Overall research methodology which we have employed is stated in *Research Methodology* Section, then Experimental protocols are stated in *Experimentral Procedure* section. Background and related studies are presented in the *Background and Related work* section. The proposed approach along with its uniqueness, overall workflow, and key benefits is demonstrated in the *Proposed Approach (BBSPI)* section. Case studies which we have used in this research were designed in the *Case Study based Evaluation* section. The *Results* section consists of the results that are obtained by performing case studies after deploying the proposed approach. Evaluation of hypotheses that we formulated is presented in *Evaluation (Hypothesis testing) section.* Detailed discussion on the results obtained and hypotheses testing is done in the *Discussion* section. The rest of the sections includes *future work*, *threats to validity*, *acknowledgments*, and finally *references*.

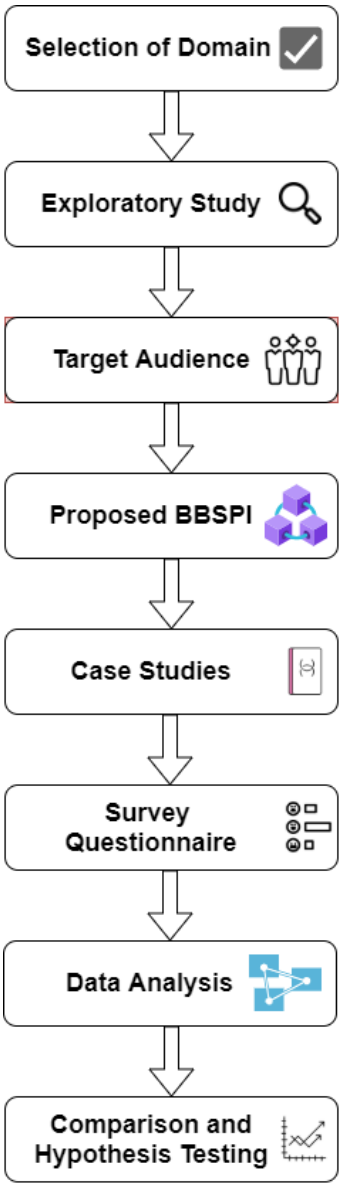

FIGURE 3. Research methodology adopted.

II. RESEARCH METHODOLOGY

The research method which we adopted consists of an exploratory study, survey questionnaires, and case studies.

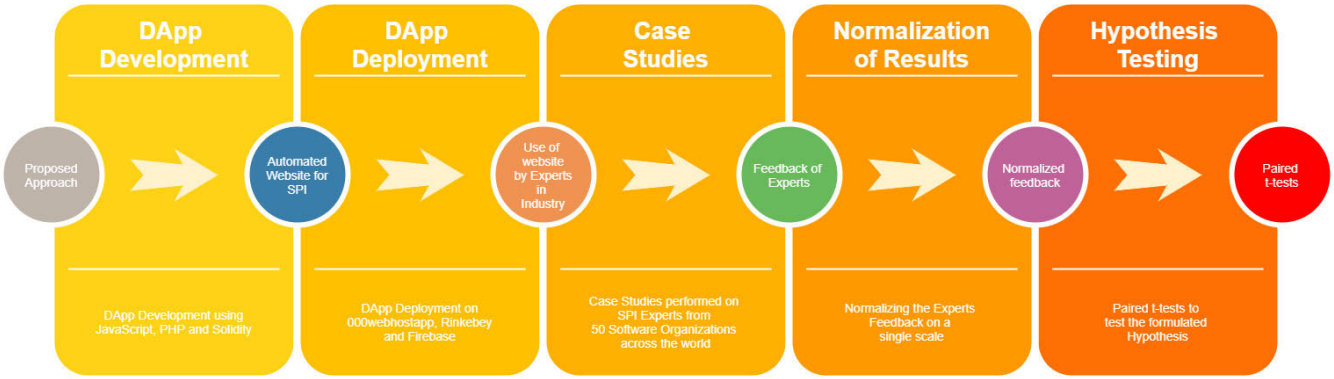

FIGURE 4. Experimental procedure followed.

The detailed research methodology which we followed is outlined as follows and is shown in

A. SELECTION OF DOMAIN

Firstly to start our research process, we have finalized the domain of interest to research. This domain was finalized based on previous background knowledge by reviewing different articles.

B. EXPLORATORY STUDY

In this step, we performed an exploratory study by reviewing numerous articles related to software process improvement, maturity models, and blockchain. After reviewing multiple articles we were able to identify limitations of existing process improvement approaches and how a new approach can overcome those existing limitations under one umbrella.

C. PROPOSED BBSPI

To overcome the identified limitations, a novel blockchain-based approach was proposed to overcome the identified limitations of software process improvement. The approach was proposed with an aim to overcome the barriers and encourage software organizations to perform process improvement for better quality, low cost, and within budget delivery of the products.

D. CASE STUDIES

Real-life case studies were designed and performed to industrially validate the identified barriers and then to test the effectiveness of the proposed approach. These case studies were performed in 50 software organizations.

E. SURVEY QUESTIONNAIRE

An online survey questionnaire was developed to get the feedback of participants of the case studies. Feedback was measured on the Likert scale which was later used to test the statistical significance of the proposed approach.

F. DATA ANALYSIS

Feedback of participants of both case studies was then analyzed and then normalized to form two datasets i.e. feedback for traditional approaches and feedback for the proposed approach.

G. COMPARISON AND HYPOTHESIS TESTING

In the final step, normalized data were used to perform statistical tests, Paired t-tests were performed in this research to check the statistical significance of the proposed approach. The hypothesis was tested based on the results of t-tests.

III. EXPERIMENTAL PROCEDURE

To test the formulated hypothesis, the experimental procedure depicted in Figure 4 is followed by this research study. The experimental procedure consists of five steps that include DAapp development, DApp deployment, performing case studies, normalization of case studies data, and then hypothesis testing.

A. DApp DEVELOPMENT

To implement our proposed approach, we firstly developed a decentralized application by implementing our proposed approach. For this, we developed the frontend of our application by using HTML5, CSS3, Bootstrap, and ReactJS. After the development of the frontend, the backend was developed by using PHP and solidity. To make the website a decentralized application, solidity was used to write different smart contracts that were used to perform different notarization and time stamping processes. Smart contracts were programmed on a locally set environment that included the truffle suite and Ganache GUI as the local blockchain.

B. DApp DEPLOYMENT

After the implementation phase, our Web Application was tested on localhost by using WampServer. Once the web application was ready to be deployed, we used the free hosting service of ''Hostinger'' named as ''000webhostapp''

to deploy our website. Smart contracts were deployed on Rinkebey by using Infura. Firebase was also used to store files off the chain to reduce the transaction costs on Ethereum's blockchain. A live version of our DApp can be visited at: http://blockchainse.000webhostapp.com/.

C. CASE STUDIES

This research used a case study based approach to test the effectiveness of the proposed approach. In the case studies, participants were requested to firstly perform process improvement traditionally and then by using the proposed approach. At the end of case studies, participants were requested to provide feedback about both approaches. This feedback was then used to test the formulated hypothesis.

D. NORMALIZATION OF RESULTS

After conducting the case studies, feedback of the participants of case studies was normalized to get a single value for all the factors. Results were normalized by using standard deviation for variability and mean for a central tendency.

E. HYPOTHESIS TESTING

Normalized results were used to perform statistical tests for hypothesis testing. For testing the statistical significance of the results, a paired t-test was performed on the normalized results and the hypothesis was rejected or accepted based on this statistical test.

IV. BACKGROUND AND RELATED WORK

The approaches and techniques of SPI in the *Introduction* section are widely used and highlighted by many research articles. Larrucea and Fernandez-Gauna [15] highlight the differences between the processes of Very Small Enterprises (VSEs) and ISO/IEC 29110 model which was mainly developed for VSEs to overcome the fact of using hugely publicized models like CMMI due to their higher costs. Although this research article elaborates on how to implement the ISO/IEC 29110 model and possible research areas that can be taken into consideration to improve the processes of VSEs however, the guidelines in this article are not validated empirically therefore software organizations usually tend to ignore these models and avoid spending extra time on these activities. The Irish Software industry is one of the examples that overlook these models as mentioned by Larrucea *et al.*

Serrano *et al.* [16] highlighted the major issues that an enterprise might face during the implementation of the CMMI model. The Authors have introduced a new method named the Action-Research method in which once a problem is identified, the multidisciplinary team analyzes that problem to perform an action plan. This could help in improving the processes of the organization as the motivation of the team increases and the implementation of the model becomes easier. However, this method does not cover all the Key Process Areas (KPAs) of CMMI and another problem of this method was the approval process for implementation and analysis which was time taking and effort-consuming process.

Bayona-Oré *et al.* [17] explain how SPI is important in the development process and explained that by selecting a few KPAs such as Requirements Management, Verification and Validation we can reduce the defects and can improve the quality of the product. The IDEAL model was used to implement the best-selected practices of CMMI. But this model focuses on just 3 KPAs of CMMI whereas there is a total of 24 KPAs of CMMI. Therefore, the coverage of CMMI in this model is very low because the improvement seeker organization cannot fully conform to CMMI.

Since CMMI is a widely used model across the world, however, the published number of appraisals (a document that CMMI publishes after successfully assessing an organization) of CMMI is far below the satisfactory level. In 2019, only 88 appraisals of CMMI 2.0 [18] and 3,040 appraisals of CMMI 1.3 were published [19], which in our opinion are below the acceptable level because software organizations are plenteous than these numbers and a major reason for this low number is the high cost of conformance to CMMI, knowledge management of these models which requires additional cost and resources, extraction of tacit knowledge from concerned personnel, and lack of organizational creativity and flexibility which bounds the productivity of SMEs [20].

Tuape and Ayalew [21] have identified that different environments such as organizational, governance, and business play an important role in the development processes of an organization. Shih *et al.* [22] have also investigated the relationship between the culture of an organization and SPI deployment and concludes that organizational culture plays an important role in SPI deployment and there might even be a need to change the organizational culture to deploy the SPI activities. The Authors in [23], [24] insist on the importance of knowledge management and the use of the previous project's data regarding process improvement in organizations for SPI activity. In another article [25] coordination and tracking amongst the customer, software product, and development tasks play an important role in SPI success.

A. NEW DIMENSION

By looking at the earlier discussion in this section, we can look for new dimensions for Software Process Improvement as in this era of technological advancement where everything is being upgraded to the best possible solutions; we can turn the software process improvement towards a new direction by introducing blockchain in it as blockchain gives an effective method to tackle issues using distributed, protected, collective and authorized ledgers [26]. The Authors [27] claim that blockchain-based applications are rapidly evolving and most of the startups are developing their services by using blockchain technology as they think that blockchain technology will be the dominant technology in near future and the majority of the business models would be transformed by using it.

Rocha and Ducasse [28] have insisted upon the importance of modeling blockchain-oriented software, Destefanis *et al.* [29] have also advocated the need for

Blockchain Software Engineering to address the issues posed by smart contract programming and other blockchain-based applications.

Marchesi [30] in their keynote also insists on the need for the introduction of software engineering in the blockchain that could lead to the solution of different problems present at moment in the blockchain. Marchesi also highlights the new opportunities that blockchain can offer. These opportunities include the authorization of empirical data used for the experiments, the ability to design processes where developers are paid upon completion of their tasks through Blockchain tokens. These highlighted opportunities by the author are very close to the approach which we are proposing in this research.

Beller and Hejderup [31] and Porru *et al.* [32] have investigated to introduce blockchain into Software Engineering and they have identified different areas of Software Engineering where blockchain can be introduced to overcome their drawbacks. Amongst the identified domains, Continuous Integration and package management are the prominent ones.

The highlighted research shows how the research community is accepting the fact that blockchain can solve different traditional Software Engineering problems and vice versa. Therefore, we are introducing blockchain in one of the major traditional software engineering problems and that is software process improvement.

This new dimension can help us to overcome the expensiveness of knowledge management in SPI, getting rid of the central body just for the ''certified'' label and can help us to perform process improvement within our organizational context without changing its culture and by employing fewer resources as compared to the other approaches and techniques which are in practice.

V. PROPOSED APPROACH (BBSPI)

As Beller and Hejderup [31] and Porru *et al.* [32] have worked in the field of Blockchain and Software Engineering where they have introduced blockchain-based Continuous Integration, Package Management, Software Testing, Enhancement of Debugging, and Software Engineering tools for blockchain-based programming languages. Therefore, as a starting point, we can refer to these two research articles to introduce blockchain into Software Process Improvement, and hence we are proposing a new methodology for SPI which we have named as Blockchain-Based Software Process Improvement (BBSPI) and proposed BBSPI emerges the idea for software engineering (SE) community to adopt the implications of blockchain to solve software engineering problems by using blockchain. Furthermore,proposed BBSPI make the SE community to change their practices to this new dimention and incorporate new blockchain based techniques that can aid deveolpers, coders, testers and desighners. Moreover, to the best of our knowledge, our proposed BBSPI approach is novel in the context of software process improvement. No one till now has incorporated blockchain to solve the problems in traditional software process improvement and we have highlighted and solved issues of traditional process improvement through blockchain technology.

According to the proposed approach in Figure 5, when an organization or its concerned department wants to improve its processes, they will visit our BBSPI portal and firstly, they will initiate a request for process improvements by providing their current organizational practices. To start the process, our BBSPI will search for peers (Process Engineers) who are available and can participate in the Software Process Improvement activity. The Improvement request will then be broadcasted to all the available peers that are available and can participate in the process improvement activity, hereafter a daisy-chain styled network will be formed of those peers who have accepted the improvement activity request. One of the peers in the network will be nominated as a Facilitator who will moderate the overall Process Improvement activity henceforth (Step 3 in Figure 5).

Once the network is formed, members (peers) of the newly formed network will now participate in the Process Improvement Activity (PIA). A comprehensive overview of PIA is shown in Figure 6. According to which our system will first send the current practices provided by the improvement seeker along with the supporting material (Gap Analysis document, best practices details, the Gas price (maximum amount which improvement seeker is willing to pay) for the task and delivery deadline, etc.) to all the members of newly formed daisy-chain network. Supporting material that is to be sent will be derived from the base standard (CMMI, SPICE, or IDEAL, etc.) that is to be used for process improvements in the BBSPI.

Now each peer will start to suggest improvements individually by doing gap analysis based on the current practices provided and the desired level of improvement to be achieved. Each peer will produce a Changes needed Document (CND) at the end of gap analysis. Once CNDs from all the peers are received, the facilitator will initiate the voting process where every peer will vote to select the best CND and suggested changes to it if needed. Peers will not be able to vote for their own CND to avoid biasedness. At the end of the voting phase, our system will have a finalized CND that will have a set of improvements that are to be implemented in the seeker organization to improve its processes.

Subsequently, the finalized CND will be implemented in the seeker organization to get their processes improved. Once the CND is implemented in the seeker organization, current practices will be recorded again and will be uploaded to the BBSPI which will send them to the facilitator of current process improvement activity for the said organization. The facilitator will now validate the current practices of the organization with the finalized CND (suggested changes).

Provided that the organization has implemented the CND as per the guidelines of the peers of BBSPI, an appraisal document will be issued by notarizing and timestamping the CND by our smart contracts to ensure its authenticity. The notarized and timestamped CND will act as the certification

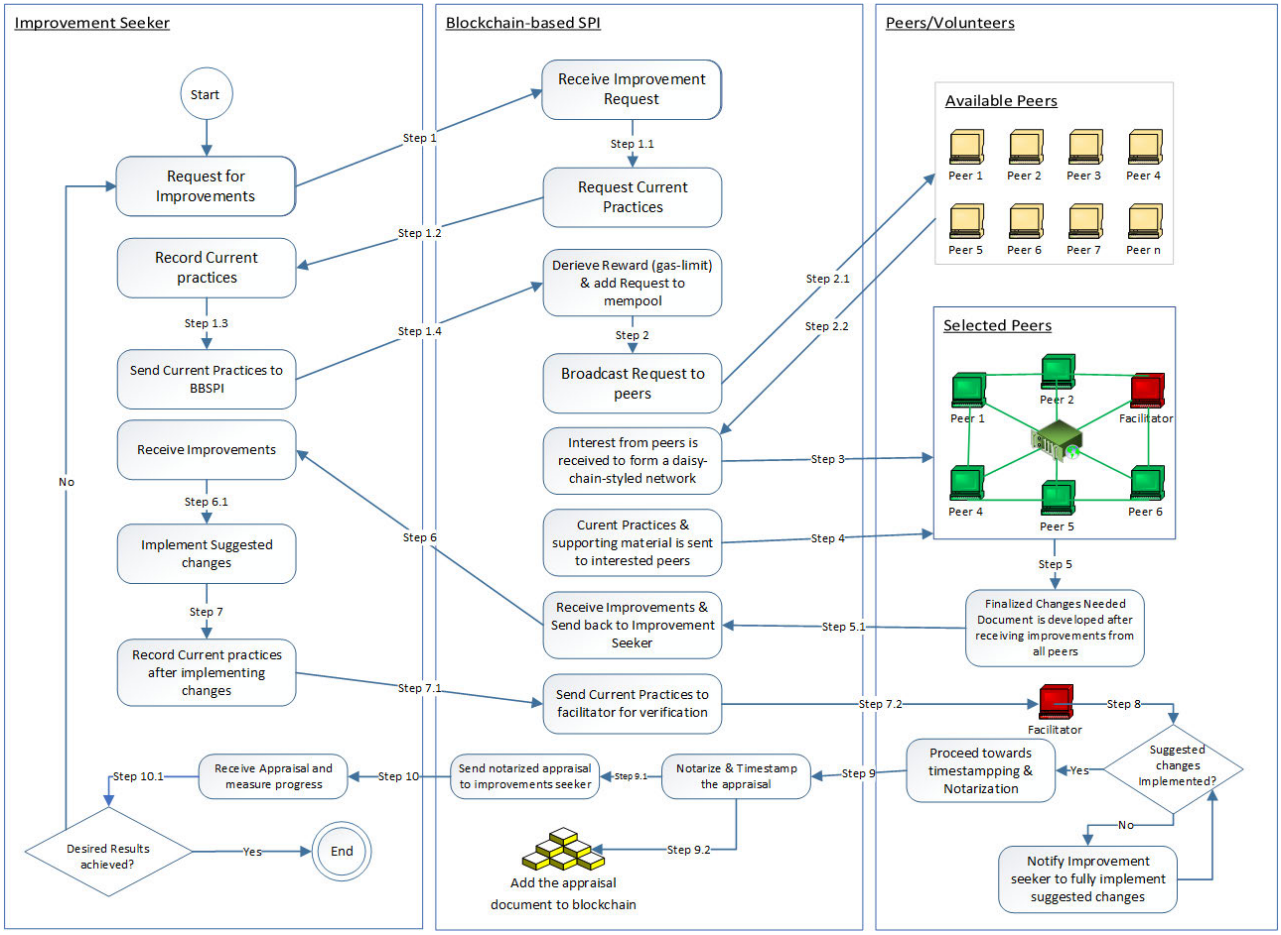

FIGURE 5. Detailed overview of the proposed approach (BBSPI).

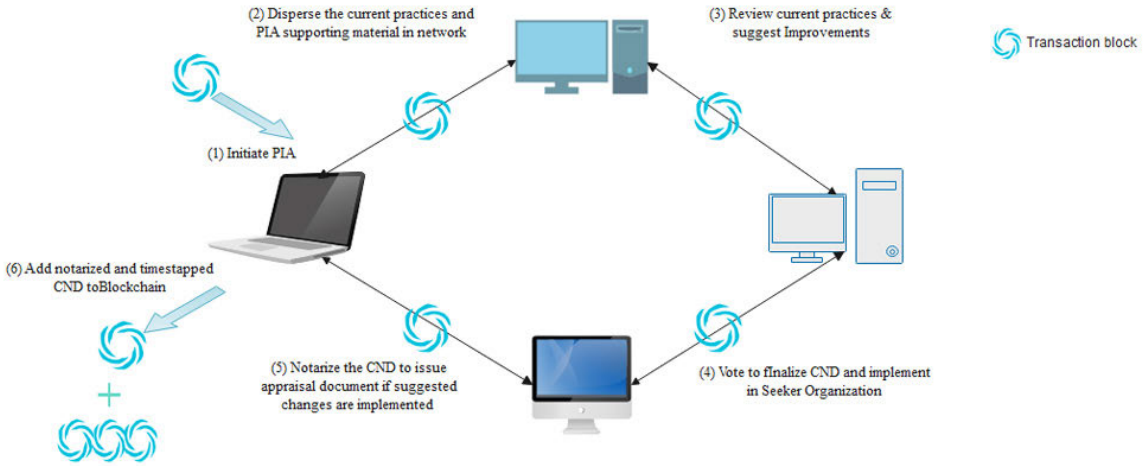

FIGURE 6. Overview of Process Improvement Activity (PIA).

document which will be a substitute for the certification provided by different standardization bodies for the seeker organization and it will be added to the blockchain so that it can be referred to at later stages.

Unlike the CMMI, ISO, and other existing models of standardization, our proposed BBSPI will be a decentralized improvement approach that contributes in the following ways:

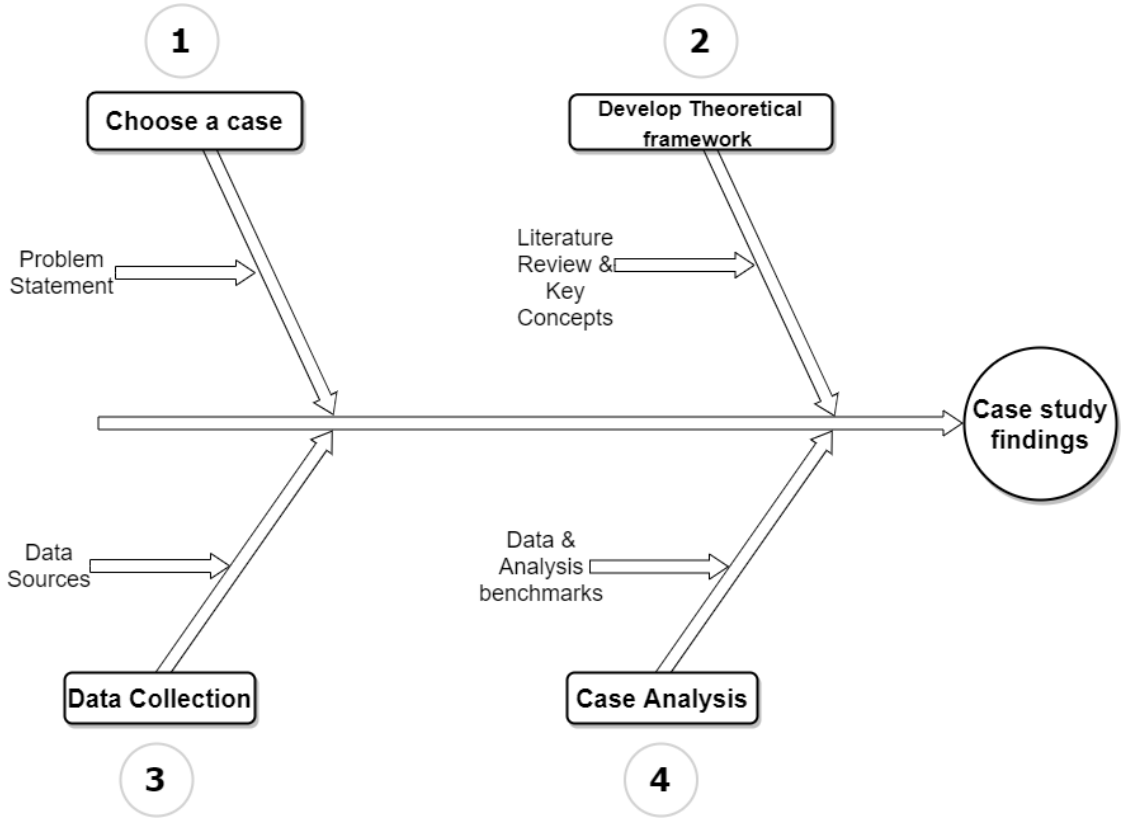

FIGURE 7. The procedure followed to design and perform case studies.

- It will disregard the concept of centralized bodies like ISO, CMMI, and others.
- Our proposed methodology could be tailored according to the essential organizational needs.
- It can improve processes of an organization equivalent up to a certain maturity level of CMMI, ISO, or other standardization models.

Apart from eliminating the concept of a centralized body, our approach to SPI will help organizations

- To have processes that are similar in maturity and capability of ISO and CMMI certified organizations by spending a fraction of the amount which certified organizations spend in getting certifications from these centralized bodies of standardizations.
- The SPI activity would be outsourced where the organizations will only have to measure their current practices and implement the improved practices.

This outsourcing of SPI activity gives the following benefits:

- Reduce the usage of human resources.
- Reduce the usage of technical resources.
- Reduce the training cost of staff to learn best practices of the existing models.
- Reduce the usage of other resources that an organization can utilize somewhere else in the organization.

Knowledge Management is another major problem in SPI that can be resolved by using ontologies and knowledge repositories in the BBSPI. Lastly, the proposed methodology can be used by organizations of any size, unlike the existing standards.

VI. CASE STUDY BASED EVALUATION

Case study based industrial experts evaluation is performed to evaluate the limitations of traditional process improvement and test the effectiveness of the proposed approach as this technique is considered the most effective evaluation technique [33]–[35]. To evaluate the limitations of the traditional process improvement approach case study entitled ''Traditional Approach Evaluation'' and to test the effectiveness of the proposed approach case study entitled ''Proposed Approach Evaluation'' was performed. Real-life case studies were taken and designed by following the procedure shown in Figure 7 and are highlighted by Ishtiaq [36] and Alpi and Evans [37].

A. CASE STUDY 1: TRADITIONAL APPROACH EVALUATION

Traditional Software Process Improvement is an approach using which organizations perform process improvement activity by following the traditional process improvement approach which is depicted in Figure 1 according to which an organization firstly will have to evaluate their current processes by documenting the steps which they are following to achieve a specific goal. After current practices evaluation,

organizations will have to plan for process improvement that includes (a-) Targeting a standard to conform to, (b-) Hiring a process improvement team (Process Engineers), (c-) Performing Gap Analysis by the hired team. After planning for process improvements organizations usually, implement the Gap Analysis recommendations after which they evaluate the implemented improvements, and finally, when they are ready to be appraised they request the standardization body to get appraised. This breakdown of tasks is shown in Figure 8.

FIGURE 8. Breakdown of tasks involved in traditional process improvement approach.

In this case study, the said approach is used to perform process improvement with the participation of 50 software organizations. All the participating software organizations were requested to perform process improvement using the traditional approach. After the completion of the process improvement activity, the participants were asked to give their feedback by using an online survey questionnaire. The online survey questionnaire was mainly targeted to capture the feedback of participants regarding the identified limitations of the traditional process improvement approach. The recorded response was then normalized and used for comparison with the proposed approach.

B. CASE STUDY 2: PROPOSED APPROACH EVALUATION

A novel approach for process improvement has been proposed by this research. In this case study, the approach shown in Figure 5 is used to perform process improvement. The proposed approach allows software organizations to outsource most of the process improvement work that enables them to be only concerned about recording current practices and implementing the suggested changes by BBPSI to improve their organizational processes. Breakdown of tasks performed for process improvement by using the proposed approach are listed in Figure 9.

In this case study, we have three different types of participants i.e. Improvement Seeker, Peers or Process Engineers, and Facilitator as stated in the *Proposed Approach* section. In the first step, we requested the same 50 software organizations to now perform process improvement by using the proposed approach. We have done a brief overview session with all the improvement seekers to give them an idea of the proposed approach.

In the second step, a group of peers (process engineers) was finalized. For this case study, peers were the members of our research group having experience in the domain of gap analysis and blockchain technology. The major task of these peers was to identify the gaps between the current improvement practices of the organization and the desired maturity level of improvement for their organization. Moreover, while using the proposed approach participants suggested us to improve our BBSPI by adding/removing some important parameters. The major difference between the finalized approach and the initially proposed approach is that Figure 10 shows the initial proposed model and Figure 5 indicates the final refined BBSPI that we have polished by incorporating some valuable suggestions of industrial experts (peers). Initially, the finalized approach does not contain the facilitator concept, we call on industry experts to evaluate our proposed model and industrial experts suggested us some changes. Looking at the valuable feedback of industrial experts, we incorporated the lead appraiser concept by mimicking it as a facilitator in our system. Another major change is that we were directly performing a transaction (Notarization and time stamping of the gap analysis document) on the blockchain after suggesting changes to the improvement seekers. Experts suggested verifying the changes before writing them to blockchain to avoid additional truncation costs. So by incorporating the feedback of experts, Figure 5 became the finalized version of the proposed BBSPI.

In the third step, the facilitator is chosen from the group of peers selected in the second step based on their work experience. The task of the facilitator is to select a set of improvements from the suggested improvements by process engineers and then redirect a final set of improvements to the ''improvement seeker organization''.

In the final step, the finalized set of improvements is notarized with the help of the developed smart contracts and by storing SHA256 hash of final notarized appraisal on Ethereum's Rinkeby test net and uploading the original file to firebase so that it can be used as a certification document which is issued by most of the standardization bodies when you conform to their standards.

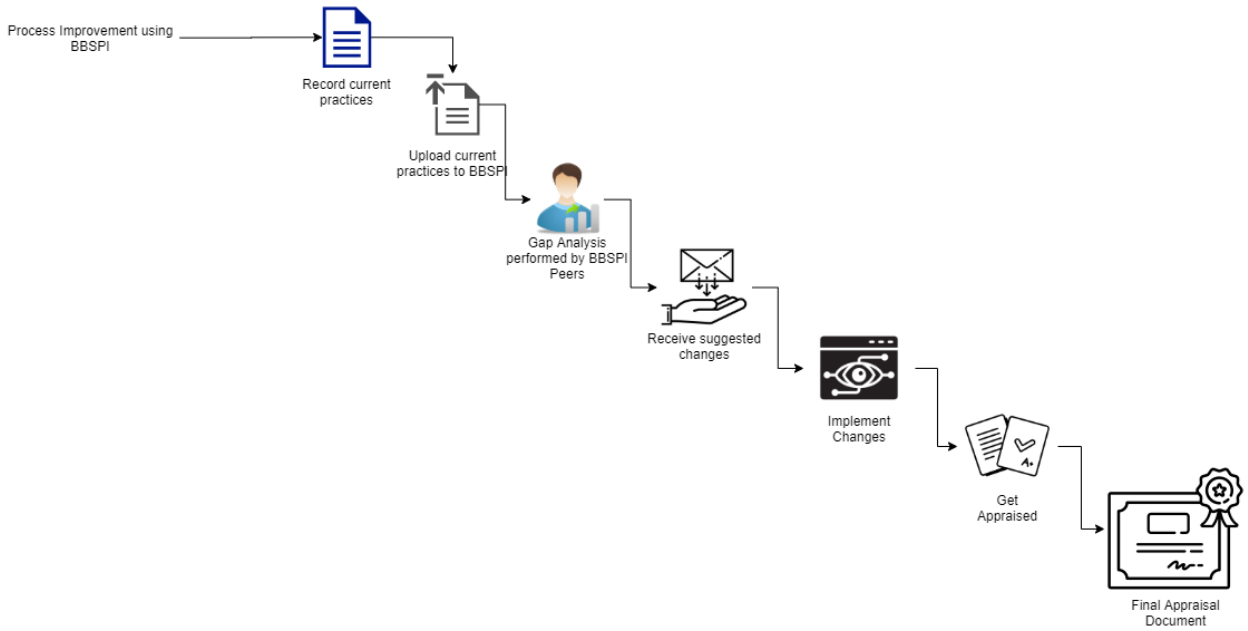

FIGURE 9. Breakdown of tasks involved in the proposed process improvement approach.

VII. RESULTS

The experimental procedure described in *Section* is used to evaluate the proposed approach by performing case studies mentioned in *Section*. Case studies were performed to verify the limitations of the traditional approach and to test the effectiveness of the proposed approach. The audience of both the case studies was the same where we requested over 150 software organizations to participate in. Out of these 150 software organizations, we received the willingness of almost 86 software organizations to participate in the case studies. From these 86 willing organizations, 55 representatives of over 50 software organizations took part in these case studies. Most of these 55 representatives were designated on senior positions in their respective organizations.

After performing the case studies, the Feedback of participants was measured on a Likert scale. The received feedback was analyzed and normalized by following the instructions given by the authors in these articles [38], [39]. Likert scale data is usually analyzed based on a composite score that is obtained from a series of questions asked on the Likert scale and its data is analyzed through a unique analysis procedure. To analyze Likert scale data one should understand the measurements of each scale to quantify and justify. Results are analyzed at an interval measurement score. Moreover, mean and standard deviation are also recommended for variability and central tendency respectively. T-test and ANOVA are also well-known data analysis procedures and we have used t-test for data analysis in the experimental results.

A. FEEDBACK OF CASE STUDY 1 PARTICIPANTS

The first case study was performed to determine the ratio of organizations that are currently performing SPI in their organizations and whether they conform to any standardization model. Major barriers to traditional process improvement were also identified and validated by experts from the software industry in case study.

This case study was performed on a small-scale group of people through an interactive session in which we introduced the traditional SPI and its limitations which were derived by performing an exploratory study as mentioned earlier in the *Introduction* section.

Afterward, we got feedback regarding traditional SPI approaches used by the participant organizations (feedback of participants of case study 1 is shown in Table 1). The organizations that were not performing SPI activities, provide us rationale (and barriers) for not using traditional SPI approaches (such as more time, more cost, more resources, etc.). According to the feedback of the audience, 69.1% of the participant organizations perform SPI activities and 30.9% of the participant organizations do not perform SPI activities due to their barriers.

Organizations that perform process improvement responded to the issues which they face while performing traditional SPI. We have measured their responses on the Likert scale for different factors as identified by our exploratory study.

According to their feedback, 59.4% of the participant organizations agreed and 6.3% of respondents strongly agreed to the fact that the ''time duration'' increases when you perform process improvement by using traditional approaches and is needed to be decreased.

42% of the respondents either agreed or strongly agreed to the fact that traditional SPI is a costly practice and overall cost expenditure increases when you perform process

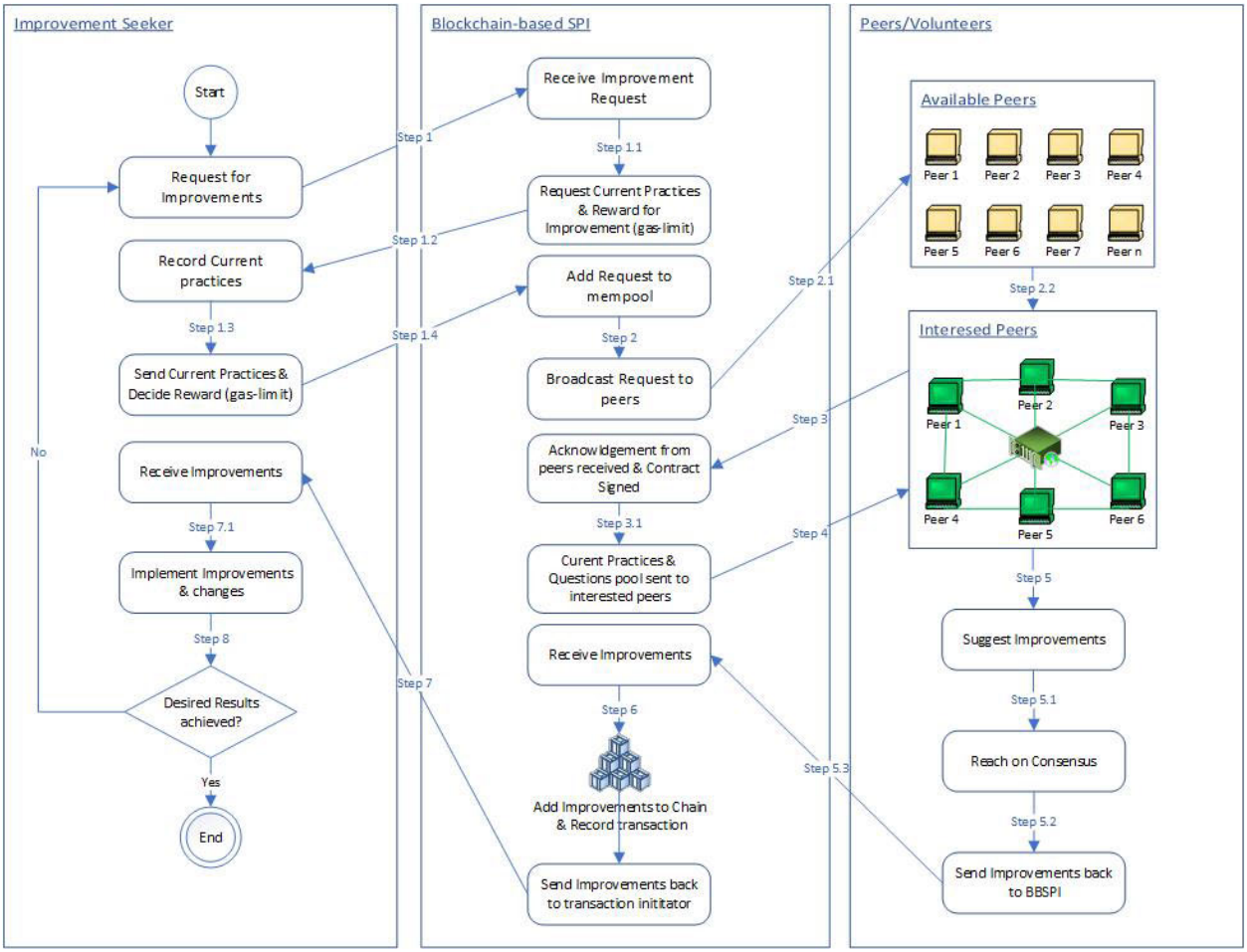

FIGURE 10. The initial version of the proposed BBSPI.

improvement traditionally. 62.6% of respondents gives the opinion that resources needed during the process improvement are not affordable for most of the organizations and agreed that there is a need to propose a new and cheap approach for process improvement.

56.3% of the respondents said that their organization must change their culture to incorporate SPI practices in their organizations. 46.9% of the respondents agreed that there is a need to effectively manage knowledge (knowledge management) related to process improvement which means that knowledge should be in the form of repositories instead of tacit knowledge. 56.3% of the respondents said that there is a need to introduce a ''decentralized approach'' which is cheaper and overcome the barriers of existing SPI approaches such as time, cost, resources, knowledge management, change in culture, and use of expensive centralized bodies.

The organizations that do not perform SPI at all have ranked the factors that were identified by our exploratory study. According to their feedback, Resource management while performing SPI and high cost of SPI are two major factors due to which SMEs avoid performing SPI activities. The time that is taken to perform SPI, knowledge management issues, and change in organizational culture were also among the major barriers of existing SPI approaches.

B. FEEDBACK OF CASE STUDY 2 PARTICIPANTS

The second case study was performed to test the effectiveness of the proposed approach. This case study was also performed on a small-scale group of people through an interactive session in which we introduced the proposed approach to them. After performing the case study, we requested our improvement seekers to provide feedback for the proposed approach by using which they improved their processes and got their appraisal document. Responses of improvement seekers are recorded after they used the proposed approach and are shown in Table 2. According to the responses received, 55.6% agreed and 20.4% of participants strongly agreed that BBSPI is an adequate tool to perform SPI activities in the organizations. 64.8% of the participants agreed and 18.5% strongly agreed that by using BBSPI, an organization can improve its processes up to the level of prominent standardization models.

83.6% said that they will accept the proposed system if its peers are highly qualified. 61.4% of participants said

TABLE 1. Experts opinion on traditional process improvement approaches and their barriers.

Sr. No	Questions	Responses	Proportion	Normalized Value
1	Does your organization perform any kind of Software Process Improvement activity right now?	Yes No	69.1 % 30.9 %	-
2	What is the impact of traditional process improvement approaches on the "time duration"? Select any to give your opinion.	Significantly Decreased Minorly Decreased Remained Constant Minorly Increased Significantly Increased	3.1 % 9.4 % 21.8 % 59.4 % 6.3 %	3.60
3	What is the impact of traditional process improvement approaches on the "Cost"? Select any to give your opinion.	Significantly Decreased Minorly Decreased Remained Constant Minorly Increased Significantly Increased	6.3 % 6.3 % 34.4 % 40.6 % 12.5%	3.47
4	What is the impact of traditional process improvement approaches on the "Resource Usage"? Select any to give your opinion.	Significantly Decreased Minorly Decreased Remained Constant Minorly Increased Significantly Increased	3.1 % 12.5 % 21.8 % 56.3 % 6.3 %	3.61
5	According to your opinion, existing process improvement approaches needed your organization to change its culture to conform to the selected standardization model. Select any to give your opinion.	Strongly Disagree Disagree Neutral Agree Strongly Agree	10.2 % 5.4 % 28.1 % 30.2 % 26.1 %	3.61
6	According to your opinion, existing process improvement approaches needed more effective Knowledge Management to conform to the selected standardization model. Select any to give your opinion.	Strongly Disagree Disagree Neutral Agree Strongly Agree	9.1 % 16 % 28.1 % 17.3 % 29.5 %	3.41
7	According to your opinion, existing process improvement approaches are more centralized and are standardization body dependent. Therefore, there is a need for a decentralized approach for process improvement. Select any to give your opinion.	Strongly Disagree Disagree Neutral Agree Strongly Agree	10.2 % 11.4 % 22.1 % 24.2 % 32.1 %	3.63
8	According to you, what are the major barriers that are preventing your organization to perform SPI activities or to conform to a standardization model? (Select all the options which you possibly think can be a barrier)	High Cost Time Knowledge Management Issues Shift in Organizational Culture Resources Management	56.5 % 39.1 % 39.1 % 43.5 % 60.9 %	-

that the outsourcing feature of the proposed SPI approach is beneficial because hiring process engineers is always a costly and time-taking activity.

As in case study 1, most of the participants mentioned time, cost, resource usage, knowledge management, change in organizational culture, and reliance on central bodies are major barriers of existing approaches therefore responding to the evaluation of the proposed approach, 56.4% of improvement seekers agreed and 12.4% strongly agreed to the fact that the proposed methodology will overcome the identified barriers.

56.4% of participants agreed that their process improvement cost will significantly decrease by utilizing the proposed BBSPI approach. 61.8% of participants give feedback that the time taken by process improvement activities will decrease by using BBSPI as compared to traditional SPI.

61.8% of respondents said that they must change their organizational culture to perform process improvement activities

TABLE 2. Experts opinion on the impact of the proposed approach for process improvement.

Sr. No	Questions	Responses	Proportion	Normalized Value
1	In your opinion, the proposed methodology is adequate to be used to perform SPI activities in organizations?	Strongly Agree Agree Neutral Disagree Strongly Disagree	20.4 % 55.6 % 20.4 % 3.7 % 0 %	-
2	If Process Engineers (Peers) are highly qualified, can you trust and implement the final appraisal document in the organization to improve your organization's processes?	Trust Completely Trust to an acceptable point Neutral Trust Partially Cannot Trust at all	20 % 63.6 % 7.3 % 9.1 % 0 %	-
3	By using this methodology, you can fully outsource your SPI activities. In your opinion, whether SPI outsourcing was made easy by the introduction of BBSPI?	Strongly Agree Agree Neutral Disagree Strongly Disagree	14.5 % 50.9 % 30.9 % 3.6 % 0 %	-
4	What impact the proposed methodology had on the overall cost expenditure of SPI activities?	Significantly Decreased Minorly Decreased Remained Constant Minorly Increased Significantly Increased	29.1 % 27.3 % 21.8 % 18.2 % 3.6 %	2.36
5	What impact the proposed methodology had on the overall time duration of SPI activities?	Significantly Decreased Minorly Decreased Remained Constant Minorly Increased Significantly Increased	30.9 % 30.9 % 16.3 % 16.4 % 5.5 %	2.32
6	What impact the proposed methodology had on the overall usage of resources during SPI activity?	Significantly Decreased Minorly Decreased Remained Constant Minorly Increased Significantly Increased	42.3 % 18 % 16.7 % 13.8 % 9.6 %	2.32
7	In your opinion, the proposed methodology had affected your organization's culture?	Strongly Disagree Disagree Neutral Agree Strongly Agree	5.5 % 9.1 % 23.6 % 54.5 % 7.3 %	3.52
8	In your opinion, the proposed methodology helped to manage SPI knowledge effectively?	Strongly Disagree Disagree Neutral Agree Strongly Agree	0 % 3.6 % 27.3 % 56.4 % 12.7 %	2.21
9	By using the proposed methodology, can an organization improve their processes to the level of prominent standardization models (CMM, ISO, LEAN, etc.)?	Strongly Disagree Disagree Neutral Agree Strongly Agree	0 % 3.7 % 13 % 64.8 % 18.5 %	2.05
10	What was your overall experience of using BBSPI to perform SPI?	Very Negative Negative Neutral Positive Very Positive	1.8 % 3.6 % 23.6 % 60 % 10.9 %	-

using the proposed BBSPI (which means that the proposed approach lack for ''change in culture'' factor). But we believe that it can vary from context to context for different-sized organizations.

69.1% of the participants support the fact that proposed BBSPI can effectively manage knowledge by introducing central ontologies and repositories. 83.3% of the participants support that BBSPI could be an effective alternative to the existing central bodies of standardization.

VIII. EVALUATION (HYPOTHESIS TESTING)

To test our formulated hypothesis, we have applied the most commonly used parametric test named as t-test that is used for the comparison of data from two population groups [40], [41].

TABLE 3. Paired t-test for statistical evaluation of null and alternate hypothesis.

Hypothesis Label	Hypothesis Description	Mean Difference	p-value two-tail	t Critical two-tail	Critical Value (α)	Null Hypothesis Status (H_0)	Alternate Hypothesis Status (H_a)
H_0	Traditional SPI approaches are cost-effective, take less resources and time to perform SPI and offer effective knowledge management because there is no need to change organizational culture to conform to the standard of certification bodies.	1.09	0.0055	2.63	0.05	Rejected	**Accepted**

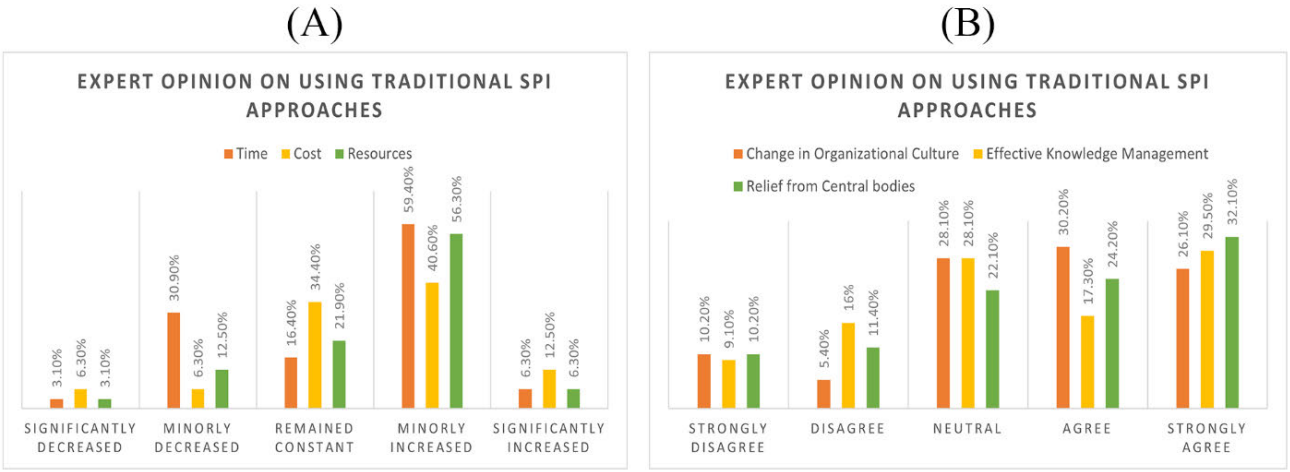

FIGURE 11. Experts opinion on using traditional process improvement approaches.

In our case, both datasets were obtained from the same population hence we have used the paired t-test as explained by Xu *et al.* [42] and Hsu and Lachenbruch [43]. Results of our applied paired t-test are shown in Table 3.

The results of the test show that the mean difference value for traditional SPI and proposed BBSPI is 1.09. We applied our t-test on 55 observations for both populations i.e. traditional SPI approaches and proposed BBSPI. For results evaluation, we have used the value of P(T <= t) two-tail and it is the most important value which helps to assess whether the results of the hypothesis are statistically significant. In our case, p-value (two-tail) is less than the significant value i.e. $\alpha = 0.05$ [43]. Based on the p-value obtained, we can conclude that difference between the populations means is statistically significant therefore, we can reject our formulated null hypothesis (H_0) and can accept alternate hypothesis.

IX. DISCUSSION

BBSPI is a newly proposed approach for process improvement that aims to encourage software organizations to perform process improvement by adopting the existing SPI models. As mentioned in the articles [15], [44], most of the organizations do not perform process improvement and do not adopt any of the models due to cost involved and increased bureaucracy in the organizations. Similarly, there are other issues of traditional SPI approaches which are identified earlier in the article.

Therefore, our main aims of this research were to:

1. Reduce the cost of process improvement.
2. Reduce the time taken to perform process improvement.
3. Reduce the usage of resources for process improvement.
4. Decrease the complexity of overall process improvement.
5. Enhance knowledge management for process improvement activity.
6. Getting rid of reliance on central bodies of standardization for certification.
7. Define a mechanism that allows the organization to perform SPI activities without changing their organizational culture.

According to the opinion of experts received after two case studies, the traditional software process improvement approaches need to be upgraded to overcome the identified barriers. The response which we received for traditional process improvement approaches is shown in Figure 11 (A) and (B). Figure 11 (A) shows the response to factors such as time, cost, and resources. According to Figure 11 (A) time, cost, and resources increase during the development lifecycle of projects when you are trying to improve your organizational processes by following traditional software process improvement approaches.

FIGURE 12. Expert opinion after using the proposed approach BBSPI.

Figure 11 (B) shows the responses received for the other three identified barriers i.e. change in organizational culture, effective knowledge management, and relief from central bodies of standardization. According to these responses, traditional process improvement face mentioned issues, and these are major barriers to process improvement which must be minimized to encourage organizations to perform process improvement.

After the introduction of BBSPI, participants were asked to give feedback. According to the feedback, the proposed approach BBSPI can reduce the number of resources needed during the overall process improvement activity that includes human resources and other technical resources. Moreover, results have also shown that the proposed approach can significantly decrease the time and cost that are required to perform SPI activities as comparison shows in Figure 12 (A). Knowledge can also be managed effectively with the help of BBSPI and an alternative of central bodies of standardization can also be formed with the introduction of BBSPI as stated by participants of our case studies and is shown in Figure 12 (B).

Furthermore, we have performed the paired t-test on our entire sample population. Our p-value results reject the defined Null hypothesis, and we can conclude that the proposed BBSPI is effective enough that it can save a significant amount of time, cost, and resources. Further, the proposed BBSPI supports effective knowledge management and gives relief from central standardization bodies (CMMI and ISO).

X. FUTURE WORK

As a novel approach to process improvement, BBSPI aims at ensuring that organizations perform SPI without changing their organizational culture. As the results of case studies showed that the proposed approach has successfully achieved its other stated goals, therefore in the future we will also incorporate ontologies along with General Data Protection Regulation (GDPR) in our system to make sure that the personal information of different stakeholders like improvement seekers and peers in the network is handled according to a standardized process. Apart from that, we are currently working on introducing blockchain to different fields of software engineering like blockchain-based requirements elicitation techniques, blockchain-based effort, and resource estimation, and other possible software engineering domains where blockchain can be introduced to develop decentralized solutions of traditional software engineering problems.

XI. THREATS TO VALIDITY

Threats to Validity discusses the degree to which a research study actually studies what the researcher purports to [45].

A. INTERNAL VALIDITY

In our case, the performance of the proposed approach may vary due to different factors. The results which we have derived are based on a certain number of organizations of different sizes hence the proposed approach can have a different impact on an organization depending on its size and context of process improvement.

B. EXTERNAL VALIDITY

Another threat to the validity of the proposed approach is that our case studies are not generalized to other cases because we have designed the case studies with the help of a research group. Although these case studies are quite comprehensive and self-explanatory however both case studies can have different results in different cases.

Moreover, the results which we have presented in this study are based on the industrial evaluation of our proposed approach from over 50 participants hence the change in sample size can also affect the results of this study.

C. CONSTRUCT VALIDITY

Peers (Process Engineers) and the facilitator in the proposed approach play an important role in gap analysis and they ensure the implementation of suggested changes in the improvement seeker organizations therefore their overall

experience of process improvement and interest in process improvement can have a major impact on the process improvement using the proposed approach BBSPI. Hence selection criteria for Peers and Facilitators can have an impact on the final outcome of BBSPI.

D. RELIABILITY THREATS

Researchers can replicate this research with the same case studies however, while replicating research results can have minor difference based on the responses and number of participants. Let suppose the number of audiences are same but still the responses/answers can vary, which is a threat to this research work.

XII. CONCLUSION

We have identified barriers for SPI by performing an exploratory study and feedback from industrial experts. Due to identified issues, SMEs and VSEs do not perform process improvement. Consequently, these barriers can increase an organization's pessimistic level towards SPI practices. Eventually, their processes would be immature and can influence the quality of products of these organizations. The proposed BBSPI is bringing a change for software community (SE) to think about the implications of blockchain for SE practices and introduces new techniques which could facilitate the SE stackholders like designers, developers, coders and testers. We have presented the case studies in effective manners which could be easily replicated. Moreover, the proposed blockchain-based approach would help SMEs and VSEs to eliminate the issues of existing techniques and it would ultimately improve their working processes by reducing the time, cost, and resource usage for SPI. Moreover, we have observed that the proposed approach also helps to manage SPI knowledge more effectively. The stated objectives are achieved by the proposed blockchain-based approach that helps the organization to get relief from the central bodies of standardization. Results of the case study have proved that our proposed approach will reduce the cost, time, and resources and it facilitates effective knowledge management. We have observed that the proposed approach is a good substitute for the central bodies of standardization as it can help the organizations to conform to SPI models by spending less time, money, and resources.

ACKNOWLEDGMENT

We would like to express our sincere gratitude to all the people who supported us during this phase and who helped us to complete this research. It was their generous support that made this research work possible. We are also very grateful to our parents, teachers, and friends for their moral support.

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