

CMMI Compliant Workflow Models to Track and Control Changes

Islam Ali¹, Syed Muhammad Ali¹, Waqar Mehmood², Wasif Nisar¹, Muhammad Qaiser Saleem³,
Majzoob K. Omer³, Mahmood Niazi⁴, Muhammad Shafiq⁵ and Jin-Ghoo Choi^{5,*}

¹Department of Computer Science, COMSATS University Islamabad, Wah Campus, Pakistan

²Department of IT and Computer Science, PAF-Institute of Applied Sciences and Technology, Mang, Haripur, Pakistan

³College of Computer Science and Information Technology, Al Baha University, Al Baha, Saudi Arabia

⁴Department of Information and Computer Science, King Fahd University of Petroleum and Minerals, Dhahran, 31261, Kingdom of Saudi Arabia

⁵Department of Information and Communication Engineering, Yeungnam University, Gyeongsan, 38541, Korea

*Corresponding Author: Jin-Ghoo Choi. Email: jchoi@yu.ac.kr

Received: 15 December 2020; Accepted: 24 May 2021

Abstract: The Capability Maturity Model Integration (CMMI) is a renowned Software Process Improvement (SPI) framework. Research studies have revealed that CMMI adoption needs a lot of resources in terms of training, funds, and professional workers. However, the software SMEs (SSMEs) have few resources and cannot adopt CMMI. One of the challenges of adopting CMMI is that CMMI tells “What to do?” as requirements to be met, and leaves “How to do?” to the implementers. The software industry especially SSMEs faces difficulties in successfully implementing various process areas (PAs) particularly Configuration Management Process Area (CM-PA). SG-2 (Track and control changes) is one of the important Specific Goals (SGs) required by CMMI to successfully implement CM-PA. As a starting point, we have achieved this SG by implementing its two contributing Specific Practices (SPs). The proposed WFM were validated through an Expert Panel Review (EPR) process. In addition, a case study approach was used for the evaluation. The results showed that the models are useful, easy to use, supportive in the achievement of SG-2, and applicable to SSMEs. It is worth mentioning that this research work has not only contributed to the implementation studies but also added to the empirical software engineering body of knowledge.

Keywords: SPI; CMMI; CM-PA; SSMEs

1 Introduction

The success or failure of an organization depends on the quality of its products or services. Customers appreciate a reliable software product that operates un-erroneously and never crashes. One way to improve software quality is to improve software development processes. That’s why many software development companies take interest in Software Process Improvement (SPI) programs. Continually improving the software process and regularly appraising its effectiveness will pave the way for the development of high-quality software and help meet customer expectations.



This work is licensed under a Creative Commons Attribution 4.0 International License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

CMMI model facilitates the software development industry to take the quality of software processes to higher levels. However, no significant numbers of small and medium software enterprises (SSMEs) are adopting it. Xu et al. [1] have the opinion that CMMI offers software enterprises only guidelines and does not provide clear workflow models resulting into heavy cost of adoption. Few among the many definitions of SMEs are given in [Tab. 1](#).

Table 1: Categorization of SMEs

Country	Medium Scaled SME	Small Scaled SME	Reference
	HR Strength	HR Strength	
Saudi Arabia	50–249	06–49	Tripathii [2]
Turkey	50–250	03–49	Karadag [3]
Korea	50–199	11–49	Divakara et al. [4]
Pakistan	36–99	10–35	Dasanayaka et al. [5]

CMMI Level II [6] contains seven PAs, including CM-PA. Various studies have been carried out to implement PAs. However, no workflow model for implementing CM-PA to help SSME was found as shown in [Tab. 2](#). Therefore, there is an urgent need to design workflow models for SPs of the CM-PA.

Table 2: Summary of workflow models devised earlier for various SPs/PAs at CMMI Level-II

No	PAs at CMMI Level-II	Work	Ref.
1	Requirements Management	WFMs for SPs (1.1, 1.2) & SPs (1.3, 1.4) of REQM, WFM for CR, Remap: of KPAs of L-2 for SAS, RCM	[7–11]
2	Project Planning	WFM for SP 1.3	[12]
3	Process and Product Quality Assurance	WFM for PPQA	[13]
4	Supplier Agreement Management	WFM for SAM	[14]
5	Configuration Management	X	X
6	Measurement & Analysis	X	X
7	Project Monitoring & Control	X	X

The focus of this research study is to achieve the second specific goal (SG-2) of CM-PA by designing workflow models (WFMs) for the implementation of two SPs (SP-2.1 & SP-2.2). To achieve research goals, the research questions are formulated and listed in [Tab. 3](#).

The organization of this paper is to introduce related work in Part 2. The research methodology is explained in Part 3. Proposed WFMs are illustrated in part 4. Validation of the proposed models is provided in Part 5. Novelties and limitations of the proposed WFMs are presented in part 6. Conclusion and future work are highlighted in Part 7.

Table 3: Questions with research rationale

No	Questions	Rationale
R-A	How to track and control changes, that is, how to implement SPs (2.1 and 2.2) contributing to SG-2 of CM-PA?	To devise WFMs to achieve SG-2 of CM-PA at level-2,
R-B	From the perspective of software SMEs, what do experts think about the “coverage” of WFMs proposed for SG-2 of CM-PA?	assess its coverage of practices,
R-C	What do experts think about the “Usefulness” of the proposed WFMs for tracking and controlling changes in software SMEs?	ease of use, ease of learning,
R-D	Considering software SMEs, how do experts feel about the “Easy to learn and Ease of Use” of the proposed WFMs for SG-2?	usability and its
R-E	What do experts think about the “Applicability” of the proposed WFM to software SMEs?	implement-ability in Software SMEs.

2 Related Work

A variety of related research was studied. However, keeping the concision in mind, only very close research i.e., WFMs devised for implementation of PAs at CMMI level-II is presented. To support SSMEs in implementing the best practices, Keshta et al. [7] designed WFMs for the two SPs of REQM-PA. The WFM for SP 1.1 includes five stages: “Request”, “Understand”, “Evaluate”, “Accept”, and “Finalize” whereas WFM for SP 1.2 includes five stages “Assess”, “Report”, “Negotiate”, “Record”, and “Commit”. Keshta et al. [8] further designed WFMs for the other two SPs of REQM-PA. WFM for SP 1.3 has six stages “Initiate”, “Validate”, “Implement”, “Verify”, “Update”, and “Release”. Another six stages named “Request”, “Maintain”, “Validate”, “Allocate”, “Verify”, and “Release” constitute the WFM for SP 1.4. The EPR process was used to validate the models against the specified criteria. The applicability of the models to SSMEs was evaluated in Saudi Arabian software industry. Bhatti et al. [9] proposed a six-phase methodology to deal with changing requirements: “Initiate”, “Receipt”, “Approve/Disapprove”, “Evaluate”, “Implement”, and “Configure” with CCB to act as process owner and play a central role. Tariq et al. [10] have recommended to include an additional SP in REQM-PA for Software as a Service and carried out validation through a case study. In the same way, Niazi et al. [11] designed the CMMI-Compliant Requirements Change Management (RCM) Model. The model is divided into five stages: “Request”, “Validate”, “Implement”, “Verify” & “Update” and was evaluated through the EPR process. Similarly, Keshta [12] also designed a WFM for the implementation of SP 1.3 of PP-PA and defined phases for a project life cycle keeping in view the SSMEs. The model includes four stages: “Plan”, “Design”, “Review”, and “Update/Rework”. Keshta et al. [13] further developed WFMs for all SPs of PPQA from the perspective of small and medium software development organizations. Vivatanavorasin et al. [14] presented a three-layered WFM for SAM-PA which contains “Contextual”, “Elaboration”, and “Definition” layers. As a proof-of-concept prototype, a Supplier Agreement Management Tool was also developed. Iskandar et al. [15] suggested practices to improve tracking changes in software development including “Initiation”, “Approval”, “Scheduling”, and “Deployment”. The deployment, in turn, is achieved through sub-practices such as “Preparation”, “Execution”, “Validation”, and “Completion/Reversion”.

After a thorough literature review, it was concluded that there are currently no WFMs available for the implementation of the said goal. Therefore, to support SSMEs, there is an urgent need to design the same.

3 Research Methodology

It has always been believed that research methodology profoundly impacts the validity of research results, so it was very meticulously designed. The phases involved in designing WFMs are shown in Fig. 1.

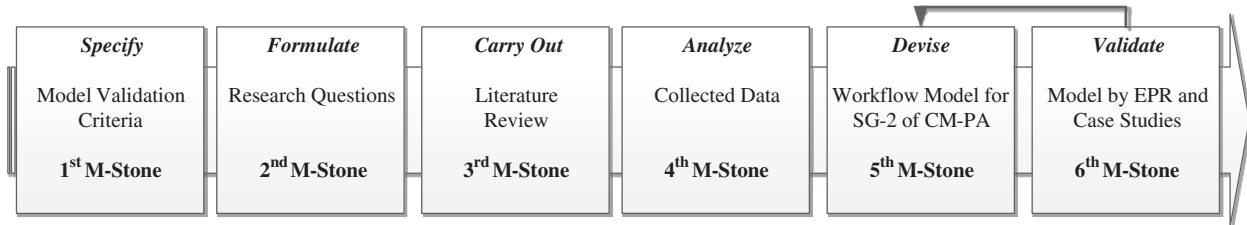


Figure 1: Methodology adopted

The success of the research largely depends on the establishment of robust validation criteria. The criterion for validation of the WFMs in this study having similar nature has been derived from the work of Keshta et al. [7,8], Niazi et al. [11], Keshta et al. [12,13], and Vivatanavorasin et al. [14] as given in Tab. 4.

Table 4: Validation criteria

Criteria	Validation
<i>Satisfaction of SPs</i>	The proposed WFMs should address the practices to achieve SG 2 of CM-PA.
<i>Satisfaction of Users</i>	Models should satisfy users and help them achieve their needs and objectives.
<i>Ease of Learning & Use</i>	The model should be simple, easy to understand, and easy to adopt.
<i>Applicability of the models to SSMEs.</i>	The WFMs should be implementable in SSMEs, that is, it should enable SSMEs to track and control changes.

4 Proposed Workflow Models

The WFMs proposed for the aforementioned SPs are composed of core stages that logically group the activities involved in a particular SP. The proposed WFMs are constructed by employing the well-known Entry-Task-Verification-eXit (ETVX) model. For each WFM, the associated inputs-outputs, the potential artifacts, and actors are identified. Note that the actors are from a sample SSME.

4.1 Workflow Model for Overall CM-PA

To design an abstract WFM for CM-PA, in addition to other research materials, PMBOK 6th Edition, SWEBOK V3.0, CMMI 1.3, and ITIL were studied. The proposed WFM for the entire CM-PA is shown in Fig. 2. The scope of this work (SG-2) is shown in light green.

4.2 Proposed WFMs to Track and Control Changes (SG-2)

The second specific goal of CM-PA is to “track and control changes”. Its purpose is to maintain the baseline established through SG-1. This is achieved by implementing two SPs, namely “Track Change Requests” and “Control Configuration Items”.

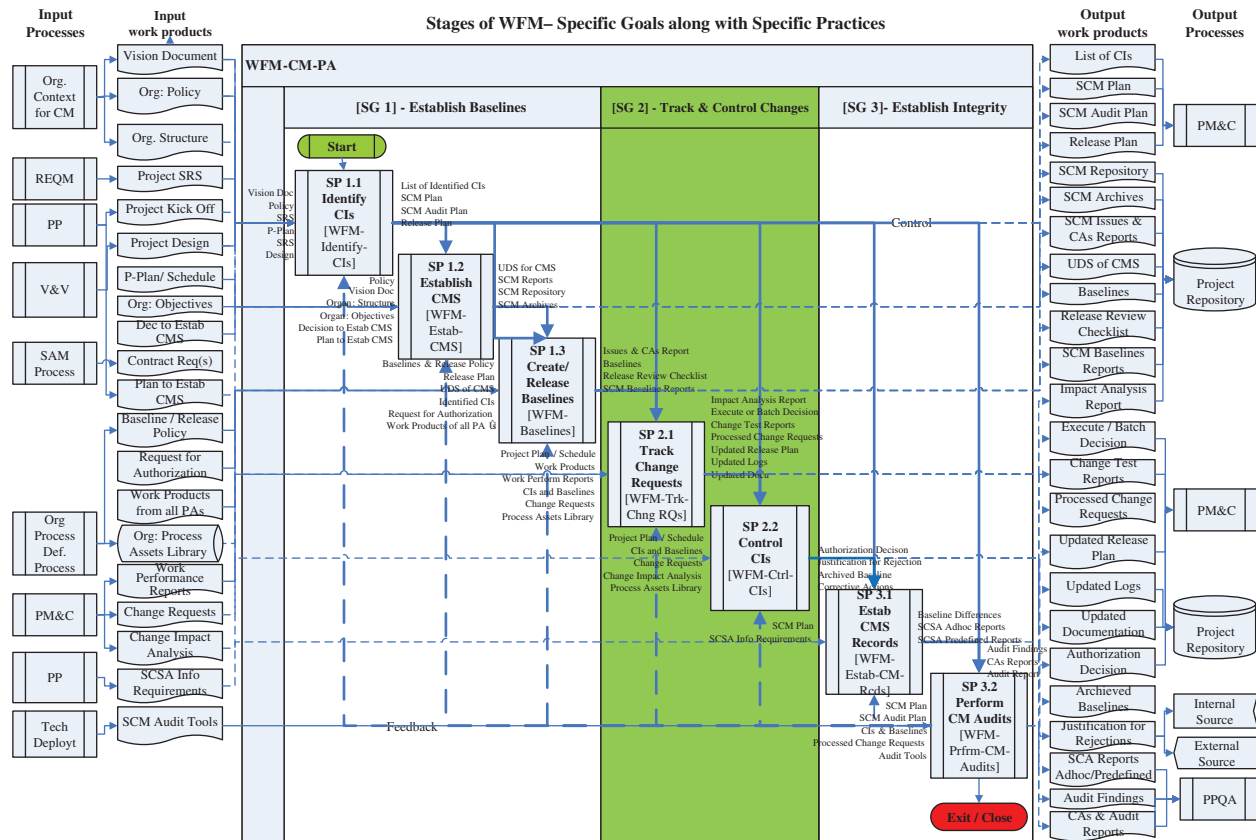


Figure 2: Overall WFM for CM-PA

4.2.1 Workflow Model to Track Change Requests

“Track change requests” is the first of two SPs contributing to SG-2. WFM for this SP has five stages, namely “Initiation”, “Evaluation”, “Implementation”, “Updation” and “Closure” as illustrated in Fig. 3. In Tab. 5 accompanying process guide is shown. Tab. 6 lists the literature findings at each stage. For the sake of brevity, only three of the many references are provided.

4.2.2 Workflow Model to Control Configuration Items

The proposed WFM for this SP is divided into five stages: “Initiation”, “Authorization”, “Maintenance”, “Review” and “Record” as illustrated in Fig. 4 followed by the pertinent process guide in Tab. 7 followed by supportive findings from literature in Tab. 8.

5 Validation of the Proposed Models

5.1 Validation through EPR

An expert panel review was conducted to verify the proposed WFMs, in which opinions on the model were obtained from 10 experts according to the specified criteria. The experts having expertise in the fields of SPI, Project Management, Configuration Management, and Software Development were consulted as shown in Tab. 9.

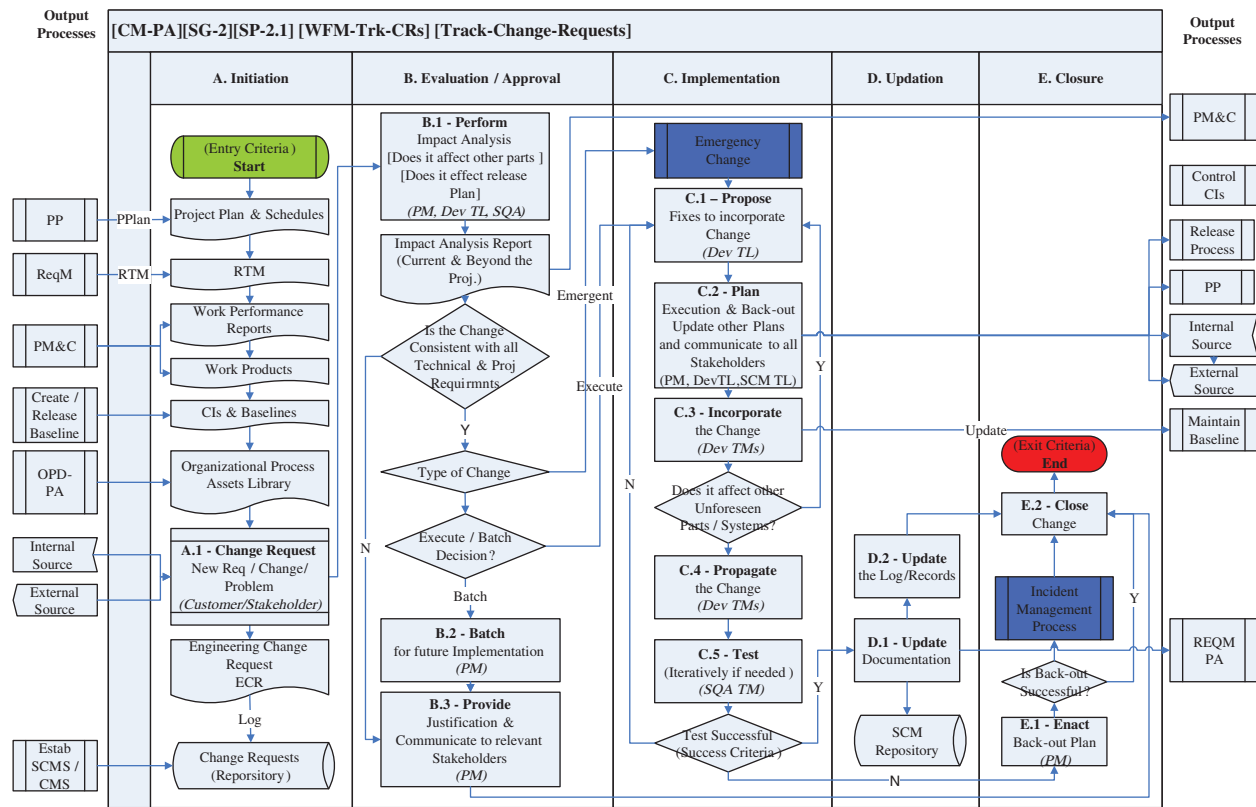


Figure 3: Proposed workflow model to track change requests (SP-2.1)

Table 5: A process guide for WFM to track change requests

Purpose	Changes in software projects are inevitable. A formal change procedure helps to effectively track, control, and manage changes, including scope creep and defects/faults	
Scope	The scope includes analyzing change requests initiated by stakeholders, evaluate the impact of changes on work products, estimate the time/cost of merging changes, obtain approvals, process and track changes to closure.	
Abbreviations	CR	Change Request
	CIs	Configuration Items
	CMS	Configuration Management System
	CCB	Configuration Control Board
	RTM	Requirements Traceability Matrix
Entry criteria	<ul style="list-style-type: none"> • The project stakeholder(s) have submitted change request(s). • The Work products/CIs to be changed have been baselined. 	
Inputs to the workflow and associated PAs/SPs	Input Work-Products	Associated PA/SP
	• Project Plan & Schedule	• PP-PA
	• Requirement Traceability Matrix (RTM)	• REQM-PA
	• CIs and Baselines	• Create or Release Baseline-SP
	• Change Requests Repository	• Establish CMS—SP
	• Change Request	• Internal or External Source

Table 5 (continued).				
Purpose		Changes in software projects are inevitable. A formal change procedure helps to effectively track, control, and manage changes, including scope creep and defects/faults		
Stage	Process Activities	Roles	Records/WPs	
<i>A. Initiation</i>	A.1	A change request should have a unique identifier whether initiated by an external source (such as a requirement provider) or an internal source (such as a team member).	Any user (Internal, External)	CR—Change Request (ChangeLog)
<i>B. Evaluation</i>	B.1	The following question should be kept in mind when conducting impact analysis: Is the requisite change consistent with other technical and project requirements? If an inconsistent change request is initiated, it should be closed and the relevant stakeholders informed with justified reasons. If there is an emergency, an emergency process should be triggered.	PM, Dev TL, SQA	Impact Analysis Report
	B.2	The changes to be incorporated later on shall be batched and the initiator should be notified about it.	PM	Execute/Batch Decision
	B.3	The infeasible change should be returned to the initiator along with justified reasons.	PM	CR with justification
<i>C. Implementation</i>	C.1	A fix to the requested changes should be proposed.	Dev TL	Proposed Fixes
	C.2	Incorporation of the changes should be planned and other plans that will affect should be revised accordingly, such as release plan/back-out plan.	PM, Dev TL, SCM TL	Updated Plans
	C.3	The changes should be incorporated.	Dev TMs	–
	C.4	Ensure that the merged changes do not affect any other components, systems, or subsystems. After then these changes should be propagated to other systems.	Dev TMs	–
	C.5	Changes should be tested iteratively. If the test goes unsuccessful, a back-out plan should spring into action.	Test TMs	Test Findings

(Continued)

Table 5 (continued).				
Purpose	Changes in software projects are inevitable. A formal change procedure helps to effectively track, control, and manage changes, including scope creep and defects/faults			
D. Updation	D.1	The logs and records should be updated.	TMs	Logs/Records
	D.2	The documentation should be updated.		Updated Docs
E. Closure	E.1	If the test criteria indicate any failure, the back-out plan should start. If the back-out plan is not implementable, the incident management process should spring into action.	PM	–
	E.2	Close/conclude the change.	SCM TL	–
Interfaces	<ul style="list-style-type: none"> • The artifacts generated in PP, PPQA, PMC, REQM, MA, SCM, etc. are subject to change. • Baselines/CIs are received from the “Create or Release Baselines” practice. • The change request repository is established and maintained through the “Establish CMS”. • If an emergent change is initiated, the emergency change process should start. 			
Output work products & associated PAs/SPs	Output Work-Products	Associated PA/SP		
	<ul style="list-style-type: none"> • Updated Plans & Schedules • Updated Software Requirements Specifications, RTM • Change(s) Incorporated 	<ul style="list-style-type: none"> • PP-PA and PM&C-PA • REQM-PA • Maintain Baseline-SP 		
Exit criteria	<ul style="list-style-type: none"> • Findings of regression testing have been closed. • A change request is rejected, batched, or an incident management process is triggered. 			
Measures	<ul style="list-style-type: none"> • Number of changes 			
Verification points	<ul style="list-style-type: none"> • PM, in coordination with Dev TL/SCM TL, should review the change requests. • The approval and status of change requests may be checked by CCB members or auditors. • Quality inspectors should evaluate the configuration control process and designated work products for effectiveness. • QC should iteratively test the change for undesired effects before propagation. 			
Training	<ul style="list-style-type: none"> • CM-PA in general and Change Management in particular, CMS Usage Training. 			
Tools	<ul style="list-style-type: none"> • MS Office, CMS Tool e.g., MS Visual SourceSafe/CVS/Team Foundation Server, etc. 			
Resources	<ul style="list-style-type: none"> • Process descriptions and tailoring guidelines, Trained HR having expertise in CM-PA. 			
Assumptions	<ul style="list-style-type: none"> • CMS is established, SCM tools are installed and users are authorized. • SCM TMs have created the required workspace in the CMS as per the scale of the project. • The change requests are maintained in the change request repository or REQM Sheet. 			
Exemptions	<ul style="list-style-type: none"> • Tailoring Guidelines 			
Applicable standards & related documents	<ul style="list-style-type: none"> • Documentation Standards Manual/PMC Process Guide • Change Request Proforma • Issues Workbook and Corrective Actions Report 			

Table 6: Evidence in the literature supporting WFM to track change requests

No.	Evidence	Author's Point of View	Reference
A—Initiation Stage			
1	WFM for Managing Change	Ismail Keshta proposed WFM for REQM's SP-1.3 and SP-1.4. The first stage of the model is "Initiation", where the user initiates a change request. A repository of change requests is maintained.	Keshta et al. [8]
2	Improving Track Changes in Software Development	Iskandar has the opinion that every change fulfills business, the technical or external requirement(s). The author designed a process to improve tracking changes in software development. The author included the "Initiation" as the first stage of the process.	Iskandar et al. [15]
3	Bhatti's Change Management Methodology	In the "Initiation" stage of Bhatti's methodology, the request is initiated by a customer or any of the team members. Change Request(s) are the work products of his stage.	Bhatti et al. [9]
B—Evaluation/Approval Stage			
1	WFM for Change Management	The second stage of WFM designed by Keshta is "Validation", which determines the nature of the change, evaluates the change, and conducts an impact analysis. Then the change is validated, that is, it is rejected, batched for the future, or approved for implementation. In fact, "Evaluation" and "Validation" are interchangeably used.	Keshta et al. [8]
2	Improving Track Changes in Software Development	Iskandar has termed the group of activities carried out at this stage as "Approval". The evaluation is done for the same purpose i.e., to arrive at the right decision to approve, batch or reject the change.	Iskandar et al. [15]
3	The flow of Change Control Process	In SWEBOK, the authors have given the title "Preliminary Investigation" to the aforesaid activities on the basis of which CCB approves a change, reject a change or batch it for future.	SWEBOK V3.0 [16]
C—Implementation Stage			
1	WFM for Change Management	"Implementation" is the third phase of WFM designed by Keshta to implement change management.	Keshta et al. [8]
2	Improving Track Changes in Software Development	Iskandar emphasized backing up the system before implementing changes so that it can be restored in the event of a failure. In the "Deploy/Execute" phase, the changes are incorporated and released to the production environment.	Iskandar et al. [15]
3	Change Control Process	The authors of SWEBOK have the opinion that in the implementation process, only approved changes should be implemented, and these changes should be discard-able to restore the previous stable state.	SWEBOK V3.0 [16]
D—Updation Stage			
1	WFM for Change Management	In the "Update" stage of WFM designed by Keshta, the relevant documents are updated before the changes are released.	Keshta et al. [8]
2	RCM Model	In the RCM model, Niazi suggests that relevant documents (DFD, ERDetc) should be updated once the changes are implemented.	Niazi et al. [11]

(Continued)

Table 6 (continued).

No.	Evidence	Author’s Point of View	Reference
3	Change management in SaaS environment	Tariq also defines steps to update the related documents before the changes are closed.	Tariq et al. [10]
E—Closure Stage			
1	WFM for Change Management	Closing activities are carried out in the “Release” stage. The documents are updated, and change(s) are then released to the production environment.	Keshta et al. [8]
2	RCM Model	In this model, closing activities are performed in the “Update” stage. Once the documents are updated, the change is closed.	Niazi et al. [11]
3	Improving Track Changes in Software Development	Iskandar has termed this stage as “Completion/Reversion”, where validation of the change should result in the completion of the change or reversion to some previous stable point.	Iskandar et al. [15]

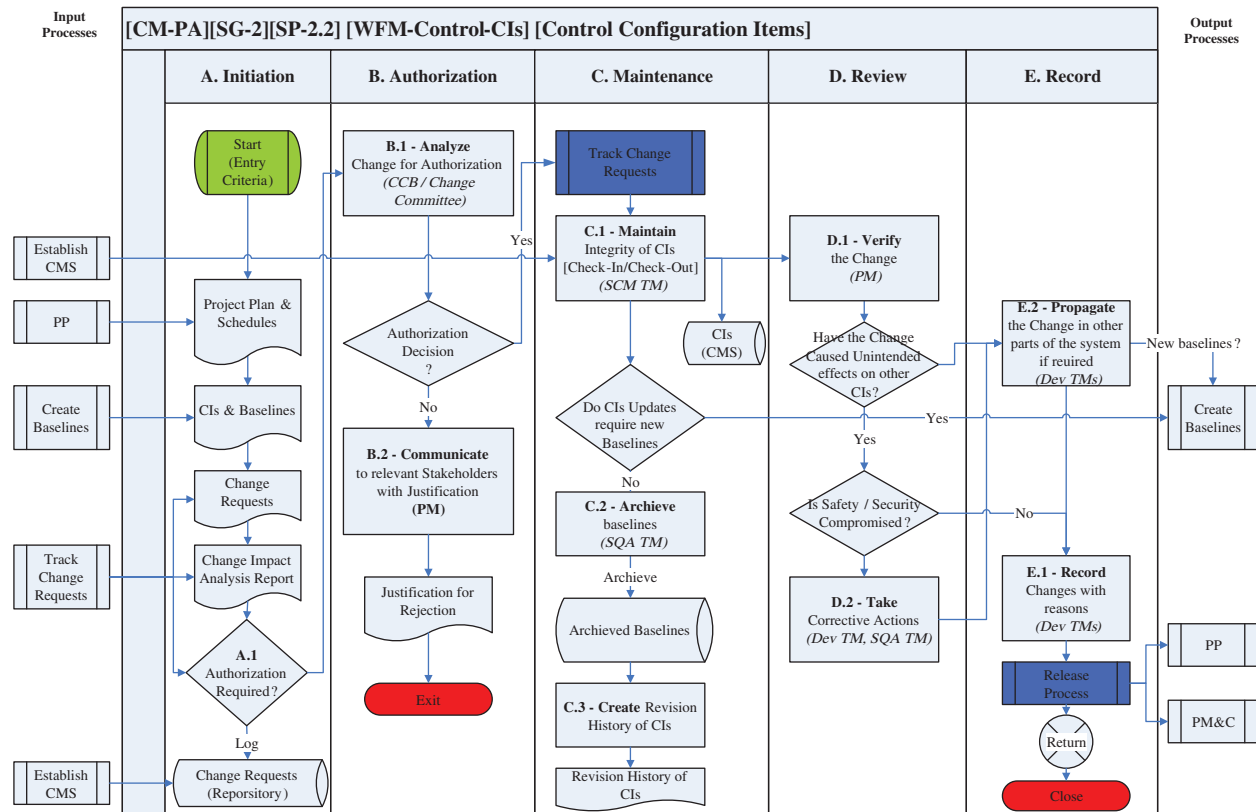


Figure 4: Workflow model for SP-2.2

Table 7: A process guide for controlling configuration items

Purpose	The purpose of SP-2.2 is to control the configuration of CIs i.e., to track the configuration of each CI, to approve new configuration, and to update the baseline accordingly		
Scope	This process starts when a change authorization request is received and comes into action each time when CI is checked out for incorporation of any change.		
Abbreviations	<ul style="list-style-type: none"> • CIs/WPs • C-I/C-O • UDS 	<ul style="list-style-type: none"> Configuration Items/Work Products Check-In/Check-Out Unified Directory Structure 	
Entry criteria	<ul style="list-style-type: none"> • CMS has been established and • Request for authorization of change in CI/baseline is received. 		
Inputs to WFM & associated PAs/SPs	Input Work-Products	Associated PA/SP	
	<ul style="list-style-type: none"> • Project Plan • CIs & Baselines • Change Requests/Authorization Request 	<ul style="list-style-type: none"> • PP-PA • Create Baselines • Track Change Requests 	
Stage	Process Activities	Roles	Records/WPs
A. Initiation	A.1 The request is initiated by a stakeholder (internal or external) for authorization.	User/Stakeholder	Requests
B. Authorization	B.1 The change should be analyzed for authorization. In case the change is small, it should be approved/rejected by PM and by CCB otherwise.	CCB/PM	Acceptance/Rejection Decision
	B.2 If the change is rejected, the initiator should be notified accordingly with justified reasons.	PM	Log
C. Maintenance	C.1 A Check-In/Check-Out System shall be established to maintain the integrity of CIs. Track-Change-Request shall be triggered to track changes.	Authorized User	Maintained UDS
	C.2 The baselines should be archived for future use.	SCM TMs	Archives
	C.3 The revision history of CIs should be created.	SCM TMs	Rev. History
D. Review	D.1 The change incorporated should be verified for any unintended effects.	SCM TL, SQA TL,	–
	D.2 If unintended effects are introduced as a result of the incorporation of the change e.g., safety or security issues, CAs/PAs should be taken.	Dev T/M, SQA TM	Corrective/Prev-entive Actions
E. Record	E.1 The change should then be propagated to other parts of the system if required.	Dev TMs	–
	E.2 All changes should be recorded with reasons.	Dev TMs	Change Log
Interfaces	Project Plans – PP-PA/PMC-PA Impact Analysis of requested changes is covered by REQM-PA		
	Output Work-Products	Associated PA/SP	

(Continued)

Table 7 (continued).	
Purpose	The purpose of SP-2.2 is to control the configuration of CIs i.e., to track the configuration of each CI, to approve new configuration, and to update the baseline accordingly
The output of WFMs & associated PAs/SPs	<ul style="list-style-type: none"> • Authorization Decision – Acceptance/ Rejection • Track Change Requests • Release Process • Revision History
Exit criteria	<ul style="list-style-type: none"> • The desired changes have been incorporated in the baseline as per the change request.
Measures	<ul style="list-style-type: none"> • No of change requests/CIs controlled
Verification points	<ul style="list-style-type: none"> • PM, in coordination with Dev TL/SCM TL, reviews the Control CIs process and WPs. • QA evaluates the Configuration Control process and designated WPs as per the schedule. • QC performs testing activities to ensure that specified requirements are addressed.
Training	<ul style="list-style-type: none"> • Configuration Control Process, Usage of CMS and relevant Templates
Tools	<ul style="list-style-type: none"> • MS Office, Any CMS Tool (MS Visual SourceSafe/CVS/Team Foundation Server, etc.)
Resources	<ul style="list-style-type: none"> • Process descriptions and tailoring guidelines • Human resources/Infrastructure needs (Hardware, Software, Facilities)
Assumptions	<ul style="list-style-type: none"> • A new project workspace and related development workspaces are created in the CMS.
Exemptions	<ul style="list-style-type: none"> • Tailoring Guidelines
Applicable standards & related documents	<ul style="list-style-type: none"> • Issues Workbook and Corrective Actions Reports • Project Monitoring & Control Process Guide/Tailoring Guidelines • Requirements Management Process Guide

Table 8: Evidence in the literature supporting WFMs to control CIs

No.	Evidences	Author's Point of View	References
A—Initiation Stage			
1	Implementing SP-1.3 & SP-1.4 of REQ-PA.	The WFM proposed by Keshta starts with an “Initiation” stage and change request repository is maintained.	Keshta et al. [8]
2	Improving Track Changes in Software Development	The process that Iskandar designed to improve tracking changes starts with “Initiation”.	Iskandar et al. [15]
3	Bhatti's Change Management Process	WFM designed by Bhatti also starts with the “Initiation” stage with the opinion that the impact analysis should lead to an authorization decision.	Bhatti et al. [9]
B—Authorization Stage			
1	CMMI for Development – Implementation Guide	Chaudhary believes that it is necessary to seek approval from CCB before updating any configuration item or putting them in the CMS.	Chaudhary et al. [17]
2	Introduction to Software Quality Assurance.	O'regan has prepared a simple process map for carrying out impact analysis, approval of CCB, and recording the approval/rejections decisions along with the rationale.	O'Regan [18]

Table 8 (continued).			
No.	Evidences	Author's Point of View	References
3	CMMI for Development	Chris believes that to import the updated CI into the CMS, an authorization procedure must be defined.	Chris et al. [19]
C—Maintenance Stage			
1	CMMI for Development – Implementation Guide	Each check-in/check-out should be done in a way that does not lose the previous version i.e., it should be ensured that each configuration item is recoverable with known state.	Chaudhary et al. [17]
2	CMMI for Development	The crisis states that check-in and check-out allow only one copy of CI to be updated at a time.	Chris et al. [19]
3	Introduction to Software Process Improvement	To maintain integrity, the CMS should enforce check-in and check-out of the repository, especially when needed.	O'Regan [20]
D—Review Stage			
1	Introduction to Software Quality Assurance	O'regan has included the “Review & Update” step in his process map for configuration management. The author also suggested updating the relevant document history.	O'Regan [18]
2	Software Engineering Body of Knowledge.	As part of the control process, CIs shall undergo quality assurance to ensure that only approved changes are made.	SWEBOK [16]
3	Mastering Software Project Management	Murali Chemuturi proposed to conduct a “Peer Review” or “Management Review” after implementation.	Chemuturi et al. [21]
D—Record Stage			
1	Introduction to Software Quality Assurance	In his process map for configuration management, O'regan included the “Record Comments” as a step to be able to answer the question “When and who modified a particular CI and what is its status?”	O'Regan [18]
2	Software Engineering Body of Knowledge	The authors suggested that software change request process should record CCB's approval for the change.	SWEBOK V3.0 [16]
3	Towards Implementation of PPQA-PA	Keshta has included the “Record” stage in his WFM for SP-2.2 of PPQA-PA where PPQA Activities are recorded.	Keshta et al. [13]

Table 9: Profiles of the panel members

Domain	No of Experts	Overall Knowledge/ Experience	CMMI/SPI Knowledge & Experience
SPI Experts/CMMI Auditors	2	20,17	20,16
QA Managers	2	19,17	19,15
Project Managers	2	20,15	15,15
Configuration Managers/CM Auditors	2	20,14	18,13
Senior Software Engineers	2	16,13	15,12

According to [22], researchers are free to develop their criteria for the classification of experts. The experts in this study are divided into 3 groups. Experts with less than 15 years of experience are classified as juniors, experts with more than 17 years of experience as senior, and the remaining experts as intermediates. According to this criterion, the panel consists of 4 seniors, 4 intermediates, and 2 juniors.

The questionnaire was specially designed to obtain the opinions of the experts on the proposed WFMs. This questionnaire is based on similar work by Niazi et al. [11] and Keshta et al. [7,8,12,13]. The questionnaire consists of three parts, including a cover letter stating purpose, demographics, and expert opinions. The questionnaire has seven questions and was reviewed by academicians to make it clearer and easier to read. The summary of the expert's responses based on the five-point Likert scale is shown in Tabs. 10 and 11. The Q-8 was open-ended that was used to collect feedback to improve the models.

Table 10: Summary of the responses to the proposed WFM to track change requests

		<i>Question</i>	<i>Measure</i>	<i>SD/</i> <i>"1"</i>	<i>D/</i> <i>"2"</i>	<i>N/</i> <i>"3"</i>	<i>A/</i> <i>"4"</i>	<i>SA/</i> <i>"5"</i>	<i>Mean</i>	<i>Rslt</i>
Practice Satisfaction (Answer to RQ-A, B)	Q-1	The proposed model will help meet the requirements of SP-2.1 and help realize the SG-2 of CM-PA.	Freq %age	0 0	2 20	0 0	4 40	4 40	3.8	Agree
	Q-2	To what extent do the proposed WFM cover SP-2.1 and its sub-practices?	Freq %age	0 0	0 0	2 20	3 30	5 50	4.3	Fully Covered
User Satisfaction Answer to RQ-C	Q-3	The proposed WFM will prove useful for the software industry, especially SSMEs.	Freq %age	0 0	0 0	2 20	4 40	4 40	4.2	Useful
	Q-4	The use of the proposed WFM will prove instrumental to improve the software development process and contribute to the quality of the products produced through it in SSMEs.	Freq %age	0 0	2 20	1 10	4 40	3 30	3.8	Agree
Ease of Learning & Use (Answer to RQ-D)	Q-5	How clear the proposed WFM represents the SP-2.1.	Freq %age	0 0	1 10	1 10	4 40	4 40	4.1	Clear
	Q-6	How much CMMI knowledge will be required to use the proposed WFM for SP-2.1?	Freq %age	0 0	1 10	2 20	3 30	4 40	4.0	Little
Implementability (Answer to RQ-E)	Q-7	Our proposed WFM can be implemented in SSMEs with little tailoring/tweaking.	Freq %age	0 0	2 20	2 20	3 30	3 30	3.7	Agree

Table 11: Summary of responses to the proposed WFM to control CIs

		<i>Question</i>	<i>Measure</i>	<i>SD/</i> <i>"1"</i>	<i>D/</i> <i>"2"</i>	<i>N/</i> <i>"3"</i>	<i>A/</i> <i>"4"</i>	<i>SA/</i> <i>"5"</i>	<i>Mean</i>	<i>Rslt</i>
Practice Satisfaction (Answer to RQ-A, B)	Q-1	The proposed model will help meet the requirements of SP-2.2 and help realize the SG-2 of CM-PA.	Freq %age	0 0	0 0	2 20	3 30	5 50	4.3	Strongly Agree
	Q-2	To what extent do the proposed WFM cover SP-2.2 and its sub-practices?	Freq %age	0 0	0 0	2 20	2 20	6 60	4.4	Fully Covered
User Satisfaction	Q-3	The proposed WFM will prove useful for the software industry, especially SSMEs.	Freq	0	0	1	5	4	4.3	Very Useful

Table 11 (continued).										
		<i>Question</i>	<i>Measure</i>	<i>SD/</i>	<i>D/</i>	<i>N/</i>	<i>A/</i>	<i>SA/</i>	<i>Mean</i>	<i>Rslt</i>
				"1"	"2"	"3"	"4"	"5"		
(Answer to RQ-C)			%age	0	0	10	50	40		
Answer to RQ-C	Q-4	The use of the proposed WFM will prove instrumental to improve the software development process and contribute to the quality of the products produced through it in SSMEs.	Freq	0	0	3	3	4	4.1	Agree
			%age	0	0	30	30	40		
Ease of Learning & Use (Answer to RQ-D)	Q-5	How clear the proposed WFM represents the SP-2.2.	Freq	0	1	0	4	5	4.3	Very Clear
			%age	0	10	0	40	50		
	Q-6	How much CMMI knowledge will be required to use the proposed WFM for SP-2.2?	Freq	0	2	1	3	4	3.9	Little
			%age	0	20	10	30	40		
Implementability (Answer to RQ-E)	Q-7	Our proposed WFM can be implemented in SSMEs with little tailoring/tweaking.	Freq	0	0	0	5	5	4.5	Strongly Agree
			%age	0	0	0	50	50		

According to the results of the EPR process, experts believe that the proposed models are easy to learn, cover sub-practices, can effectively implement SP, help achieve SG-2, help improve the quality of the software produced, and are suitable for SSME as well as for the software industry. However, like other things, there is room for improvement in the proposed model.

5.2 Validation through Case Studies

To test the worth of the model in the real world, a case study was conducted in two Pakistani SSMEs willing to implement WFMs. In order to maintain confidentiality, the cover names are used. The participating SSMEs are briefly defined in [Tab. 12](#).

Table 12: Participant SMEs of the study

Software SME	Size	Core Expertise
Small Software Enterprise	32	Software development and provision of support to Pakistani Sugar Mills.
Medium Software Enterprise	83	Development of ERP for SMEs and the provision of maintenance support.

The participating SSMEs were appraised by CMMI experts for readiness against the underlined SPs at level-II and were found unready. A brief presentation covering the objectives of the study was delivered in an opening session for both the SSMEs. In order to evaluate the effectiveness of the proposed WFMs after implementation, SCAMPI Type-“C” and Type-“B” appraisals were conducted by the lead auditor in both SSMEs against the said SPs. The result of appraisals was encouraging. Both the SPs were declared “Fully Implemented” and its contribution towards the satisfactory achievement of the SG-2 in both the SSMEs was appreciated. According to the lead auditor’s statement, both SSMEs will undoubtedly be rated as “fully implemented” in the SCAMPI Type “A” assessment. Feedback was also collected from participating professionals at the closing meeting.

5.3 Mitigation Actions Taken Against Threats to Result's Validity

First, the closed-ended questions in the questionnaire may not have captured the true views of respondents. In order to reduce the impact, an open-ended question was included to get free opinions thereby improving the accuracy of the response. Second, the panel members may have a different interpretation of the questions/WFMs and may have responded accordingly. Due to the close correlation, the questionnaire was taken from the work of Keshta. This was further refined by adding coverage of the framework at the sub-practices level and reviewed by another proficient academician. Third, the responses may have been limited to the knowledge and experiences of the respondents. Fortunately, experts with extensive industry experience participated in this study. The presence of world-renowned experts in the panel added to the effectiveness of the review process. Fourth, the responses of senior, intermediate, and junior experts might be different. The P of Chi-Square (X²) test was calculated and found > 0.05 for $\alpha = 0.05$ and the degree of freedom = 2 against the responses. This means that the difference between the answers provided by the experts is negligible. Finally, the general literature review process may not have seen the relevant research work. However, according to Hossain et al. [23], this cannot be regarded as a systemic omission.

6 Novelities and Limitations of the Proposed Models

6.1 Novelities

Novelties of the models are tabulated as under in [Tab. 13](#).

Table 13: Novelities of the WFMs in terms of features compared with the earlier models for PAs of CMMI

Features of the Proposed WFMs	The Proposed Models	Features of Earlier Models								
		Keshta et al. [7]	Keshta et al. [8]	Bhatti et al. [9]	Tariq et al. [10]	Niazi et al. [11]	Keshta [12]	Keshta et al. [13]	Vivatanavorasin et al. [14]	Chemuturi et al. [21]
Compliant to CMMI representation— Staged.	☼	☼	☼	☼		☼	☼	☼	☼	
Help to achieve objectives of SG-2 of CM-PA.	☼	☼	☼		☼	☼	☼	☼		
Devised SP-wise.	☼	☼	☼		☼	☼	☼	☼		
Satisfy the relevant SPs	☼	☼	☼			☼	☼	☼	☼	
Cover the Sub-SPs.	☼									
Satisfy user.	☼	☼	☼			☼	☼	☼		
Easy to learn/easy to use.	☼	☼	☼	☼		☼	☼	☼		☼
Provide Inputs/ Outputs of the workflow.	☼								☼	
Provide the roles responsible for each step.	☼	☼	☼	☼	☼		☼	☼	☼	

Table 13 (continued).

Features of the Proposed WFMs	The Proposed Models	Features of Earlier Models								
		Keshta et al. [7]	Keshta et al. [8]	Bhatti et al. [9]	Tariq et al. [10]	Niazi et al. [11]	Keshta [12]	Keshta et al. [13]	Vivatanavorasin et al. [14]	Chemuturi et al. [21]
Applicable to Software SMEs.	☼	☼	☼				☼	☼		
Follow the ETVX Model.	☼									
With relevant templates, forms & checklists.	☼		☼			☼	☼	☼	☼	
Associated process guide prepared.	☼									
Address the overall CM-PA.	☼									

6.2 Limitations

Although the models have all the novelties, these have some limitations as well. First, these models are compatible with the current version of CMMI. Second, its applicability was tested in Pakistani SSMEs. However, these need to be revised for future versions and validated for other countries.

7 Conclusion and Future Work

The main purpose of this research is to design a workflow model to realize the SG-2 “Track and control changes” of CM-PA at CMMI level-II and validate it. To this end, five research questions (RQ-A~RQ-E) were formulated. Further WFMs were designed for its two associated SPs. Responses received from the experts as per the five-point Likert scale satisfy the validation criteria. The results were further confirmed by conducting case studies. The results showed that Pakistani SSMEs are capable of adopting the proposed models with minor adjustments. Satisfactory comments from experts and participating organizations speak well of the WFMs and add to the confidence in the evaluation results. The WFMs were refined after several rounds of improvements by incorporating suggestions from academicians, professionals, and finally feedback from case study participants. This work should continue to design WFMs for other SPs of this PA, other PAs of Level-II, and higher levels for which workflow models have not yet been developed.

Funding Statement: This work was supported by the Basic Science Research Program through the National Research Foundation (NRF) of Korea funded by the Ministry of Education under Grant 2018R1D1A1B07048948.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

References

- [1] G. Xu, H. Hu, P. Yu, J. Lv, P. Qu *et al.*, “Supporting flexibility of the CMMI process framework with a multi-layered process model,” in *Proc. Web Information System and Application Conf.*, Yangzhou, China, pp. 409–414, 2013.

- [2] A. Tripathi, "SMEs in Saudi Arabia—An innovative tool for country's economic growth," *Science International (Lahore)*, vol. 31, no. 2, pp. 261–267, 2019.
- [3] H. Karadag, "The role and challenges of small and medium-sized enterprises (SMEs) in emerging economies: An analysis from Turkey," *Business and Management Studies*, vol. 1, no. 2, pp. 179–188, 2015.
- [4] S. Divakara and H. N. S. K. Surangi, "A literature review on small & medium-size enterprises," *Journal of Business and Technology*, vol. 2, no. 3, pp. 17–33, 2018.
- [5] Dasanayaka, "SMEs in globalized world: A brief note on basic profiles of Pakistan's small and medium scale enterprises and possible research directions," *Research Journal of the Institute of Business Administration Karachi—Pakistan*, vol. 3, no. 1, pp. 69–90, 2008.
- [6] CMMI Product Team, "CMMI for Development, Version 1.3," Software Engineering Institute, pp. 433–454, 2010.
- [7] I. Keshta, M. Niazi and M. Alshayeb, "Towards the implementation of requirements management specific practices (SP 1.1 and SP 1.2) for small- and medium-sized software development organisations," *IET Software*, vol. 5, pp. 308–317, 2020.
- [8] I. Keshta, M. Niazi and M. Alshayeb, "Towards implementation of requirements management specific practices (SP 1.3 and SP 1.4) for Saudi Arabian small and medium-sized software development organizations," *IEEE Access*, vol. 14, pp. 24162–24183, 2017.
- [9] M. W. Bhatti, F. Hayat, N. Ehsan, A. Ishaque, S. Ahmed *et al.*, "A methodology to manage the changing requirements of a software project," in *Proc. Int. Conf. on Computer Information Systems and Industrial Management Applications*, Krakow, Poland, pp. 319–322, 2010.
- [10] A. Tariq, S. A. Khan and S. Iftikhar, "Remapping of CMMI level-2 KPA's for development process improvement of software-as-a-service (SaaS) cloud environment," in *Proc. Int. Conf. on Open Source Systems and Technologies*, Lahore, Pakistan, pp. 43–51, 2014.
- [11] M. Niazi, C. Hickman, R. Ahmad and M. Ali Babar, "A model for requirements change management: Implementation of CMMI level 2 specific practice," in *Proc. Lecture Notes Computer Science*, vol. 5089, LNCS, pp. 143–157, 2008.
- [12] I. Keshta, "A model for defining project lifecycle phases: Implementation of CMMI level 2 specific practice," *Journal of King Saud University—Computer and Information Sciences*, 2019.
- [13] I. Keshta, M. Niazi and M. Alshayeb, "Towards implementation of process and product quality assurance process area for Saudi Arabian small and medium-sized software development organizations," *IEEE Access*, vol. 6, pp. 41643–41675, 2018.
- [14] C. Vivatanavorasin, N. Prompoon and A. Surarerks, "A process model design and tool development for supplier agreement management of CMMI: Capability level 2," in *Proc. XIII ASIA PACIFIC Software Engineering Conf.*, Bangalore, India, pp. 385–392, 2006.
- [15] M. Iskandar, B. David and A. Bin Shamsudin, "Improving track changes in software development," *Journal of Software Maintenance and Evolution*, pp. 1–17, 2016.
- [16] A. Abran, J. W. Moore, R. Dupuis, R. Dupuis and L. L. Tripp, "Software configuration management," in *Guide to the Software Engineering Body of Knowledge (SWEBOK), Ver 3.0. A Project of the IEEE Computer Society*, vol. 6, pp. 1–15, 2014.
- [17] M. Chaudhary and A. Chopra, "CMMI Design," In: *CMMI for Development – Implementation Guide*, India: Apress, vol. 2, pp. 9–69, 2017.
- [18] G. O'Regan, "Configuration Management," in *Introduction to Software Quality Assurance*, Ireland, Cham Heidelberg, New York, Dordrecht, London: Springer, vol. 5, pp. 89–99, 2014.
- [19] M. B. Chrissis, M. Konrad and S. Shrum, "Configuration Management," in *CMMI for Development*, 3rd edition, Addison-Wesley, pp. 243–255, 2017.
- [20] G. O'Regan, "Configuration management," in *Introduction to Software Process Improvement*, London, Dordrecht, Heidelberg, New York: Springer, vol. 5, pp. 116–125, 2011.
- [21] M. Chemuturi and T. M. J. Cagley, "Change management in software development projects," *Mastering Software Project Management*, vol. 8, pp. 157–169, 2010.

- [22] S. U. Khan, M. Niazi and R. Ahmad, "Empirical investigation of success factors for offshore software development outsourcing vendors," *Institute of Engineering and Technology Software*, vol. 6, no. 1, pp. 1–15, 2012.
- [23] E. Hossain, M. Ali Babar and H. Y. Paik, "Using scrum in global software development: A systematic literature review," in *Proc. Fourth IEEE Int. Conf. on Global Software Engineering*, Limerick, Ireland, pp. 175–184, 2009.