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María Angélica Astorga Vargas

DIRECTORA DE TESIS

Dra. Brenda Leticia Flores Rios

CODIRECTOR DE TESIS

Dr. Guillermo Licea Sandoval

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KNOWLEDGE MANAGEMENT MEASUREMENT MODEL BY SECIC-IS PROCESSES CAPABILITY LEVELS WITH A FOCUS ON SOFTWARE PROCESS IMPROVEMENT

A THESIS

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Presented by

María Angélica Astorga Vargas

THESIS DIRECTOR

Dra. Brenda Leticia Flores Rios

THESIS CODIRECTOR

Dr. Guillermo Licea Sandoval

Mexicali, Baja California, Enero 2020

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KNOWLEDGE MEASUREMENT BY SECIC-IS PROCESS CAPABILITY LEVELS WITH A FOCUS ON SOFTWARE PROCESS IMPROVEMENT

Abstract approved by:

Dra. Brenda Leticia Flores Rios
Director

Dr. Guillermo Licea Sandoval
Codirector

Background

Software Development Organizations (SDOs) are knowledge-intensive entities (Alavi & Leidner, 2001; Dingsøyr et al., 2009). Likewise, Software Process Improvement (SPI) is considered an intensive knowledge activity (Wan et al., 2011) and also an opportunity to reach a process capability level that enables SDOs to be competitive. Despite the benefits of SPI initiatives, only a few SDOs in Mexico are certified in CMMI-DEV (Capability Maturity Model Integration for Development), particularly in Baja California. This is why Knowledge Management (KM) becomes a key tool for a successful implementation of an SPI initiative. However, to strengthen the impact of KM in SDOs and encourage them to implement KM processes as a strategy, it is necessary to put in place a KM assessment model that expresses results by capability levels in a common view and interpretation to Software Engineering standards concerning SPI.

Objectives

The main objective of this research is to assess the capability of Knowledge Management processes in SDOs measuring the implementation of tacit and explicit knowledge to support Software Process Improvement. Consequently, three steps were determined in order to reach the main objective. First, to develop a Knowledge Management capability assessment model, then, to apply this model to a CMMI-DEV certified SDO and bring real context to the implementation of best practices in software industry, and lastly, to validate the correspondence between the Knowledge Management capability level and CMMI-DEV maturity level.

Method

A SECIC-IS[1] assessment model focused on Software Process Improvement was developed to measure the capability of Knowledge Management processes into five levels: L1 Socialization, L2 Externalization, L3 Combination, L4 Interiorization, and L5 Knowledge Creation. The SECIKC-SE model was adapted from models and standards of the Knowledge Management and Software Engineering context. The Knowledge Management context is based on the Theory of Knowledge Creation by Nonaka (1994), Knowledge Management Reference Process Model by (Flores-Rios, 2016), Wan et al. (2011), and North & Kumta (2014). The Software Engineering context is supported by the reference assessment model (ISO/IEC 15504/02, 2010) and the Software Process Reference Model (CMMI-DEV, 2010). To ensure a scientific quantitative research, the measurement instrument was evaluated for reliability and validity. Next, a factor analysis was performed to validate the common meaning of capability levels. Five hypotheses were stated to test the incremental knowledge flow path between the capability levels. The case study research method was applied to five SDOs following the assessment process developed to empirically test the SECIKC-SE Model measurements.

Results

The SECIKC-SE capability process profile of all five SDOs was L1 Socialization. This result confirmed that the incremental capability path is based on the previous level.

Conclusions

The validation of the applicability of the SECIKC-SE model and its measurement framework through a case study research method and the execution of assessment activities, allowed for a successful empirical measurement of the degree of implementation of indicators in five SDOs. However, the comparison of the SECIKC-SE capability results with the correspondence of the SDOs maturity level of CMMI-DEV showed that current practices of knowledge management were not sufficient.

[1] The term SECIC-IS will be use in the rest of the document as SECIKC-SE

Dedication

To God, Virgin Mary, and my parents for making me feel their love and grace every day.

Acknowledgments

First, I want to thank my family and friends for always being there with a lovely word, warm hugs, and happy smiles that encouraged me to reach this goal.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1. Introduction

Software Development Organizations (SDOs) are knowledge-intensive entities (Alavi & Leidner, 2001; Dingsøyr et al., 2009) that have found in Software Process Improvement (SPI) a motivation to raise their process capability through by implementing best practices to develop quality products so they can be competitive in national and international markets (Ward & Aurum, 2004; Dingsøyr et al., 2009; Oktaba & Piattini, 2008; Flores-Rios et al., 2014). Each level represents continuous and intense learning and adds new practices based on previous levels that SDOs must complete to achieve incremental improvements and also confirm by an assessment process to measure the degree of implementation of these practices (ISO/IEC 15504/2, 2010).

One of the success factors that can sustain the continuous and intense learning promoted by Software Engineering (SE) processes (Flores-Rios, 2016) and in Software Process Improvement (SPI) initiatives (Rus & Lindvall, 2002) is Knowledge Management (KM) (Rus & Lindvall, 2002; Goldoni & Oliveira, 2010), considering that the main goal of KM is to preserve and to make knowledge available in order to create new knowledge (Maciel et al., 2018; O'Leary & Studer, 2001).

Edwards (2003) considers that KM is vital to improve effectiveness in Software Engineering (SE) areas or departments, as a strategy that provides a simple way to learn in-depth knowledge about software organizations (Humayon & Qazi, 2015). KM enables a formal and informal exchange of knowledge among software developers (Rus & Lindvall, 2002); contributing greatly to tacit and explicit knowledge-building practices that support Software Process Improvement (SPI) (Wan et al., 2011). However, if knowledge is not shared or understood the value of knowledge is lost (Shin et al., 2016), When knowledge is restricted to an individuals' mind due to the lack of personal motivation or committed leadership and management, implementing an SPI initiative becomes more difficult. In principle, since it is not possible for this knowledge to be available to others, teams are prevented from learning from the expert. If the experts leave the organization, their knowledge leaves with them, and the inexperienced are left with a knowledge gap that becomes impossible to close in the short term, causing a setback in the organization's maturity (North & Kumta, 2014).

The ability to understand the knowledge involved in organizational work and adopt appropriate KM initiatives requires the measurement of this knowledge to improve processes (McIver & Wang, 2016). However, assessing the impact of KM is one of the major challenges that modern organizations have to face (Xu & Bernard, 2011; Asoh et al., 2011; Maciel et al., 2018) since its benefits are intangible and difficult to detect and measure (Asoh et al., 2011). Alavi and Leidner (2001) argue that assessment shortage in

KM is due to its multifaceted nature and the multiple interpretations of knowledge; while Kankanhalli and Tan (2005) expressed that despite the need and efficacy of metrics, research on the use of metrics to evaluate the implementation of KM is widely underdeveloped.

Within the context of SDOs, some difficulties that arise in an SPI project are due to the lack of strategy or organizational culture, tacit or explicit that manages knowledge assets acquired through quality practices (Kankanhalli &Tan, 2005; Goldoni & Oliveira, 2010). On the other hand, it is a challenge to establish a common language between SPI and KM initiatives, taking into account that SDOs are measured and compared to each other based on capability and maturity levels. In this same approach, a KM assessment model is required within the SE context that defines the measurements by capability and maturity levels producing a higher visibility and better understanding of the importance of KM in SDOs.

A recent Systematic Literature Review (SLR) carried out from 2007 to 2019, revealed the lack of research to assess the effects of KM in SDOs (Goldoni & Oliveira, 2010; Maciel et al., 2018) particularly in a quantitative manner. As a result, SDOs are not aware of the current state of KM practices, especially on areas of weakness and their impact on an SPI initiative.

Therefore, this research aims to bring a KM Management capability model that can be applied in Software Development Organizations to measure the effects of KM on Software Engineering, providing support to the success of an SPI initiative and enabling them to establish a capability comparison with other organizations.

1.1 Problem statement

Software Processes Reference Models (SPRM) such as ISO/IEC 12207 Information Technology / Software Life Cycle Processes, and CMMI-DEV 1.3 are a set of process areas and best practices gathered from the software industry (CMMI-DEV, 2010; ISO/IEC 15504/02, 2010), that is, a collection of tacit and explicit knowledge of SDOs. Implementation of these practices had been proposed through an evolutionary path by capability process and maturity levels due to the effort required by SDOs to implement and maintain best practices by adapting their processes, technology and above all, personnel participation and knowledge.

The main benefits of implementing SPRMs are getting to a capability level that will improve productivity, quality, scheduling and cost estimation, meet customer needs, as well as having a reliable assessment method that informs SDOs about their gaps in order to improve their processes (CMMI-DEV, 2010). However, comparing these benefits with statistics about the success of software projects reported by the Standish group in 2017, only 29% of projects were completed on time and within budget, while in 1992 only 16% did. This would seem like an improvement, but it is not enough considering that the adoption of SPI initiatives is more than 20 years old. In addition to this, the three leading causes of failure in software projects are the abandonment of a methodology that guides the process of software development, the lack of skilled personnel, and the culture of organizations (Standish group, 2017).

In the context of SDOs in Mexico, according to the last report of the Secretary of Economy (SE, 2016), there were 661 verified or certified development centers, 180 in CMMI-DEV, and 481 in NMX-I-059-03/NYCE-2011 (MoProSoft) (NMX-I-059, 2011). Moreover, in the last NYCE (Normalization and Certification) report corresponding to the third quarter of 2018 (NYCE, 2018) (Table 1) a total of 490 development centers were reported, of which 48.57% have (ML-1) (Maturity Level ML), 47.14% (ML-2), only 2.83% (ML-3), and less than 1% (ML-5). In 2002 the Secretary of Economy reported that the average capability level of SDOs in Mexico was less than 1; nowadays, according to the NYCE report, the level is 1.6, a result not so favorable after 17 years. On the other hand, in the first quarter of 2019, the CMMI Institute (CMMI Institute, 2019) reported 210 Mexican SDOs certified in CMMI-DEV (Table 1), of which 40.95% have (ML-2), 43.81% (ML-3), less than 1% (ML-4), and 14.29% (ML-5). These results show that a considerable effort has been made to obtain a CMMI-DEV certification, considering that it is a model with a higher number of international implementations, allowing Mexican SDOs to compete in a global market. The average ML is 2.9; despite this effort, the number of certified companies is low compared to the total SDOs in the country.

Table 1. Verified and certified SDOs in Mexico.

NMX-I-059-03 (MoProSoft)			**CMMI-DEV 1.3**	
Maturity Level	**Number of SDO**	**%**	**Number of SDO**	**%**
5	1	0.20	30	14.29
4	0	0.00	2	0.95
3	14	2.86	92	43.81
2	231	47.14	86	40.95
1	238	48.57		
0	6	1.22		
TOTAL	**490**	**100**	**210**	**100**

There are 280 SDOs (Cluster TI BC, 2019) in operation in Baja California, distributed in four locations (Table 2). The main locations are Mexicali and Tijuana. 11 SDOs are certified in CMMI-DEV 1.3; this means Baja California represents 5.23% of 210 certified SDOs in Mexico. According to ML, 10 have ML-2 and 1 has ML-3 (Table 2). Figure 1 shows a certification timeline per year 2015 (1), 2016 (3), 2017 (4), and 2018 (3) demonstrating the lack of effort of the software industry in Baja California to reach capability levels compared to the total SDOs, since only 3.93% are certified (Table 2). This shows the need for strategies to encourage and enable SDOs to achieve certification.

Table 2. SDOs in Baja California.

Location	Number of SDOs	ML-2	ML-3	%
Mexicali	127	8	1	7.09
Tijuana	132	2	0	1.52
Tecate	3	0	0	0.00
Ensenada	18	0	0	0.00
Total	**280**	**10**	**1**	**3.93**

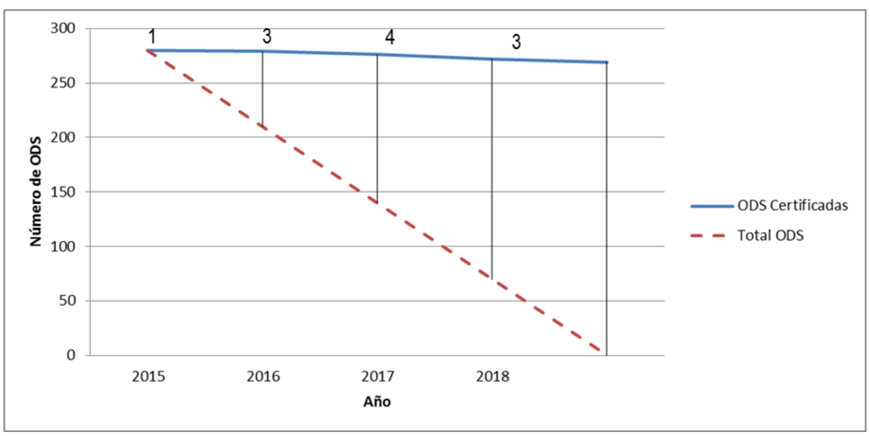


Figure 1. Certification timeline of SDOs in Baja California

Results showing a lack of successful software projects on international level and the current software process capability context of SDOs in Mexico, suggest that there is a gap between the efforts towards an SPI initiative supported by KM. On the one side, ML-2 and ML-3 certifications do not imply that all bussines units or software projects are within the scope. Meaning that KM best practices have not been implemented in the entire organization. On the other side, for an SDO to consider KM strategies as successful, they need to measure to what extent knowledge has added value to the organization and their processes (Goldoni y Oliveira, 2010). In this regard, key indicators are needed to provide information about an event in order to measure KM (Straub et al., 2002; Asoh et al., 2011; Kankanhalli and Tan, 2005). In relation to SPI initiatives, the use of indicators to measure the software process capability level is mandatory (ISO/IEC 15504, 2010). Hence, the measurement of KM processes by capability levels under the guidance of Software Engineering standards that support an SPI initiative is an opportunity to create a common view and interpretation of results between both disciplines, KM and SE.

1.2 Research questions

Do Software Development Organizations certified in CMMI-DEV have implemented knowledge management practices according to their maturity level?

Can the incremental path of capabilities be established to measure Knowledge Management using the capability measurement of Software Engineering standards concerning SPI?

1.3 Research objectives

General objective

To assess capability levels of Knowledge Management processes in Software Development Organizations certified in CMMI-DEV 1.3 to measure the degree of tacit and explicit knowledge and their implications on an SPI initiative.

Specific Objectives

O1. To develop a Knowledge Management capability assessment model to measure the degree of implementation of knowledge processes focused on an SPI initiative.

O2. To measure the capability of knowledge process in some Mexican SDOs certified in CMMI-DEV 1.3 ML-2, ML-3, and ML-5 using the KM assessment model proposal.

O3. To validate the KM processes capability level impact on the capability level of CMMI-DEV 1.3

1.4 Methodology

In order to fulfill the research questions developed in section 1.2, the following methodology steps were conducted:

1. A background review as well as an in-depth Systematic Literature Review were carried out in order to identify the most up-to-date Knowledge Management strategies with emphasis on quantitative assessment focused on software process improvement.
2. To guide the development of the KM assessment model focused on an SPI initiative, Knowledge Management models, and Software Reference Process Models and Assessment Process Models standards were adopted.
3. A case study research method was used to test the KM assessment model in software development organizations certified in CMMI-DEV 1.3 ML-2, ML-3, and ML-5.
4. A comparison analysis was performed to assess KM process capability of each SDO with their capability or maturity level of CMMI-DEV 1.3.

1.5 Outline

The rest of the document is organized as follows:

Chapter two is focused on Knowledge Management concepts, the theory of knowledge creation, reference process models, knowledge as an asset in software engineering, and the application of the SECI model into Software Development Organizations.

Chapter three describes the Software Reference Process Model and the Software Assessments Process Models, particularly CMMI-DEV and its SCAMPI appraisal method, as well as ISO/IEC 12207(2008) and its assessment model ISO/IEC 15504/02 (2010).

Chapter four presents the results of a systematic literature review on quantitative measurement of knowledge management in Software Development Organizations, as a way of discovering the methods and indicators that were used, as well as the knowledge and software processes that were measured.

Chapter five describes the design of an instrument that measures the explicit and tacit knowledge conversion effects of the SECI model applied to a case study in a scholar software company.

Chapter six presents a SECIKC-SE capability assessment model of Knowledge Management towards a Software Process Improvement Initiative, its measurement framework, and the assessment process by Knowledge Management models and Software Reference Process characterization, and the conformity with the Assessment Reference Process Models. This chapter also describes in detail the research findings of five SDOs assessed.

Finally, chapter seven presents the conclusions of this research study as well as future work.

Chapter 2. Knowledge Management and Knowledge creation

2.1 Knowledge and Knowledge Management

Knowledge is a concept that has taken many different definitions due to its nature. Alavi & Leidner (2001) define knowledge as “the information possessed by the minds of individuals.” Bollinger & Smith (2001) defines it as “a valuable resource for an organization’s ability to innovate and compete; it exists individually within each employee and in a composite sense within the organization.” Whereas for Shbair et al. (2016) knowledge is “the interpretation of information in a context, is the result of perception, learning and reasoning”. According to Polanyi (1962), knowledge is classified as tacit and explicit knowledge. Tacit knowledge is subjective, it represents the base knowledge experiences of each individual, and it is not codified. Explicit knowledge is objective, rational, and available in a codified format for other individuals to use it and understand it.

KM has also been associated with several definitions. For example, Aurum et al. (2008) state that its essence is to create, preserve and apply the knowledge that is available within organizations. While for Hung et al. (2005) KM is an integrated and systematic management strategy that combines information technology with organizational processes. It is a knowledge-based set of activities and solutions applied to problems and events that happen within the company, as well as the access to data with the purpose of answering and making adequate decisions to reach the objectives of the organization (Hung et al., 2005; Goldoni & Oliveira, 2010). For this research, Alavi and Leidner’s (1999) definition has been adopted as a “systemic and organizationally specified process for acquiring, organizing and communicating both tacit and explicit knowledge of employees so that other employees may make use of it to be more effective and productive in their work”.

2.2 SECI model: Knowledge Creation

According to the theory of knowledge creation proposed by Nonaka (1994), knowledge is transferred from two dimensions: epistemological and ontological, in a process of continuous learning within a spiral that represents the theory of organizational knowledge creation (Figure 2). In the epistemological dimension, tacit knowledge is converted to explicit knowledge and vice versa. These modes of knowledge conversion are triggered epistemologically through a conversion cycle or knowledge spiral between the processes of knowledge: Socialization, Externalization, Combination, and Interiorization, known as the SECI model, on which knowledge is created, considered critical for sustainability and success of any organization.

On the other hand, in the ontological dimension, knowledge evolves from individuals to workgroups, then to an organizational level until it reaches an inter-organizational level. The interaction scale between tacit and explicit knowledge increases as it moves through ontological levels.

The process of knowledge creation begins with socialization that makes experience and abilities (tacit knowledge) among individuals easier to share with others who need it; it is a harmonized knowledge. It happens regularly through meeting records, task-modeling so repeating a task helps others to learn by example. In externalization, tacit knowledge becomes explicit; it is a conceptual knowledge, easy to understand through the capture, organization, structuring, representation and coding of knowledge to facilitate its management by converting it from tacit to explicit. During combination, the current explicit knowledge is converted into a new explicit knowledge; it is a systemic knowledge created from the combination of individual pieces of explicit knowledge that is stored using repositories that provide an easy access. The fourth process is Interiorization which is carried out by practicing what has been learned from explicit knowledge.

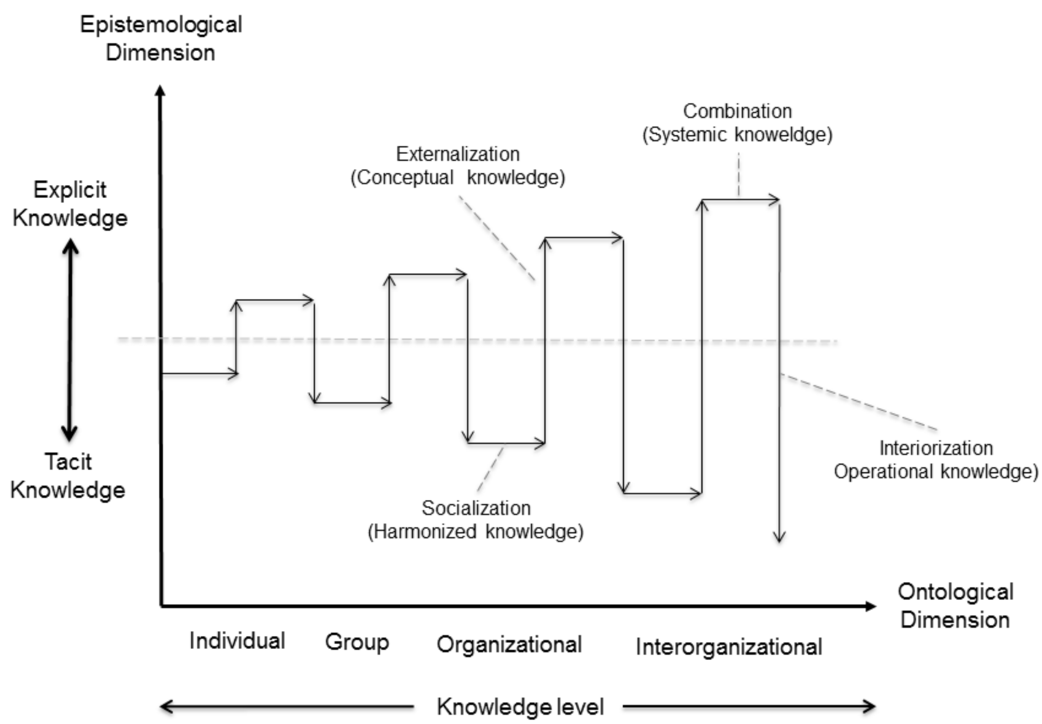


Figure 2. Knowledge creation dimensions (Flores-Rios, 2016) adapted from (Nonaka,1994).

It is important to emphasize that interactions between different types of knowledge are not only linear and sequential, but also exponential and dynamic, also known as the knowledge spiral (Nonaka & Takeuchi, 1995; Gil & Carrillo, 2014). The difference between knowledge modes is determined by the four knowledge flows of the SECI model (Table 3). When knowledge reaches Interiorization, tacit knowledge is enriched and the knowledge spiral begins again, but this time at a higher level which leads to creation of new concepts based on the continuous dialogue between tacit and explicit knowledge (Nonaka, 1994).

Table 3. Conversion of 4 modes of knowledge (Astorga et al., 2017) based on (Nonaka, 1994).

Knowledge Modes	**Knowledge flows between processes**		**Spiral increment**
	From	**To**	
Tacit-Tacit	Socialization	Socialization	
Tacit-Explicit	Socialization	Externalization	
Explicit - Explicit	Externalization	Combination	
Explicit -Tacit	Combination	Interiorization	

2.3 KM Process Reference Models

The timeline of KM process and KM Process Reference Models (KMRPM) applied to SE with a focus on SPI initiative (Table 4) shows that until 2010, there is a new development adding a measuring process in order to establish the status and impact of KM within the organization (Galvis-Lista, 2015; Flores-Rios 2016) and the results attained (Goldoni & Oliveira 2010). Furthermore, only the proposals by Galvis-Lista (2015) and Flores-Rios (2016) were developed as KMRPM, the first one for Colombian SDOs and the second one for Mexican businesses. Both KMRPM used ISO/IEC 24774 to determine the requirements (process name, proposal, results –products-, activities, tasks and information elements) that describe a formal standard process. Also, both models took into account the ISO/IEC 15504, Galvis-Lista (2015) to comply with verification requirements of a process reference model, and Flores-Rios (2016) to analyze the type of knowledge required in ML1 and ML2 concerning the NMX-I-059/NYCE-2011 and their relationship with knowledge processes. On the other hand, Flores-Rios (2016) integrated the SECI model in the process life cycle to promote practices from the Knowledge creation theory by Nonaka (1994). However, none of them proposed a process assessment model.

Table 4. KM process and KM process models.

Characteristics	Alavi & Leidner (1999)	Ward & Aurum (2004)	Goldoni & Oliveira (2010)	Galvis Lista (2015)	Flores-Rios (2016)
	Create	Create	Creation	Identification	Identification
	Store	Acquire	Storage	Application	Create/Generate /Acquisition
	Transfer	Identify	Dissemination	**Evaluation**	Externalize
	Apply	Adapt	Utilization	Transfer	Store
		Organize	**Measuring**	Acquisition	Transfer
		Distribution		Creation	Interiorize
		Apply		Codified	**Measure**
				Protection	Evolution
ISO/IEC 15504				x	x
SECI Model					x
Process name (ISO/IEC 24774)				x	x
Proposal				x	x
Activities (ISO/IEC 24774)				x	x
Products (ISO/IEC 24774)					x
Technology and support systems (ISO/IEC 24774)				x	x
Roles					x
Process assessment model				-	-

2.4 Knowledge as an asset in software development organizations

The application of KM in the SE field is an opportunity to create a common language among software developers, so that they can interact, negotiate and share knowledge and experiences (Aurum et al., 2003), applying what has been learned to improve the quality of software products by reducing defects (Dingsøyr & Conradi, 2002) and costs. Given that software is not only code but the sum of all the documents that go along with it, that makes it possible to operate and maintain such software (Sommerville, 2001; Serna & Serna, 2014).

Software quality is defined as “the conformance to explicitly stated functional and performance requirements, explicitly documented development standards and implicit characteristics expected of all professionally developed software” (Pressman, 2005). For software development, there are several SPRM such as CMMI-DEV, ISO/IEC 12007, NMX-I-059-NYCE-2011 (MoProSoft) and specific models as RUP, SCRUM, PSP, TSP, among others, with the purpose of introducing best practices that guarantee software quality. These models define workflows that guide the project team in every activity to generate work products necessary for successful development and maintenance. Besides, these models enable knowledge processes of Socialization, Externalization, Combination, and Interiorization to be present in the software development lifecycle during conversion of tacit and explicit knowledge (Wan et al., 2011; Chikh, 2011).

At the individual knowledge level, software development team members are considered “intellectual workers” (Demarco & Lister, 1987; Ryan & O’connor, 2009), since the software development process implies tacit coordination of experiences from these team members (Faraj & Sproul, 2000). However, even though agile methodologies rely on strong communication dynamics among the project team members and on tacit knowledge (Lenberg et al., 2017), it does not mean that explicit knowledge is excluded. Since software quality requires explicit documentation of customer requirements (Sommerville, 2001) with a minimum level of detail needed for understanding and traceability to develop the next baseline artifacts for software development. This contributes to preserving knowledge and prevents misunderstanding requirements. (Kotlarsky et al., 2015). In this sense, Ghobadi (2015) suggests the need to increase knowledge sharing between developers about the different components that have been developed and used.

It is unlikely that all members of a team will have the knowledge required for software development activities (Ryan & O’Connor, 2009). Therefore it is important to share such tacit knowledge among members (Chau & Maurer, 2004) and transform it into explicit knowledge (Nonaka & Takeuchi, 1995) in a way that it eases the fulfillment of customer’s specific requirements, while progressing towards group ontological knowledge. Software project teams struggle with functional and divisional structures that prevent the integration of knowledge practices. Besides, some project teams include members in different contexts or domains (Navimipour & Charband, 2016; Niknafs & Berry, 2017), which come together only during the project or part-time only. More experienced workers often consult fewer knowledge bases (explicit) (Ko & Dennis, 2004); however, they contribute more to the knowledge that has been internalized (tacit) so that it is available to other members who can make use of it.

In this context, knowledge transference is critical to members who usually work as a team; therefore, KM becomes an enabler of learning organizations (Chouseinoglou et al., 2013), consequently moving from group knowledge to organizational knowledge. Due to the nature of software projects and their complexity, not having information available can be the reason for failure to solve problems (Aurum et al., 2008). Therefore, KM gives SDOs the opportunity to appreciate the challenges and complexities inherent to software development (Ward & Aurum, 2004). For organizations in need to overcome these challenges, SPRM allows them to implement a set of best practices that have been gathered from the software industry and reflect tacit and explicit inter-organizational knowledge of SDOs. This knowledge collection has motivated SDOs to implement SPI initiatives where knowledge plays an important role as an asset in organizations.

2.5 Application of SECI model: Knowledge creation in software engineering

Applying the SECI model for knowledge creation within SE and SPI projects is a way to increase and improve tacit and explicit knowledge among all the roles of the software project team: analysts, designers, programmers, testers, users, project managers, business experts, and other stakeholders (Chikh, 2011). Explicit knowledge is easy to obtain and understand, unlike tacit knowledge, which is associated with one of the main risks in software engineering: the lack of understanding or omission of requirements, especially those stored in users' minds which are difficult to transmit (Bohem, 1991; Kwak & Stoddard, 2004).

The application of each knowledge process of the SECI model in SE is described below.

Socialization. It encourages the exchange of experiences to learn from each other. Promoting socialization is of great importance for the interaction among project team members, customers. This process makes individuals and organization´s tacit knowledge available to others through current systems, work sessions, and demonstrations, where project team members can observe how users execute their tasks to obtain the customers' requirements. Socialization is essential to all members in the organization to support a common understanding of characteristics and requirements that the software must provide as well as to ensure their commitment to the Project (Chikh, 2011).

Externalization. After the exchange of knowledge that occurs in socialization, project team members are able to externalize the new explicit knowledge. Formalization of knowledge is to standardize documents through templates, meeting records, and to define knowledge maps as the experience and skills of employees (Jensen & Szulanski, 2007; Basri & O'Connor, 2011; Flores-Rios et al., 2014). Formalization allows to document the project's implicit objectives and capture customer's requirements, that relate the tacit requirements with specific project characteristics, to develop business models, analysis and design, code, testing, manuals, etc., according to the software process model and specific methodologies for software development and maintenance.

Combination. During externalization, explicit knowledge versions are obtained in different work products, and are used as inputs and outputs between the flows associated with the software development life cycle; all these are combined to become a new explicit knowledge. Software development processes are iterative and incremental, so software products are released based on the previous baseline. These baselines are stored in repositories of the knowledge base according to the nature of the documents. It is important to keep the traceability of the requirements until it becomes a software component so that every time a change arises and new versions or combinations are created, project team members know what to store and how to store it.

Interiorization. When the explicit knowledge created is reflected and discussed among the project team members, customers, and users, the internalization process occurs. So, explicit knowledge learned from the different roles, workflows, or documents becomes easier to understand and practice, bringing knowledge to evolve to a higher level. The evolution of tacit knowledge allows both users and project team members to propose changes or to add new requirements in the early stages of the project, managing to satisfy the real needs of the customer and users (Chikh, 2011). Training team members with the explicit knowledge available in the knowledge base is another mechanism that motivates internalization and increases new explicit knowledge.

Chapter 3. Software Reference Process Models and Assessment Process Model

In an SPI initiative, a Software Process Reference Model (SPRM), such as CMMI-DEV (Capability Maturity Model Integration – Development) and ISO/IEC/IEEE 12207 (Systems and software engineering – Software life cycle processes) measures the effectiveness of the implementation using capability and maturity level paths to achieve incremental improvements in SDOs. These models require Software Process Assessment Models (SPAM) to determine the capability and maturity level implemented by the SDO. CMMI-DEV uses SCAMPI (Standard CMMI-Based Appraisal Method for Process Improvement) for this purpose. While ISO/IEC 12207 (2008) uses the ISO/IEC 15504 Information-Technology Process Assessment standard. Capability represents a process ability to meet current business objectives and is applied individually to process areas (CMMI-DEV, 2010; ISO/IEC 15504/01, 2004), while maturity describes the set of process areas defined by the SPRM as a whole.

3.1 CMMI-DEV 1.3 and SCAMPI appraisal methods

CMMI-DEV is comprised by a set of Process Areas (Figure 3). “A process area is a cluster of related practices that, when implemented together, they fulfill a set of specific and generic goals considered important to improve that area” (CMMI-DEV, 2010). A specific goal corresponding to a specific process area, represents a feature that needs to be implemented through Specific Practices that are expected for this process area. A specific practice is an activity that creates work products and is supported by sub practices. Generic goals are established on multiple process areas and represent the items that are required to institutionalize processes to be implemented in a process area (CMMI-DEV, 2010).

CMMI-DEV supports both continuous improvement frameworks as well as stage-based frameworks for processes used by SDOs to develop products. A continuous improvement framework enables SDOs to achieve Capability Levels by selecting a specific process area or a group of process areas. Four levels are established from Level 0-Incomplete to Level 3-Defined (Table 5). A stage-based framework helps SDOs to achieve 4 Maturity Levels (ML) (Table 6), progressing from low maturity: ML-2 Managed and ML- 3 Defined until reaching high-levels ML-4 Quantitatively Managed and ML-5 Optimizing (CMMI-DEV, 2010). Table 6 shows ML and the process areas corresponding to each level.

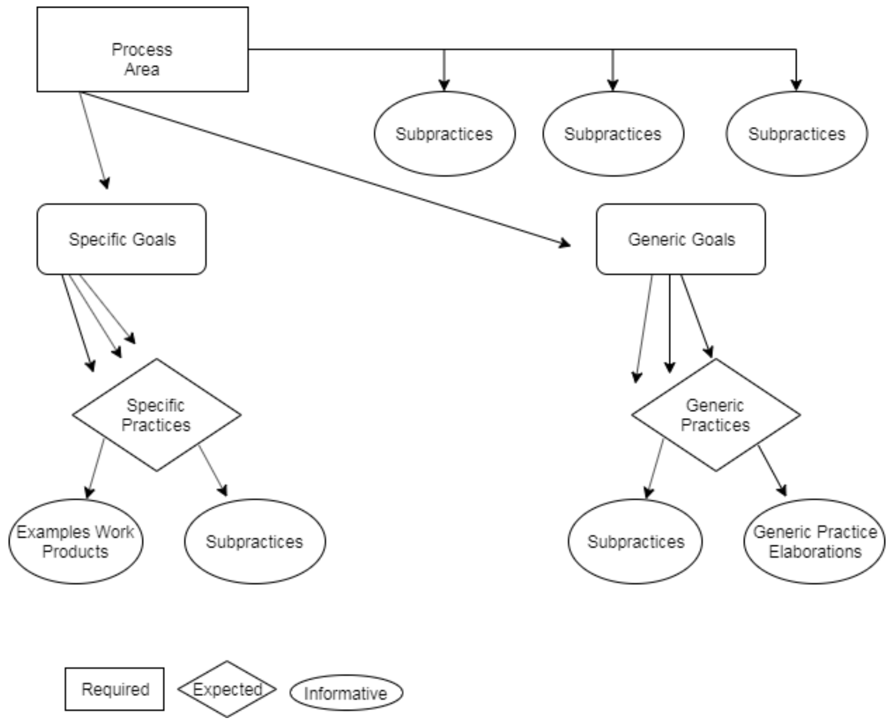


Figure 3. CMMI Components. Source CMMI-DEV (2010).

Table 5. CMMI-DEV 1.3 Capability and Maturity Levels.

Level	**Continuous – Capability**	**Stage – Maturity**
Level 0	Incomplete	None
Level 1	Performed	Initial
Level 2	Managed	Managed
Level 3	Defined	Defined
Level 4	None	Quantitatively Managed
Level 5	None	Optimizing

Source CMMI-DEV (2010).

Table 6. CMMI-DEV 1.3 Maturity Levels and process areas.

Maturity Level (ML)	Scope	Process Area
ML1-Initial	Processes are usually improvised and chaotic. Organizations are not guided by process but depend on the competence of only a few members to achieve success in their projects. The excess of commitments due to lack of planning, causes project team members to abandon the process and success becomes difficult to recreate.	None
ML2-Managed	Projects follow process and planning; execution and compliance with policies and standards is carefully tracked. Work products obtained are controlled to meet specifications. Project team members have qualified competences, stakeholders are involved. Processes are maintained even in times of stress.	Requirements Management (REQM) Project Planning (PP) Project Monitoring and Control (PMC) Supplier Agreement Management (SAM) Measurement and Analysis (MA) Process and Product Quality Assurance (PPQA) Configuration Management (CM)
ML3-Defined	Processes are well-described and have associated procedures, standards, and tools. Consequently, any deviations from standard process, are formally documented following an established procedure that allows adaptation, execution, and repetition.	Requirements Development (RD) Technical Solution (TS) Product Integration (PI) Verification (VER) Validation (VAL) Organizational Process Focus (OPF) Organizational Process Definition (OPD) Organizational Training (OT) Integrated Project Management (IPM) Risk Management (RSKM) Decision Analysis and Resolution (DAR)
ML4-Quantitatively Managed	Quantitative objectives are in place to measure process organization, quality, and performance. Quantitative objectives consider the needs of the client, end-users, the organization and the process implementers. An objective analysis is carried out using statistical measures and other quantitative techniques to help achieve the business goals.	Organizational Process Performance (OPP) Quantitative Project Management (QPM)
ML5- Optimizing	There is a continuous improvement in the organization based on the	Organizational Performance Management (OPM)

	interpretation of a quantitative analysis of business and performance goals. Deviations in the process performance are investigated in order to have an understanding and implement improvement actions under the focus of increments and technological improvements. Implementation of improvement actions is analyzed using statistical and quantitative techniques. Historical project data is analyzed to determine deficiencies or performance gaps in and in turn promote continuous measurable improvements.	Causal Analysis and Resolution (CAR)

Source CMMI-DEV (2010).

The high-level Process Areas (PA) from ML-4 and ML-5 describe the use of statistical techniques and other quantitative approaches to predict whether an SDO will be able to achieve business goals, providing insight of their deficiencies and identifying process and technology improvements (CMMI-DEV, 2010). For the scope of this research, only the PA of MA, OPP and, QMP are described to emphasize the importance and necessity of SDOs to have indicators showing them evidence and knowledge about their process for reliable and convenient decision-making. MA defines and collects the measures aligned to the objectives of the project, the organization, and the business, as well as the analysis techniques. OPP establishes and maintains a quantitative understanding of the process performance in the organization, while QMP manages the project quantitatively to achieve quality and performance goals of the process within the project (CMMI-DEV, 2010).

SCAMPI Appraisal methods

The Standard CMMI Appraisal Method Process Improvement (SCAMPI) is a method that measures the effectiveness of CMMI-DEV implementation (SCAMPI-MDD, 2014). There are three appraisal SCAMPI methods that guide SDOs to verify their capability or ML. The SCAMPI appraisal Class C allows SDOs to diagnose their current process status concerning the reference model implementation scope during the beginning of an SPI initiative or for periodic self-assessment by project. Class C only requires one type of objective evidence. SCAMPI appraisals Class C and B are apriori to Class A and do not generate ratings. The principal aim of Class B is to determine the implementation gap of the practices to meet Class A requirements, so the SDO can set an improvement action plan in place to achieve the desired ratings. SCAMPI B requires artifact and affirmations as objective evidence (SCAMPI-MDD, 2014). SCAMPI Class A is an in-depth and rigorous method that collects objective evidence to ensure reliable appraisal results. Results may then set a benchmark to compare between certified SDOs.

Objective evidence comes from artifacts that demonstrate the implementation of one or more process area practices and affirmations by members who usually carry out the process corroborating the model application. Artifacts are work products or a demonstration by the employees performing the process activities. Affirmations can be interviews, questionnaires, presentations or demonstrations. Ratings are assigned according to the rules for quantifying the implementation of model practices using four ordinal scales: Fully Implemented (FI), Largely (LI), Partially Implemented (PI) and, Not Implemented (NI). The appraisal team members rate the objective evidence through a consensus evaluating the extent to which practices are implemented to support sufficient presence, lack or absence of objective evidence as well as potential weaknesses (Table 7).

Table 7. Rules for quantifying the implementation of model practices.

Ratings	Meaning
Fully Implemented (FI)	Sufficient artifacts and/or affirmations are present and considered adequate to demonstrate practice implementation, and no weaknesses are found.
Largely Implemented (LI)	Sufficient artifacts and/or affirmations are present and considered adequate to demonstrate practice implementation, and one or more weaknesses are found.
Partially Implemented (PI)	Some or all data required are absent or considered inadequate, some data are present to suggest some aspects of the practice are implemented, and one or more weaknesses are found. Data available to the team (artifacts and/or affirmations) conflict – some data indicate the practice is not implemented, and one or more weaknesses are found.
Not Implemented (NI)	Some or all data required are abscent or considered inadequate, data available does not indicate that the practice is implemented, and one or more weaknesses are found.
Not Yet (NY)	The basic unit or support function has not yet reached the stage in the sequence of work, or point in time where the practice can be implemented.

Source SCAMPI-MDD (2014).

3.2 ISO/IEC 12207 and ISO/IEC 15504

ISO/IEC 12207 is a SPRM focused on defining a software lifecycle (ISO/IEC 12207, 2008). An SPRM provides necessary process descriptions that measure the capability process based on a set of indicators (ISO/IEC 15504/02, 2010). So, this SPRM is addressed by process in which the purpose, results, activities and expected work products are defined. It has 45 processes organized in 3 categories: the first aimed at primary life cycle processes, the second corresponds to the organizational life cycle, and the third attends the support life cycle. Each category has process subgroups that meet their scope. This research does not intend to describe each category and process, but only to establish the importance of SPRM as a starting point to an assessment model. An example of the Engineering (ENG) group corresponding to the Primary life cycle category is shown in Figure 4.

Primary Life Cycle Processes

Engineering Process Group

ENG.1 Requirement elicitation
ENG.2 System requirements analysis
ENG.3 System architectural desing
ENG.4 Software requirements analysis
ENG.5 Software design
ENG.6 Software construction
ENG.7 Software integration
ENG.8 Software testing
ENG.9 System integration
ENG.10 System testing
ENG.11 Software installation
ENG.12 Software and system maintenance

Figure 4. Engineering Process Group. Source ISO/IEC 12207 (2008).

ISO/IEC 15504

ISO/IEC 15504 outlines an evaluation process and the minimum requirements to perform an assessment (Figure 5) that guarantees consistency and duplicity of ratings to determine improvements and capability levels (ISO/IEC 15504/02, 2010). The evaluation process is supported by an assessment process model and a measurement framework. Capability levels are determined from 0-incomplete to 5-optimizing (Table 8) and supported by 9 Process Attributes (PA) that provide a set of indicators mapped from SPRM to collect objective evidence and determine how a PA had been achieved. Indicators can be extensible; some of them can be omitted or added to others (ISO/IEC 15504/05, 2012).

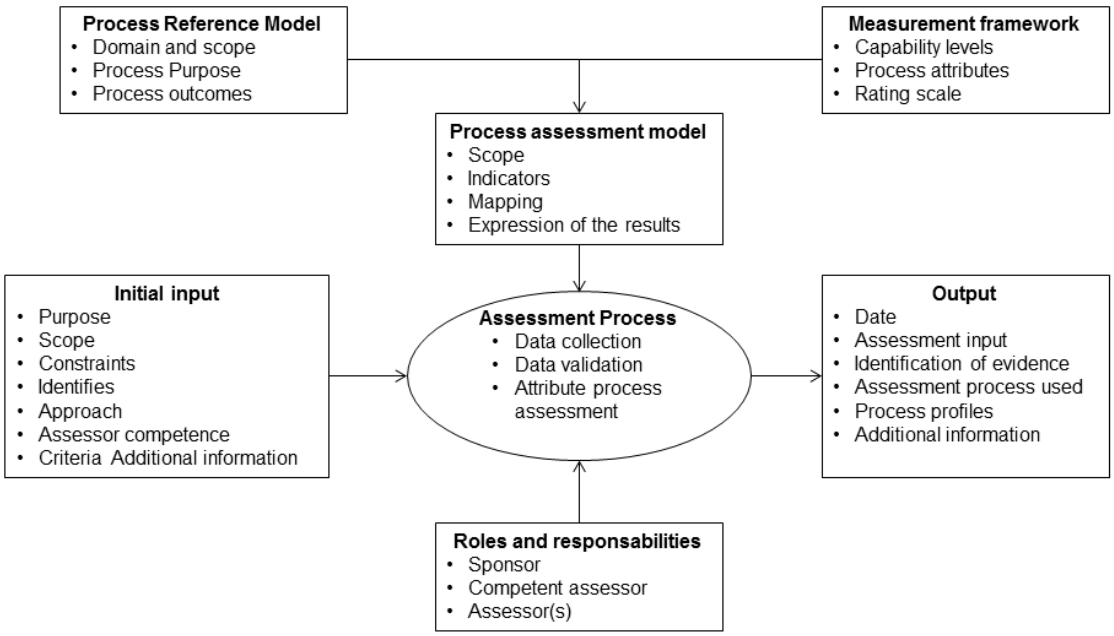


Figure 5. Requirements for process assessment models. Source ISO/IEC 15504/02 (2010).

Table 8. Capability levels and Process Attributes.

Level	Scope	Process Attribute	Definition
L5 Optimizing	A predictable process continuously improves to achieve current and future business goals	5.1 Process innovation	Measures change identification within the process, using common causal analysis of performance variations as well as investigating innovative approaches to define and implement the process.
		5.2 Process optimization	Measures the effective implications of the changes on the definition, management, and performance of the process, to achieve the applicable improvement of the process goals.
L4 Predictable	The defined process operates within certain limits to achieve results	4.1 Process measurement	Measures the degree to which the measurement results are used to ensure that the process supports the achievement of the applicable process objectives and defined goals.
		4.2 Process control	Measures the degree to which the process is quantitatively managed to create a capable and predictable process within defined limits.
L3 Established	The managed process is implemented through a defined process adapted from the standard process.	3.1 Process definition	Measures the degree to which the standard process is maintained during the implementation of the defined process
		3.2 Process deployment	Measures the effectiveness in the implementation of the standard process as a defined process that achieves results
L2 Managed	The process performance is managed (planned, supervised and	2.1 Performance management	Measures the degree of process performance management.
		2.2 Work product	Measures the degree of work

	adjusted) and work products are properly established, controlled and maintained.	management	product management generated by the process
L1 Performed	The implemented process achieves the purpose	1.1 Process performance	Measures the degree of accomplishment of its purpose
L0 Incomplete	The process is not implemented or does not reach the purpose of the process		

Source ISO/IEC 15504/02 (2010).

The assessment process model establishes a process dimension and a capability dimension (Figure 6). The process dimension describes a set of SPRM processes that will be measured and the capability dimension describes the six levels and their corresponding PA. Figure 5 shows an example of the relation between SPRM ISO/IEC 12207 processes and the Capability dimension (ISO/IEC 15504/03, 2004).

The measurement framework guides the capability process measurement using capability levels, PA and scale ratings. Each PA outlines a particular aspect of the capability process by a set of indicators. An indicator helps collect objective evidence to demonstrate the implementation of required practices for the achievement of PAs (ISO/IEC 15504/01, 2004). PAs are assessed using four rating scales (N, P, L, F) according to the percentage of the indicator implementation based on absence (unpredictable) or presence (systematic) of objective evidence (Table 9).

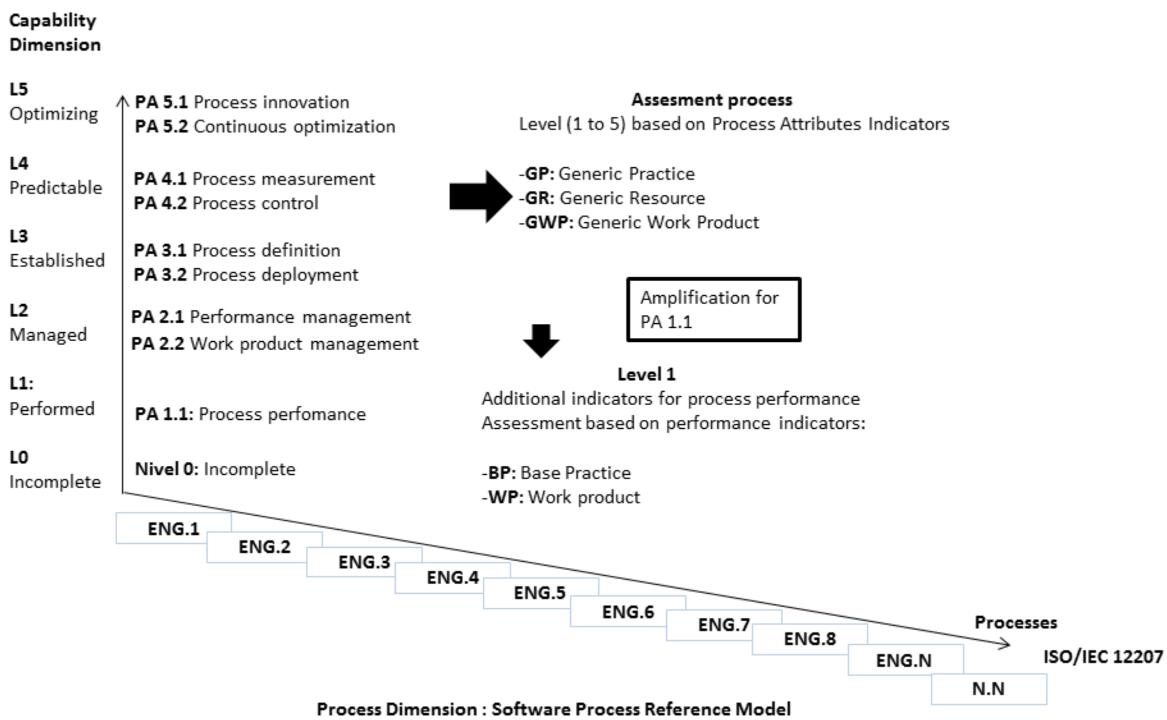


Figure 6. Relationship between assessment indicators and capability process. Source ISO/IEC 15504/05 (2012).

Objective evidence comes from work products or statements by the personnel who perform or manage the process. During the assessment, the appraisal team documents and collects evidence for each PA indicators to justify the assigned ratings. To facilitate assessment documentation, it is required to develop instruments such as checklists or questionnaires to support data recording and assessment results (ISO/IEC 15504/03, 2004). The set of processes that are within the scope of the assessment constitutes a profile of capability level (Table 10) (ISO/IEC 15504/03, 2004).

Table 9. Rating scale of process attributes.

Acronym	Achievement of the defined process attributes		Percentage 15504/02
N	Not achieved	There is little or no evidence of achievement of the defined attribute in the assessed process	0 to 15% of the scope
P	Partially achieved	There is evidence of a sound systematic approach to and achievement of the defined attribute in the assessed process. Some aspects of achievement may be unpredictable.	>15% to 50% of the scope
L	Largely achieved	There is evidence of a sound systematic approach to and significant achievement of the defined attribute in the assessed process. Process performance may vary in organization.	>50% to 85% of the scope
F	Fully achieved	There is evidence of a complete and systematic approach to and full achievement of the defined attribute in the assessed process. No significant weaknesses exist across the organization.	>85% to 100% of the scope

Source ISO/IEC 15504/02 (2010).

Table 10. Process capability level profile. Source ISO/IEC 15504/04 (2004).

Level	**Capability Processes**	**Maximum PA rating for each capability level**				
	Process Attributes (PA)	**1**	**2**	**3**	**4**	**5**
L1	AP 1.1 Process performance	L	**F**	**F**	**F**	**F**
L2	AP 2.1 Performance management	L	**F**	**F**	**F**	**F**
	AP 2.2 Work product management	-	L	**F**	**F**	**F**
L3	AP 3.1 Process definition	-	F	**F**	**F**	**F**
	AP 3.2 Process deployment	-	-	L	**F**	**F**
L4	AP 4.1 Process measurement	-	-	L	**F**	**F**
	AP 4.2 Process control	-	-	-	L	**F**
L5	AP 5.1 Process innovation	-	-	-	L	**F**
	AP 5.2 Process optimization	-	-	-	-	L

Chapter 4. Quantitative Knowledge Measurement in Software Development Organizations: Systematic Literature Review

KM assessment requires the use of metrics and measurements that yield key data on KM practices (Asoh et al., 2011). One of the challenges in KM is how to assess and analyze the value of knowledge from a quantitative approach (Ryan & O´connor, 2009; Xu & Bernard, 2011). Likewise, SE processes require quantitative and qualitative process measurements. A quantitative measurement provides the information needed to determine the effects of process improvement initiatives using mathematical or statistical techniques (SWEBOK, 2014), while a qualitative measurement can be used to increase quantitative results.

The Systems and SE Standard (ISO/IEC/IEEE 24765, 2010) defines several concepts related to measuring and metrics. A measurement is "a standard, unit, or a result". A metric is "a quantitative measure of the degree to which a system, entity, or process holds a given attribute". For Straub et al. (2002) KM measures support a number of goals, including to secure funding for KM implementation; to evaluate implementation success; to acquire lessons learned for future implementation and benchmark development. Quantitative measurements are based on the needs of the client, end-users, organization and process implementers. They are also useful to understand past, present, and possible future scenarios before making decisions (Asoh et al., 2011). Although KM has been implemented since 1990 in SDOs (Rus & Lindvall, 2002; Goldoni &, Oliveira, 2010) the assessment (Maciel et al., 2018) and effectiveness of KM is an ongoing research agenda developed to increase workers' efficiency and productivity in the creation of competitive knowledge (Asoh et al., 2011; Aurum et al., 2008). Additionally, for SDOs to measure a capability and maturity levels, they must describe their processes in quantitative terms based on metrics and measurements defined from low maturity levels. However, SDOs typically use qualitative measurements because establishing metrics based on identification, collection, and analysis of data implies a greater challenge and effort. In high maturity levels, the use of quantitative measurements is mandatory, since they indicate where process improvement is needed and to evaluate results of process improvement initiatives (CMMI-DEV, 2010). Consequently, the assessment of KM-based SPI projects should become routine or a mandatory activity in SDOs for reaching and maintaining high maturity levels.

This SLR aims to identify the actual need of SDOs for quantitative knowledge measurement to support SPI initiatives. Current SRL results show that no other SLR has any research addressed to quantitative methods for measuring KM in SDOs. This study is considered a valuable reference for the software industry, researchers, and practitioners who want to back the success of an SPI initiative implementing KM measurements.

Therefore, it can be advantageously replicated within the SDO, to establish a quantitative comparability (comparative evaluation) of KM with other SDOs.

Methodology

An SLR was carried out in order to discover the most updated KM measurement and assessment guidelines from 2007 to 2019 in relation to SE and SPI. The methodology adopted was provided by Kitchenham & Chartes (2007). Therefore, this study was conducted following three phases: 1) Planning, 2) Conducting the review, and 3) Reporting the review. The main activities of phases one and two are described below:

4.1 Planning the Review

Starting the Planning phase, the need for the study was established, as well as the research questions. Subsequently, a protocol to develop the review was defined. The purpose of this study is to identify the quantitative measurements of tacit and explicit knowledge in SDOs according to the following Research Questions (RQ):

RQ1: What is the purpose of measuring the effects of KM in SE within an SDO?
RQ2: Which quantitative methods have been used to measure tacit and explicit knowledge within SDO?
RQ3: Which processes of Knowledge Management have been measured in SDOs?
RQ4: Which software development processes have been measured in SDOs?
RQ5: Which indicators have been established in the measurement of KM processes and software processes?

4.2 Conducting the Review

Search process

The search process was conducted using scientific research sources like Science Direct (Elsevier), Scopus and ACM library. This process follows the methodology adopted by (Ivarsson & Gorschek, 2009) using specific limited-to-indexed journals, which may contain more mature research papers in their main field as well as conference proceedings to obtain a greater amount of quality empirical evidence (Kitchenham et al., 2009) (Table 11) in this case, SE and KM.

The first researcher coordinated the different stages of the SLR and was responsible for the execution of the database searches under the supervision of the second researcher. The articles were classified into three levels of compliance: 1) primary study, 2) secondary study, and 3)dismissed for being outside the research scope. The first three researchers independently evaluated each of the items in the list of results and classified them according to 3 levels. Afterwards, they provided feedback on the results until reaching agreement on the final version. This version was converted to an Excel spreadsheet, where the properties of the extracted information were added: source, general information, study type, context, research problem, research methods, instruments, quantitative methods to measuring tacit and explicit knowledge, KM processes, SE processes. The first researcher began with reading the full text of each article and extracted the information with the required detail by applying each of the inclusion criteria. Once the inclusion criteria were confirmed: content, context and replication, the next step was to assess the quality. The second and third researchers validated the extracted data as well as the assessment quality. The results of the assessment were discussed until reaching an agreement. The fourth, fifth and sixth authors provided input on the structure and presentation of the information.

Table 11. Sources for the SLR and total selected studies.

Source	**Articles**		**Studies selected**
	Journal	**Conference**	
1. Journal of Systems and Software	72	2	1
2. Information and Software Technology	83	4	2
3. International Journal of Knowledge Management	18	0	1
4. IEEE Transactions Software Engineering	2	0	0
5. IEEE Software	5	0	0
6.International Journal of Software Engineering and Knowledge Engineering	8	1	0
7. Software Practice and Experience	2	0	0
8. Empirical Software Engineering	14	0	0
9.Journal of Research and Practice on Information Technology	0	0	0
10. Journal of the ACM	259	0	0
11.ACM Transactions on Software Engineering and Methodology (TOSEM)	281	0	0
12. Journal of Knowledge Management	2	0	0
13. International conference on software engineering and knowledge engineering	0	9	0
14.International Symposium on Empirical Software	0	3	0

Engineering and measurement			
15. Proceedings International Conference on Software Engineering	0	12	0
16. Proceedings International Symposium of Software Metrics	0	0	0
17. Proceedings International Symposium on Empirical Software Engineering	0	3	0
18. ACM International Conference Proceeding Series	0	30	0
Total	**747**	**63**	**4**

Search string strategy

For the construction of the search string, keywords associated with the study terms were used within the scope of this research; considering the combination of KM measurement with SE or SPI. After the first results, the terms “metrics”, “evaluation”, and “assessment” were added to KM measurement. The final search string was assembled as follows:

(“knowledge management measurement” OR “knowledge management metrics” OR “evaluation of knowledge management” OR “assessment of knowledge management” OR “measure for tacit knowledge” OR “measure for explicit knowledge” OR “explicit knowledge” OR “tacit knowledge”) AND (“software process improvement” OR “software engineering” OR “software industry” OR “software organization” OR “software development organization” OR “software development domain OR “software development companies”)

Inclusion and exclusion criteria

Articles meeting the following criteria were included:

Year: Articles published between 2007 and 2019.

Language: Only publications written in the English language.

Content: The articles in which quantitative methods of KM measurement have been used on SE processes or activities.

Context: The validation of measurement has been made within SDOs.

Replicated: The description of the proposed measurement method allows other SDOs to replicate it.

Articles with the following criteria were excluded:

Content: Exclude if the focus on the publication is clearly not on SE.

Quality assessment in relation to rigor and relevance

In addition to the inclusion and exclusion criteria, it is important to assess the quality of Primary Studies (PS) to determine which beset represent the field, according to their rigor and relevance. For this, we followed the assessment checklist established by Ivarsson & Gorscheck (2011). Rigor is a synonym for the amount of confidence in the evidence provided. Rigor has two components; the first one is a complete description of how the research method was applied in the context; the second has to do with an adequate presentation of the results including aspects such as the related work, research goal, research problem, hypothesis, context, study design, validity, limitations, study execution, analysis, presentation and result interpretation (Ivarsson & Gorscheck, 2011). The lack of both components limits the possibility of the results being replicated in other organizations (Wohlin, 2009). The variables included in the assessment checklist are Context (C), Study design description (S), Validity discussion (V), which are quantified on an ordinal scale Weak (0), Medium (0.5), Strong (1). Studies that scored within the range of 0-1.5 are considered as low-rigor, scores above 1.5 are considered high-rigor (Ivarsson & Gorscheck, 2011).

Study relevance refers to the impact of research results in academy and mainly in industry, in such a way that results can be adequately transferred to other organizations (Ivarsson & Gorscheck, 2011) (Zelkowitz et al., 1998) through the research methods used (Sjoberg et al., 2005). A study is considered of great relevance when the research methods are executed within organizations where studied subjects, as well as participating scale users and context of the process and tasks are real (Ivarsson & Gorscheck, 2011). The variables evaluated for relevance are: users/subjects (U), scale (S), research methodology (RM) and context (C). Studies with a score within the range of 0-2 are considered of low-relevance, scores above 2 are considered high-relevance.

The total quality of the study is classified according to the score obtained in four categories A, B, C and D from four possible combinations of rigor and relevance: Category A for High rigor - high relevance; Category B for High rigor - low relevance; Category C for Low relevance - high rigor; and Category D for Low relevance - low rigor (Ivarsson & Gorscheck 2011).

Data collection and analysis

The extracted data properties: source, general information, study type, context, research problem, research methods/instruments, quantitative methods to measure tacit and explicit knowledge, KM processes and SE processes in each study were mapped to the research questions. Researchers extracted the data following guidelines by Kitchenham & Chartes (2007). The first researcher extracted data, and the second and third researchers validated the extraction. Final validation results were discussed by all three researchers until reaching an agreement.

4.3 Reporting the review

4.3.1 Identification of primary studies

The first search resulted in 814 articles (Table 11). Four duplicates were eliminated, leaving a total of 810 articles: 747 from journals, and 63 from conference proceedings. After an initial evaluation, the first selection criteria based on the title, abstract and keywords yielded a total of 29 potential studies. The abstract was taken as an approximation to the context, objectives, methods, results, and conclusions. Inclusion selection based on abstract reading is considered a heavy inclusion allowing more documents to be scrutinized and, as a result, the risk of missing relevant documents is reduced (Ivarsson & Gorschek, 2009).

4.3.2 Primary studies quality assessment

After applying the inclusion criteria regarding aspects of quality assessment, four articles were selected as Primary Studies (PS) (Table 12) and three articles were dismissed. Backward snowball sampling (Wohlin, 2014) was used to identify other relevant studies cited by the PS; also, citations to these PS were considered to avoid the omission of any relevant study, but no additional studies were found. All PS used a case study as a research method. The quality assessment of the four PS showed that three of them were in category A and only one in category B, which garanteed that 75% of representativity had high rigor and relevance; while 25% had low rigor but high relevance in the field of study. Table 13 shows a quantitative summary of the total number of organizations and the number of participants per PS.

Table 12. PS qualitative assessment with respect to rigor and relevance.

PS	Source	Year	Authors	Title	C	D	V	Rigor Sum	U	S	RM	C	Relevance Sum	Category
PS1	Journal of Systems and Software	2009	Ryan S. & O'Connor R.	Development of a team measure for tacit knowledge in software development teams	1	1	1	**3**	1	1	1	1	**4**	A
PS2	Information and Software Technology	2013	Chouseinoglou O., Iren D., Karagöz N., Bilgen S.	AiOLoS: A model for assessing organizational learning in software development organizations	1	1	1	**3**	1	1	1	1	**4**	A
PS3	Information and Software Technology	2013	Ryan S. & O'Connor R.	Acquiring and Sharing tacit knowledge in software development teams: An empirical study	1	1	0.5	**2.5**	1	1	1	1	**4**	A
PS4	International Journal of Knowledge Management	2014	Mehrez A.	Reassessing software quality performance: The role of knowledge management	0.5	1	0	**1.5**	1	1	1	1	**4**	B

Table 13. Number of SDO and participants.

PS	Country	Organizations	Subjects/Users
PS1	Ireland and the United Kingdom	3	48 software development teams
PS2	Turkey	2	SDO 1 (1 team with 46 members) SDO 2 (3 teams, 3-20 members)
PS3	Ireland and the United Kingdom	46	181 individual team members
PS4	Egypt	111	142 software developers
	Total	**162**	

4.3.3 The object of measuring the effects of KM on SE

The objective of each PS selected (Table 12) was inferred from the analysis of their research questions. PS1 formulated three research questions: 1) Does tacit knowledge of a team predict performance in software development teams?, 2) Is there a relationship between tacit knowledge and knowledge explicit work?, and 3) Do teams with high levels of social interaction also have high levels of tacit knowledge? (Ryan & O'Connor, 2009). To test their research questions, the authors developed a Team Tacit Knowledge Measure (TTKM) model, exploring the relationship between tacit knowledge, explicit job knowledge of work, and social interaction and their effect on performance defined in two dimensions: efficiency and effectiveness.

PS2 addressed the research question of How to model and evaluate learning capabilities in SDOs? To define the problem scope, two more questions were posed: 1) What are the main process areas and core processes of learning organizations in SDOs?, and 2) How can the measurement results be used in SPI? In response to these questions, the authors proposed a model named AiOLoS to assess the level and characteristics of a learning organization in SDOs that improves the capabilities, providing a basis to develop SPI activities (Chouseinoglou et al., 2013).

The object of PS3 was to investigate the relationships between transactive memory system, quality and quantitative social interaction, as well as team tacit knowledge and team performance. Team tacit knowledge was measured using the TTKM method developed in PS1 (Ryan & O'Connor, 2013. They enhanced their study with two questions: 1) How do software development teams acquire and share tacit knowledge? and 2) What roles do tacit knowledge and transactive memory play in successful team performance? (Ryan & O'Connor, 2013).

Finally, the goal of PS4 was to test whether the inefficiency of KM implementation activities may be the reason for defects that diminish quality in the software industry. To do this they first measured the implementation of KM activities in the software industry; secondly, they measured the implementation of quality control measures during the software development process and, lastly, the relationship between KM and quality (Mehrez, 2014).

4.3.4 Measurement methods

PS1 conducted a series of three studies. In the first one, the consistency of the questionnaire administered to experts in the software domain was validated using the unified validity framework. Then, a second one was performed to compare the construct produced by experts with novices. Considering the unequal sample sizes between novices and experts the Mann-Whitney U non-parametric statistical test was used to differentiate the measurement of tacit knowledge among the novice group versus the experts. In the third study, quality social interaction within the team, team performance and job explicit knowledge were measured using a self-report survey and descriptive statistics. Finally, Cronbach's alpha test was used to validate the internal consistency of the TTKM within all measured constructs. Correlation and regression analysis were performed in order to evaluate the TTKM relationship between all constructs and establish predictability of theTTKM. (Ryan & O'Connor, 2009).

PS2 defined measuring formulas (Chouseinoglou et al., 2013) using the Goal Question Metric (GQM) approach (Basili & Weiss, 1984) oriented to measure software processes, products, and projects and applied through AiOLoS proposal model. To collect the measurement data three-SDOs were used to conduct the studies allowing the normalization of the metrics in the interval of their upper bound. The first study was exploratory within a software engineering course environment, the second study was conducted within a public sector SDO and the third study was conducted within a private sector SDO.

PS3 measured 5 constructs (Ryan & O'Connor, 2013): TTKM, quality social interaction, team performance, Transactive Memory System (TMS) and quantity social interaction. TTKM, quality social interaction, and team performance were measured using the same methods described in PS1. The TMS instrument was validated through three studies, two of them evaluated using Structural Equation Modelling (SEM) to establish reliability and validity and the third one was evaluated using a weighted composite score because the sample was too small to use SEM. The quantity of social interaction was measured using the method described by (Levesque et al., 2001): first dividing the actual amount of interactions by the total possible interactions, and then by other team members and the team interactions by the mean of its member's interaction scores. Lastly, a bivariate correlated analysis between all constructs was obtained based on the mean results for team-level, then a hierarchical regression analysis was carried out to predict TMS and social interaction on tacit knowledge, and for predicting the effectiveness of team performance on TMS, social interaction and TTKM.

PS4 administered two surveys to measure the effects of KM in software quality (Mehrez, 2014). The first one was administered to software customers to assess the ideal degree of importance of software quality performance and the actual degree of delivery process and software products. The second one was administered to software developers to assess the degrees of importance and actual implementation of KM activities to reach quality. The method used to compare the ideal and actual degrees was a paired sample T-test (t student). Then, a correlation analysis was conducted to measure the effects of KM on the quality process and; finally, in order to test this relation, a linear regression was performed.

Finally, Table 14 summarizes the measurement instrument and methods found in every PS.

Table 14. Measurement instrument and methods.

PS	**Measurement instrument**	**Measurement criteria**	**Measurement methods**
PS1	Unstructured interview using repertory grid and questionnaire	Ordinal	Mann Whitney U Correlation analysis Regression analysis
PS2	Semi-structured interviews, questionnaire and historical data.	Numerical	Measurement formulas based on Goal Question Metric (GQM)
PS3	Survey online, self-report questionnaire	Ordinal	Structural Equation Modeling (SEM): Means, standard deviations, reliabilities Correlations analysis Regression analysis
PS4	Questionnaire	Ordinal	Paired T-test Correlation analysis Regression analysis

4.3.5 Knowledge Management Processes

The KM processes were grouped by the definition stated by each PS. It was found that some of them were named differently but had the same definition, so we assigned a unique name according to the most common term used in literature (Ryan & O'Connor, 2013). In this way a total of 11 KM processes were measured among all PS, according to their unique name: Identification, Creation, Acquisition, Integration, Sharing, Utilization, Organization, Preservation and Deleting, Evaluation, Selling and Publication, and Evolution (Table 15).

It was found that the Acquisition and Sharing processes were measured in all PS. The Integration and Utilization processes were measured in two PS (PS2, PS4) and merged into one process named Utilization. The development process measured in PS2 and the creation process measured in PS4 were considered as a single process named Creation. The Selling and Publication processes were measured in PS2 as two separate processes, but considering that both have the same purpose of showcasing knowledge outside organization boundaries, they were merged as one. The Identification, Organization, Preservation and Deleting, Evaluation, and Evolution processes were measured only in PS2.

Table 15. KM Processes measured by PS.

PS1	PS2	PS3	PS4	Unique name
	Identification			Identification
	Development		Creation	Creation
Acquisition	Acquisition	Acquisition	Acquisition	Acquisition
	Integration		Documentation	Integration
Sharing	Dissemination	Sharing	Transfer	Sharing
	Usage		Utilization	Utilization
	Organization			Organization
	Preservation and Deleting			Preservation and Deleting
	Evaluation			Evaluation
	Publication and Selling			Publication and Selling
	Evolution			Evolution

4.3.6 Software Processes

KM measurements in SE were performed from selected software processes, methodologies, and SPRM (Table 16). PS1 and PS3 measured activities in agile methodologies. PS2 was oriented to activities that are involved in SPI initiatives using different methodologies and the ISO/IEC 12207. PS4 only considered the quality software process.

Table 16. Software processes identified in PS.

PS	Software processes
PS1	Agile method
PS2	SPI-ISO/IEC 12207
PS3	Agile method
PS4	Quality software process

4.3.7 KM indicators related to Software Process (RQ5)

A total of 90 indicators were measured in all four PS distributed as follows: PS1 (24), PS2 (39), PS3 (3) plus 21 from PS1, and PS4 (24). Figure 7 shows the number of indicators by KM Process. The three processes with the highest number of indicators were Acquisition (24), Sharing (18) and Utilization (10).

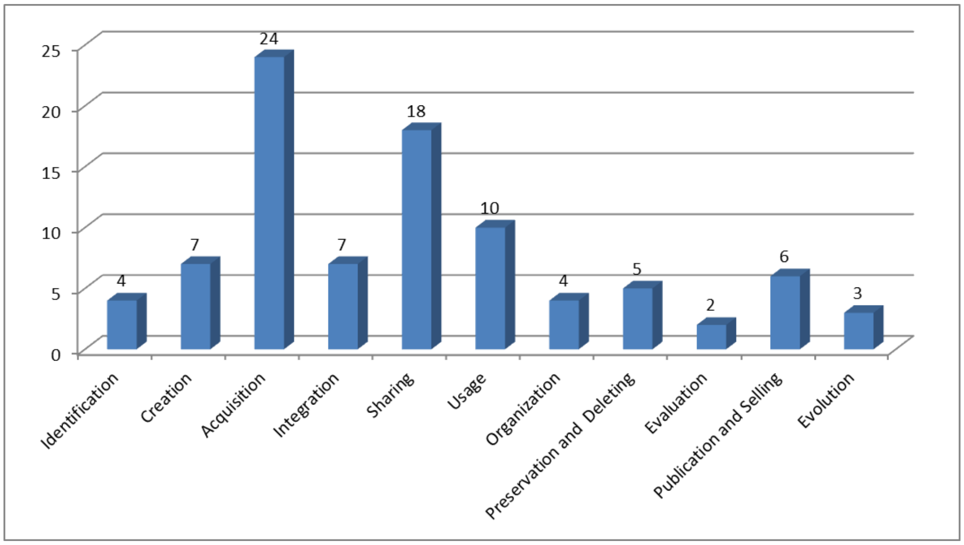


Figure 7. Indicator distribution by KM Process.

Table 17 shows the indicators that were related between KM and SE. In this manner, the TK set of indicators was related to the qualitative and quantitative social interactions between project team members and other stakeholders; transactive memory system asked about specialization, credibility, and coordination; team performance comprises the coordination of software development teams and how well they know each other, work quality, team operations, the ability to meet project goals, the extent of meeting design objectives and work excellence reputation. The EK set of indicators were related to the efficiency of the schedule and budget, explicit job knowledge concerning reliance on written procedures, client´s requeriments, knowledge maps, new publications, etc., as well as familiarity with written procedures.

Table 17. Relationship between KM and SE process by indicator.

KM Process	**PS1**	**PS2**	**PS3**	**PS4**
Identification		– What is the % of internally completed document sections/headings to total document sections? – How many employees received/conducted internal training? – What is the % of tasks completed with existing knowledge to total tasks? – What is the % of employee participation in internal trainings?		
Creation		– How many creative ideas were developed? – How many creative ideas developed were considered to be applicable?		– Striving to find knowledge combinations that contribute to identify – Rewarding developers for creating new knowledge and testing new ideas – Exploring new issues using scenarios or simulation techniques – Analyzing benchmarks at the industry level – Conducting data mining to discover new knowledge and insights
Acquisition	**Team Tacit Knowledge Measure** – Clear well-defined goals – Clearly specified client requirements – Project scope and importance – Clear procedures – Innovative Project – Project length – Experienced team – Diverse team membership – Project scope and importance – Competition within the team – Clear non-competing roles – Client's needs met – Client from the same organization **Job explicit knowledge** – Reliance on written procedures	– How many employees received/ acquired external training? – What is the % of helpful responses to questions asked to external entities? – What is the number of external written documents that were used? – What is the % of employee participation in external trainings?	**Team Tacit Knowledge Measure** – Clear well-defined goals – Clearly specified client requirements – Project scope and importance – Clear procedures – Innovative Project – Project length – Experienced team – Diverse team membership – Project scope and importance – Competition within the team – Clear non-competing roles – Client's needs met – Client from the same organization	– Regularly collecting information about customer´s needs – Regularly conducting analysis of knowledge needs for developers – Hiring new staff members who pass missing knowledge – Conducting research to explore future needs or to gain technical knowledge – Considering competitors as sources of inspiration for developing new methods and/or products

	– Familiarity with written procedures **Team performance** – Ability to meet project goals		**Job explicit knowledge** – Reliance on written procedures – Familiarity with written procedures **Team performance** – Ability to meet project goals	
Integration		– How many tasks are similar/different compared to previous tasks? – How many documents sections/headings were prepared that are similar/different compared to previous document sections/headings? – How many incorrect document section/headings were identified/corrected in reviews?		– Using brainstorming sessions for problem-solving – Systematically informing employees of changes in procedures, handbooks, and so forth – Encouraging experts to make explicit the methods used by the company in developing software products – Keeping and maintaining knowledge maps, knowledge networks, and data warehouses
Sharing	**Team Tacit Knowledge Measure** – Team is motivated and capable – Co-operative team-Knowledge required for Project is available within the team – Adequate resources – The third party is involved in the Project – Team size – Management experience and control – Management back up and support – Morale – On Schedule and Budget – Measure of success criteria in evidence – Clear team communication – Team challenges to management	– What is the number of push information messages sent by the management to employees? – How many meetings were held in total? – How many man-hours were spent attending meetings? – How many topics/issues were raised/ discussed on all meetings? – How many people attended meetings?	**Team Tacit Knowledge Measure** – Team is motivated and capable – Co-operative team-Knowledge required for Project is available within the team – Adequate resources – The third party is involved in the Project – Team size – Managerial experience and control – Management back up and support – Morale – On Schedule and Budget	– Knowledge is distributed in a formal way – Holding regular meetings to discuss software development issues – Members of firms regularly inform each other about positive experiences and successful work methods – Conducting intercollegiate reviews in which firm members discuss their methods of working – Reviewing job regularly in order to distribute developers know-how

	are welcome **Team performance (Efficiency)** – On Schedule and Budget **Team performance (Effectiveness)** – Work quality – Team operations – Extent of meeting design objectives – Reputation of work excellence **Quality of social interaction** – Interacting face-to-face – Attained goal in the interaction		– Measure of success criteria in evidence – Clear team communication – Team challenges to management are welcome **Team performance (Efficiency)** – On Schedule and Budget **Team performance (Effectiveness)** – Work quality – Team operations – Extent of meeting design objectives – Reputation of work excellence **Quality of social interaction** – Interacting face-to-face – Attained goal in the interaction **Quantity of social interaction** – How much work with each team member. **Transactive memory** ***Specialization*** – Each team member has specialized knowledge of some aspect of our Project – I have knowledge about an aspect of the Project that no other team member has – The specialized knowledge of several different team members was needed to complete the Project deliverables	

			– I know which team members have expertise in specific areas ***Credibility*** – I was comfortable accepting procedural suggestions from other team members – I was confident relying on the information that other team members brought to the discussion – When other members gave information, I wanted to double-check it for myself (reversed) – I did not have much faith in other members' expertise (reversed) ***Coordination*** – Our team worked together in a well-coordinated fashion – Our team had very few misunderstandings about what to do – We accomplished the task smoothly and efficiently – There was much confusion about how we would accomplish the task (reversed)	
Utilization		– What is the % creative ideas used/utilized of the total creative ideas? – What is the quality of the project artifacts produced? – How many issues were solved on all meetings? – What is the % of issues solved vs issues raised on all meetings?		– Using customer´s feedback in order to improve products and services – Using existing know-how creatively for new publications – Doing marketing research among potential clients before developing new products or services – Trying to conquer dysfunctional beliefs with the organization – Utilizing multi-disciplinary teams to perform tasks and/or make decisions – Creating capabilities to integrate knowledge across different areas – Maximizing knowledge use

				through organizational structure, management systems, and practices
Organization		− How many different links/references exist in a document that come from other documents developed in the same phase? − What is the horizontal linking/referencing number? − How many links/references exist in a document that come from other documents created in previous phases? − What is the vertical linking/referencing number?		
Preservation and Deleting		− How much knowledge was preserved from previous phases to this phase? − How many tasks on that phase were done differently (per management's request) regarding the guidelines? − How many document sections/headings were prepared differently (per management's request) regarding document templates? − What is the number of knowledge preservation, storing, archiving, usage tools utilized? − What is the % of stored knowledge items in the utilized knowledge preservation, storage		
Evaluation		− How much of the acquired/used knowledge items can be evaluated by employees regarding its value to them? − How much of the acquired/used knowledge items on that phase cannot be evaluated by employees regarding its value to them?		
Publication and Selling		− How many internally developed guidelines were used internally? − How many internally developed guidelines were distributed externally? − How many publications were published in academic terms? − How many patents/licenses/studies were developed? − How many guidelines/templates were		

		given to external organizations? – How many educations/trainings/consulting services/conferences/seminars were given to external organizations?		
Evolution		– How many guidelines have been edited before being used in the next project? – How many tasks have been redefined before being used in the next project? – How many deliverable templates have been edited before being used in the next project?		

4.3.8 Discussions

Based on the findings reported in all PS, it was possible to answer the five RQ defined in the SLR. The search results reveal the lack of literature on assessment (Maciel et al., 2018) and specifically in the quantitative measurement of KM about SE focused on SPI initiative. It is also noted that the first PS was published in 2009 and the last one in 2014. We compared our results with the SRL by Maciel et al. (2018), and from 24 PS identified, only 2 PS are really focused on quantitative measurements. One of them by (Chouseinoglou et al., 2013) was already included in our PS, specifically PS2. The other one was presented by Singh (2008), nonetheless it did not meet the inclusion criteria of focusing on SE process activities with enough detail, nor described the relationship with KM activities, and did not provide enough information on the instrument to replicate the study.

The results correspond to the reality of 162 SDOs with different organizational and cultural contexts located in Ireland, United Kingdom, Turkey, and Egypt, besides the number of participants per PS (Table 13). All of them with the same objective (RQ1) to assess the impact of KM (Tacit and Explicit) on the success of activities associated with SE and/or SPI initiatives using quantitative measurements that reveal the actual implementation status of both disciplines and their relationship. Knowledge is not easy to measure due to its intangible nature, especially in its tacit state. Respect to RQ2, it was possible to objectively demonstrate the effect of KM by measuring the percentage in which the indicators explain results in the SPI and SE activities. Along these lines, PS1, PS3 and PS4 relied on statistical techniques with non-parametric Mann-Whitney U and parametric techniques of correlation analysis, followed by regression analysis using KM as the independent variable and the software processes as dependent variable; while PS2 used a measuring method based on a software process metrics approach adapted from GQM (Basili & Weiss, 1984).

A greater interest was observed in all PS for measuring KM process sharing and acquisition (RQ3). Among the four PS, we found several different names for the same process within KM, but their definition or scope was the same. Only PS2 included a process to evaluate the acquisition of knowledge that confirms the assertions of the lack of measurements in KM regarding SE (Asoh et al., 2011; Ryan & O'Connor, 2009). These findings also demonstrate the gap in KM process models since not a single one is recognized as a standard for organizing the processes that must be integrated and the need to emphasize KM measurement.

In relation to measuring the software processes (RQ4), PS1 and PS3 focused mainly on Agile methodologies considering tacit knowledge to be more critical to manage for the project team members. Instead, PS2 focused on the SPRM ISO/IEC 12207 activities taking into account the relevance of this model to implement an SPI initiative. PS4 only measured the quality process; however, the reach of this process involved all software process activities to reduce defects.

The measurements of these four SP demonstrate that even though knowledge is not easy to measure mainly due to its TK nature, it was possible to select a set of key indicators aimed to describe the relationship between TK and EK and SE processes (RQ5). However, the identification, collection, and analysis of data involving tacit and explicit knowledge indicators to promote software improvements is still a challenge for SDOs.

4.3.9 Conclusions

The literature review showed a shortage of SDOs willing to address the quantitative measurement of KM concerning SE activities focused on SPI initiatives. Three of the four PS (Ryan & O’Connor, 2009; Ryan & O’Connor, 2013; Mehrez, 2014) used statistical methods of correlation and regression, and only one developed their measurement formulas (Chouseinoglou et al., 2013). This is why collecting quantitative data is vital to establish a scientific measurement (Ryan & O’Connor, 2009) of the degree to which the variables of the KM influence SE.

Quantitative measurement requires providing numerical information on the implementation status over time; it is supported by the use of metrics to compare the level of knowledge evolution and its impact on SPI initiatives. Quantitative measurement performed in all PS was backed by a set of indicators; a total of 90 indicators were extracted from 11 KM Processes.

This research is a starting point for those SDOs who are interested in what and how to quantitatively measure the effects of KM to comply with an SPI initiative. The most critical KM processes were acquisition and sharing, measured in all PS on the quality software process, agile methodologies, as well as the set of processes of ISO/IEC 12207.

Chapter 5. Designing an instrument to measure knowledge management in Software Engineering

A first version of the instrument with 30 items was developed following the KMPRM process and indicators by Flores-Rios (2016). This model was selected to focus on the SPI project; in addition, each process of the KM life cycle is associated with a knowledge measurement component adapted from previous studies (Perez-Soltero, 2007; Wan et al., 2011). This instrument was used in a case study within a scholar software company to measure knowledge conversion following the knowledge flows of the spiral of the SECI model to demonstrate the effects of KM on SE.

5.1 Case study of a Scholar Software Company

A learning process is a mechanism through which, information is converted into knowledge; therefore, higher education institutions play an important role in the learning process of undergraduate students (Eid & Nuhu, 2011). One of the strategies to build student's competitiveness as professionals is to recreate environments similar to those in the industry during their training, such as university-based technology companies (Smilor et al., 1990). This type of scholar model Software Company was set up by the undergraduate program of Computer Systems at Autonomous University of Baja California's (UABC) School of Engineering, so students could be immersed in a work environment similar to a software development organization solving real life problems. This simulated company is deemed as scholar because students associate more than one learning course during their participation (Astorga et al., 2015).

Research method and hypotheses

Data collection

The population under this study is integrated by undergraduate Computer Systems students in UABC that participate as employees in a scholar software company, in which they undertake some of the roles found in these organizations, such as analysts, architecture designers, programmers, testers, among others. Students work in the simulated company for a period of one year; after that the team is rotated with the addition of new students (Astorga-Vargas et al., 2015). When students start working in the company, they have little experience in their roles, so the training is given by the most experienced students and professors associated with the project.

Research limitations

The population is limited to a small company with a range of 12 to 20 students per class. To have a representative population, the last three generations (2014, 2015, and 2016) were chosen in order to get greater feedback on the degree of perception knowledge managed by students. A total of 44 students were surveyed (Table 18).

Table 18. Total students surveyed.

Generation	Frequency	Percentage
1	17	38.6
2	15	34.1
3	12	27.3
Total	44	100.0

Hypotheses

Based on the proposal of knowledge creation in organizations, four hypotheses were established (Table 19) to measure knowledge conversion effects in undergraduate students. Knowledge flow of origin significantly affects the target knowledge flow switching the knowledge mode spiraling between tacit and explicit knowledge.

Methods and measures

In order to establish correspondence with the processes from the SECI model (Socialization, Externalization, Combination, and Interiorization) only Transfer, Externalize, Store and Internalize processes from the KMRPM by Flores-Rios (2016) were considered.

Thus, the survey instrument was integrated with four constructs: transfer, externalize, store and internalize, totaling 17 items. 5-level Likert scale was used (5-Strongly Agree, 4-Agree, 3-Neither disagree nor agree, 2-Disagree and 1-Strongly Disagree). Also, semi-structured interviews were conducted with the students to expand and corroborate the answers received.

Table 19. Research hypotheses

Interaction of knowledge flows		Hypotheses
From	To	
Socialization	Externalization	H1: Socialization of undergraduate students positively influences the externalization of tacit knowledge to create explicit knowledge
Externalization	Combination	H2: Externalization of undergraduate students positively influences the combination of explicit knowledge to create new explicit knowledge
Combination	Interiorization	H3: The existing explicit knowledge in the scholar Company positively influences interiorization of tacit knowledge of undergraduate students to create e new tacit knowledge in them
Socialization		H4: Interiorization of undergraduate students positively influences socialization of knowledge in the scholar company to create new tacit knowledge

Reliability and validity

To estimate the internal consistency of the survey instrument, a reliability analysis was performed using the Cronbach α method. According to Huh, DeLorme and Reid (2006), the value of reliability in exploratory research must be equal to or greater than 0.6. The survey obtained a value of α= 0.879. Subsequently, consistency was calculated by construct. To improve the Externalize construct, an item was dropped. The value of α constructs was between 0.600 and 0.702 which is considered acceptable when it is near 0.6 and above (Table 20). The final value of the instrument was α= 0.88.

Table 20. Reliability constructs.

Construct	No. Items	α
Externalization	4	0.600
Store	4	0.727
Transfer	4	0.702
Internalize	3	0.702
Total items	15	0.880

To validate the survey, a factor analysis was performed by construct. The main component extraction method was executed with a varimax rotation. The Kaiser Meyer-Olkin (KMO) and Bartlett Test of Sphericity were used to verify the normalization of the factors. The KMO values ranged between 0.548 and 0.656 ($p<0.001$). Therefore, the sample was adequate to conduct a factor analysis. The extraction of factors by construct was determined by the number of items with a value greater than 1.

Table 21 shows the transfer construct which was extracted in a single factor called *Socialization*. It integrates items S1, S2, S3, and S4. The factor explained 53.392% of the total variance; KMO = 0.627 and $p < 0.001$.

Table 21. Factor of Socialization.

Factor	Items	Loading Factor
Socialization	S3 Roles are aware that their knowledge can be shared	0.775
	S2 Roles are encouraged to share knowledge by building trust, granting incentives, time and available resources	0.769
	S1 The knowledge that I possess is really available to others	0.696
	S4 Existing explicit knowledge is distributed in electronic format (emails, intranet, information systems, etc.)	0.677
	Eigenvalue	2.136
	Accumulated variance explained	53.392

The Externalize construct was extracted in 2 factors (Table 22). Factor 1 integrates items E1 y E3 called *Externalization tacit requirements*. Factor 2 integrates items E2 y E5 and was called *Externalization explicit requirements*. The two factors explained 75.644% of the total variance, KMO = 0.551 and $p < 0.001$.

Table 22. Factor of Externalization.

Factor	Items	Factor Loading	
Externalization tacit requirements	E1 There is a formalization to document the implicit goals of the project	0.910	
	E3 Customer tacit requirements are related to specific project characteristics (subjective requirements to objective requirements)	0.842	
Externalization explicit requirements	E2 Customer requirements are formally and systematically captured		0.935
	E4 The work is reciprocally verified and validated		0.558
	Eigenvalue	1.958	1.068
	Accumulated variance explained	45.566	75.644

The Storage construct was extracted into 2 factors (Table 23). Factor 1 integrates items C1, C2, C3 y C5 called *Combination*. The two factors explained 55.492% of the total variance; KMO = 0.622 and $p < 0.001$.

Table 23. Factor of Combination.

Factor	Items	Factor Loading
Combination	C1 Roles know how to store the knowledge and experience that they possess and create	0.807
	C2 Roles are aware or agree that knowledge must be stored	0.795
	C3 Roles are encouraged to capture knowledge assets and have access to them	0.700
	C4 Customer evaluations, comments and complaints are recorded	0.669
	Eigenvalue	2.220
	Accumulated variance explained	55.492

The interiorize construct was extracted in a single factor called *Interiorization.* It integrates items I1, I2 and I3 (Table 24). The factor explained 64.034% of the total variance; KMO = 0.644 and p < 0.001.

Table 24. Factor of Interiorization.

Factor	Items	Loading Factor
Interiorization	I2 Work products or procedures are reviewed to create knowledge or reflections by the roles	0.855
	I3 Tools that boost innovation and knowledge creation are used	0.813
	I1 Roles are encouraged to take training courses	0.728
	Eigenvalue	1.921
	Accumulated variance explained	64.034

Research findings

In order to determine the effects of knowledge conversion from tacit to explicit and vice versa, associated with the four hypotheses (Table 19), the stepwise regression analysis method was used. The significance level is p* < 0.05, p** < 0.01. For hypotheses H1, the Socialization (S) process was considered as the independent variable on the two factors of Externalization (E); for that reason, two regression models were executed. The whole Socialization factor (Table 25) shows that it is significant and positively correlated with the *Externalization tacit requirement* (p= 0.024) and also with the *Externalization explicit requirement* (*p*= 0.011). The effect of regression on Model 1 S-E (Table 26) encompassing the whole Socialization factor is significant with the *Externalization tacit requirement* (p=0.024). Adjusted R^2 is 0.095 indicating that a 9.51% of the total variance of tacit requirement created by the students is explained by Socialization. Likewise, it is significant with the *Externalization explicit requirement* in Model 2 S-E (Table 26) (p= 0.011) and (adjusted R^2 = 0.123) indicating that 12.3% of a total variance created by students is explained by Socialization. In the Model SE (Table 25) the analysis shows which items of Socialization are most used in the *Externalization tacit requirement* (Table 26). The item that most contributes is S1 *The knowledge that I possess is really available to others* (p=0.017) and the one that contributes least is S4 *Existing explicit knowledge is distributed in electronic format (emails, intranet, information systems, etc.)* (p=0.860). In the same way, Model 3 S-E (Table 26) the item that contributes the most in the *Externalization explicit requirement* (Table 26) is S1 (p=0.003) and the least contributing is S3 *Roles are aware that their knowledge can be shared* (p=0.560).

Table 25. Correlation of Socialization and Externalization.

	Socialization	S1	S2	S3	S4
Externalization tacit requirement	0.340*	0.357*	0.335*	0.123	0.202
Sig.	0.024	0.017	0.026	0.425	0.189
Externalization explicit requirement	0.378*	0.439**	0.263	0.045	0.373*
Sig.	0.011	0.003	0.084	0.773	0.013

Table 26. Effects of Socialization on Externalization.

Model 1 S-E: Tacit-Explicit (Externalization tacit requirement)= $\beta_0 + \beta_1 S$

Model	β	t	Sig.	R^2	adjusted R^2	F	Sig.
Socialization	.340	2.345	.024	0.116	0.095	5.497	0.024

Predictor variable: (Constant), Socialization

Dependent variable: Externalization tacit requirement

Model 2 S-E: Tacit-Explicit (Externalization tacit requirement)= $\beta_0 + \beta_1 S1 + \beta_2 S2 + \beta_3 S3 + \beta_4 S4$

Model	β	t	Sig.	R^2	adjusted R^2	F	Sig.
Constant	-2.229	-2.448	0.019	0.128	0.107	6.144	0.017
S1	0.357	2.479	0.017				
S2	0.253	1.725	0.092				
S3	0.029	0.192	0.849				
S4	0.030	0.178	0.860				

Predictor variables: (Constant), S1, S2, S3, S4

Dependent variable: Externalization tacit requirement

Model 3 S-E: Tacit-Explicit (Externalization explicit requirement)= $\beta_0 + \beta_1 S$

Model	β	t	Sig.	R^2	adjusted R^2	F	Sig.
Socialization	.378	2.647	.011	.143	.123	7.008	.011

Predictor variable: (Constant), Socialization

Dependent variable: Externalization explicit requirement

Model 4 S-E: Tacit-Explicit (Externalization explicit requirement)= $\beta_0 + \beta_1 S1 + \beta_2 S2 + \beta_3 S3 + \beta_4 S4$

Constant	-2.741	-3.129	0.003	0.193	0.174	10.035	0.003
S1	0.439	3.168	0.003				
S2	0.150	1.039	0.305				
S3	-0.080	-0.549	0.586				
S4	0.204	1.285	0.206				

Predictor variables: (Constant), S1, S2, S3, S4

Dependent variable: Externalization explicit requirement

For hypotheses H2 the two factors of Externalization (E) were considered as the independent variable on Combination (C). The whole factor of *Externalization tacit requirement* (ETR) (Table 27) shows it is positively correlated (p=0.043) with Combination, but its items are not significant. The correlation with *Externalization explicit requirement* (EER) is significantly (p= 0.000) and positively, as are items E2 and E4 ($p < 0.01$). The effect of regression Model 1 E-C (Table 28) shows that both factors of Externalization are significant (Adjusted R^2 = 0.388) indicating that 38.8% of the Combination that the students perform to create explicit to new explicit knowledge is based on the process of Externalization, 33.2% of which is by explicit requirement and 38.8% by tacit requirement. The regression analysis by items in Model 2 E-C (Table 28) corresponding to the *Externalization explicit requirement* shows that the items that contribute the most are E2 *Customer requirements are formally and systematically captured* (p=0.000) and E4 *The work is reciprocally verified and validated* (p=0.040), while the least contributing item is E1 *There is a formalization to document the implicit goals of the project.*

Table 27. Correlation of Externalization and Combination.

Combination	Externalization tacit requirement	E1	E3	Externalization explicit requirement	E2	E4
	0.262	0.219	0.280	0. 590**	0.484**	0.531**
	0.043	0.153	0.065	0.000	0.001	0.000

Table 28. Effect of Externalization on Combination.

Model 1 E-C: Explicit-Explicit = $\beta_0 + \beta_1 ERE + \beta_2 ERT$							
Model	β	t	Sig.	R^2	adjusted R^2	F	Sig.
Externalization explicit requirement (EER)	0.590	4.944	0.000	0.348	0.332	22.396	0.000
Externalization tacit requirement (ETR)	0.262	2.199	0.034	0.417	0.388	4.837	0.034

Predictor variable: (Constant), Externalization explicit requirement, Externalization tacit requirement

Dependent variable: Combination

Model 2 E-C: Explicit-Explicit= $\beta_0 + \beta_1 E1 + \beta_2 E2 + \beta_3 E3 + \beta_4 E4$

Constant	-5.454	-5.134	0.000	0.405	0.376	8.491	0.006
E4	0.613	3.434	0.001				
E2	0.620	2.914	0.006				
E1	0.100	0.736	0.466				
E3	0.110	0.842	0.405				

Predictor variables: (Constant), E4, E2, E1, E3

Dependent variable: Combination

For the hypotheses H3 the Combination process (C) was considered as the independent variable on Interiorization. The whole factor of *Combination* is significantly (p= 0.003) and positively correlated with *Interiorization* as its item C1. Items C3 and C4 are significant (Table 29). The effect of regression on Model 1 C-1 (Table 31) is significant (p=0.003) and (adjusted R^2 = 0.172) indicating that 17.2 % of Combination of the students affects Interiorization to create tacit knowledge. The regression in Model 2 C-I of Combination by items (Table 30) shows that the item that contributes the most is C1 *Roles know how to store the knowledge and experience that they possess and create* is (p=0.004). The item the least contributed is C2 *Roles are aware or agree that knowledge must be stored* (p=0.980).

Table 29. Correlation of Combination and Interiorization.

	Combination	C1	C2	C3	C4
Interiorization	.437**	.424**	.221	.332*	.311*
	.003	.004	.149	.028	.040

Table 30. Effect of Combination on Interiorization.

Model 1 C-I: Explicit-Tacit = $\beta_0 + \beta_1 CC$

Model	β	T	Sig.	R^2	adjusted R^2	F	Sig.
Combination	.437[a]	3.150	0.003	0.191	0.172	9. 921	0.003

Predictor variable: (Constant), Combination

Dependent variable: Interiorization

Model 2 C-I: Explicit-Tacit= $\beta_0 + \beta_1 C1 + \beta_2 C2 + \beta_3 C3 + \beta_4 C4$

Constant(e)	-3.018	-3.002	0.005	0.179	0.160	9.184	0.004
C1	0.674	3.031	0.004				
C2	-0.004	-0.025	0.980				
C3	0.158	0.971	0.337				
C4	0.204	1.410	0.166				

Predictor variables: (Constant), C1, C2, C3, C4

Dependent variable: Interiorization

For hypotheses H4, Interiorization (I) was considered as the independent variable on Socialization (S). In the whole factor of Interiorization as well as its items is correlated with Socialization. Table 31 shows that the correlation between Interiorization and Socialization is significantly (p=0.000) and positively. The effect of regression on Model 1 I-S (Table 32) is significant (p=0.000). Adjusted R^2 is 0.263 indicating that 26.3 % of student's interiorization affected the conversion of tacit to tacit knowledge in Socialization. Model 2 I-S shows the effect of Interiorization on Socialization by items. The item that contributes the most is I1 *Role are encouraged to take training courses* is significant (p=0.000) and the item that contributes the least is item S2 *Work products or procedures are reviewed to create knowledge or reflections by part of the roles* (p=0.262).

Table 31. Correlation of Interiorization and Socialization.

	Interiorization	I1	I2	I3
Socialization	0.530**	0.572**	0.382*	0.337*
	0.000	0.000	0.010	0.025

Table 32. Effect of Interiorization on Socialization.

Model 1 I-S: Tacit-Tacit= $\beta_0 + \beta_1 S$

Model	β	t	Sig.	R^2	adjusted R^2	F	Sig.
Interiorization	0.530	4.046	0.000	0.280	0.263	16.368	0.000

Predictor variable: (Constant), Interiorization

Dependent variable: Socialization

Model 2 I-S: Tacit-Tacit = $\beta_0 + \beta_1 I1 + \beta_2 I2 + \beta_3 I3$

Constante	-3.348	-4.455	0.000	0.327	0.311	20.417	0.000
I1	0.779	4.519	0.000				
I2	0.152	1.122	0.268				
I3	0.160	1.137	0.262				

Predictor variables: (Constant), I1, I2, 13

Dependent variable: Socialization

5.2 Discussions

Undergraduate students' education in SE, as well as other professions, is not only based on theory but also on practical insight into real situations learning mainly from the tacit knowledge from an expert (Göksel and Aydintan, 2016) or in similar environments in the context of scholar companies (Smilor, 1990). The findings of this study in a scholar company context have shown that the conversion of tacit knowledge into explicit (H1), explicit knowledge into new explicit knowledge (H2), explicit knowledge into tacit (H3) and tacit knowledge into new tacit knowledge (H4) has a positive effect on each knowledge conversion in students. Similarly, Wan et al. (2011) analyzed the interaction of tacit and explicit knowledge in SPI projects under the interaction of Socialization and Externalization, and Combination and Interiorization to create explicit and tacit knowledge respectively. On the other hand, findings in Chikh (2011) describe the application of the SECI model within SE processes.

H1 in Model 2 S-E and Model 3 S-E (Table 26) show that the item that contributes the most is S1 *The knowledge I have is really available to others,* explaining 10.7%. This finding is comparable to the item *Communication among project team members* in Wan et al. (2011) and was considered one of the most successful factors for SPI projects. One statement among student's responses was "Knowledge is transmitted verbally or by example so that others can acquire knowledge".

H2 in Model 2 E-C (Table 28) showed that the most significant items were E5 and E2. E5 *The work is reciprocally verified and validated* with 24.4%. The contribution of this item allows for a conversion of explicit knowledge into new explicit knowledge based on changes made to previous versions, using verification and validation reports (Chick, 2011). One response from the programmers was "The framework allows us to test our work and have other roles review us as well". The item E2 *Customer requirements are formally and systematically captured* explain a 10.5 %. One of the responses was "Customer requests for information are documented in user's stories". This item was also in Wan et al. (2011) with the difference that its effect was measured in the creation of tacit knowledge within the factor "documentation of requirements".

H3 in Model 2 C-I (Table 30) the item C1 *Roles know how to store the knowledge and experience they possess* shows a 16% effect in Interiorization to create tacit knowledge from explicit knowledge. This finding can be compared to the integrating documents in Wan et al. (2011), having been one of the factors of greater contribution.

H4 in Model 2 I-S (Table 32) the item that contributes the most is I1 *Roles are encouraged to take training courses* with a 31% effect on Socialization. In (Wan et al., 2011) this item was analyzed together with combination to create new tacit knowledge but was only statically significant without contributing to the regression to explain its effect on knowledge creation. Concerning this item, one of the students answered: "all employees were trained with scrum videos, code and research topics for the best learning, as well as investigation of tools for better traceability".

Based on the items that were not significant, the study reveals the need to establish a plan of action to continue improving the implementation of KM practices with a more significant effect on the conversion of the four modes of knowledge.

5.3 Conclusions

The findings of this study conclude that undergraduate students who are currently in training and their experience is not yet comparable to professionals in software organizations are capable of creating knowledge from the knowledge flows interaction of the SECI model with a positive effect. So, that allows them to develop best practices associated with KM as part of the software development lifecycle, which is a key to successful SE and SPI initiatives. It emphasizes the value of interaction between knowledge creation processes in which project team members must socialize, externalize, combine, and interiorize software requirements in order to convert tacit knowledge into explicit knowledge and vice versa to develop a software product.

Chapter 6. SECIKC-SE a capability assessment model of KM process towards an SPI initiative

After the first version of the measurement instrument (see appendix Table 64), the indicators of each process were characterized in terms of knowledge capabilities based on the KM and SE contexts. KM context based on the SECI model: the theory of Knowledge Creation by Nonaka (1994), the study by North & Kumta (2014), and the processes (Table 33) and elements of the KMPRM by Flores-Rios (2016). On the other side, the SE context was supported by ISO/IEC 15504/02 (2010) and CMMI-DEV 1.3 (2010) according to capability and maturity levels.

Then, given that indicators must be mapped from the model process (ISO/IEC 15504/02, 2010) and derived from the analysis of KM models and SPI standards, a total of 42 indicators were obtained (see appendix Table 65); in the first version, six indicators were not significant and were eliminated (1.3, 2.5, 2.7, 4.3, 4.5, 5.3); the wording of three indicators was modified for clarity purposes (1.4, 3.5, 6.1); indicator 6.2 was split into three indicators (6.2, 6.3, 6.4) according to the previous study by Wan et al. (2011); and seven indicators (1.5, 4.3, 4.5, 5.3, 5.4, 5.6, 6.5) were added following the studies by Wan et al. (2011) and Flores-Rios (2016). Also at the measurement process, nine indicators (7.1, 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9) were added from (Flores-Rios, 2016; ISO/IEC 15504/02, 2010; CMMI-DEV, 2010; Nonaka, 1994). Furthermore, this second version of the measurement instrument was compared to the SRL results. It was concluded that seven processes and 42 indicators were in the scope of the 11 processes and 90 indicators measured in the four SP.

Table 33. KMPRM processes. Adapted from (Flores-Rios, 2016).

Process name	Purpose
Identification	To reveal and achieve transparency in the existing knowledge within the organization, both in individuals, artifacts or entities.
Create, Acquire	To acquire or receive knowledge thorough training, individual experience and interactions between roles, and documents outside the organization. Furthermore, to develop and to create skills through experience and generation of ideas, models, tools, and innovative products.
Externalization	To formalize the capture, structure, and organization of tacit knowledge to explicit knowledge.
Store	Storing products in repositories (knowledge bases) to maintain access for all the members of the organization to the knowledge assets according to their requirements.

Transfer	To allow the exchange of tacit knowledge between the roles to promote the cross-development of roles through a common language, ease of communication, and analysis based on explicit knowledge.
Interiorization	To reflect and discuss explicit knowledge between roles, facilitating easy understanding and practice of what has been learned from different roles, workflows, and documents that involve knowledge.
Measure	To quantify the degree of tacit and explicit knowledge to describe the current process state of the organization and what the impact of KM practices have for the creation of new knowledge that motivates innovation.

Based on the fact that the degree of process improvement is measured by capability levels (ISO/IEC 15504/02, 2010), the SECIKC-SE process assessment model (Socialization, Externalization, Combination, Interiorization, Knowledge Creation in Software Engineering) was developed based on capability levels towards an SPI initiative (Table 34). The development of SECIKC-SE as a KM capability process assessment model, was adapted in conformity with the requirements from ISO/IEC 15504/02 (2010) and ISO/IEC 15504/-05 (2012) (Figure 8) which states that the process assessment model of this standard can be used as an example to develop specific assessment models.

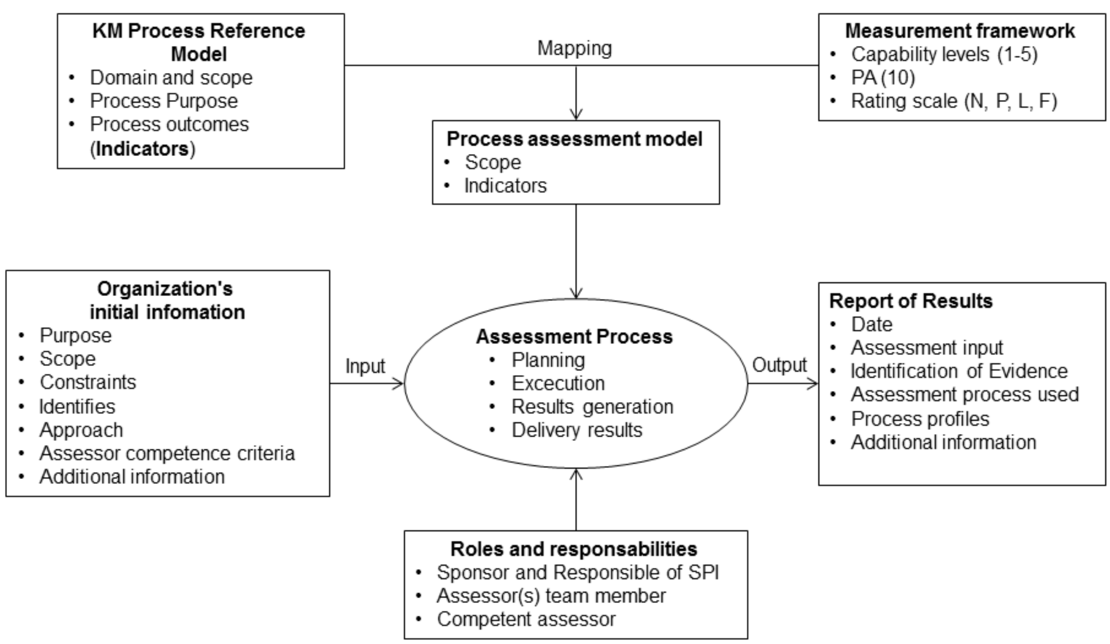


Figure 8. Elements of the SECIKC-SE process assessment model. Adapted from ISO/IEC 15504/02 (2010).

Table 34. Description of the SECIKC-SE Model.

	Purpose	The purpose of the SECIKC-SE model is to support the assessment of KM processes to determine their capability through five levels (L1 to L5).	
CONTEXT OF KNOWLEDGE MANAGEMENT		**CONTEXT OF SOFTWARE ENGINEERING**	
	Capability Level SECIKC	**Level SE**	**Description**
	Knowledge creation	**L5**	The creation of new knowledge increases inside the organization, and this promotes continuous improvement in process and innovation of products and services (ISO/IEC 15504/02, 2010; CMMI-DEV, 2010) based on the interiorization and reflection of the measurement and analysis results. Their knowledge or methods are unique (Nonaka, 1994; North & Kumta, 2014), they are spread among the members of the organization, and external knowledge is acquired (Nonaka, 1994).
	Interiorization	**L4**	The explicit knowledge created in the previous levels is reflected and discussed obtaining new tacit knowledge. This encourages the organization to know itself (self-knowledge) and the specific experience of each member. Actions are implemented to formally and informally train staff. It allows them to set quantitative quality and performance goals to be achieved by their processes. The measurement of objectives and performance is understood in statistical and management terms through their lifecycle (CMMI-DEV, 2010).
	Combination	**L3**	Each piece of explicit knowledge is integrated into a whole. The knowledge of project team members is standardized (Nonaka, 1994) and it is reused in guides, manuals, etc. Procedures and methods are followed and tools are supported. Likewise, roles identify and apply the knowledge needed for the job (CMMI-DEV, 2010).
	Externalization	**L2**	Tacit knowledge of the interested parties becomes explicit. Templates are available to identify and code knowledge (Flores-Rios, 2016). Team members have the right knowledge and skills (CMMI-DEV, 2010). Documented knowledge is managed through knowledge bases, and discipline is maintained for members to carry it in a sustained manner even in times of stress. The documentation is verified and validated.
	Socialization	**L1**	Tacit knowledge is shared among project team members and executives. It is observed that knowledge is imitated and learned from other members. They collaborate closely, but knowledge communication and documentation mechanisms are not formalized. In some cases, there is the idea that sharing knowledge means losing power, so there are isolated efforts by some members to communicate their tacit knowledge. On the other hand, organizations do not value or reward it (North & Kumta, 2014).

The purpose of the SECIKC-SE capability process assessment model is to determine the process capability of the KMPRM (Flores-Rios, 2016) considering that measuring knowledge process capability helps to identify the advantages, weaknesses, and risks with certain indicators to encourage process improvements in the same way that (ISO/IEC 15504/02-03, 2004; CMMI-DEV, 2010). Capability is measured in the ordinal scale of five levels (L1 to L5) according to their measurement framework (Table 35). For this, the Knowledge creation process was added to the SECI model in correspondence to the five levels in a SE context. Therefore, SECIKC-SE capability is supported by the use of indicators that collect objective evidence to demonstrate the achievement of PA. The indicators can be extensible, but for this release model proposal, the indicators of the 7 KMPRM processes within scope (Table 60) were selected considering their purpose and results that demonstrate PA achievement.

6.1 Capability measurement framework of the SECIKC-SE

The capability measurement framework of the SECIKC-SE was developed following the requirements of ISO/IEC 15504/02 (2010). In this manner, the measurement framework (Figure 9) comprises the dimensions of capability and process required. The process dimension capability is related to the capability levels and a set of ten PA integrated by a subset of indicators (Table 58 – 62). The indicators were grouped within the ten PA according to a content validity stated by the characterization of each of the five capability levels (see section 3.1.1 and 3.1.2). Likewise, these PA groups or constructs were validated through a factor analysis. The detail of this validation is further explained in section 6.2.5 Reliability and validity. The dimension of KM processes describes the set of processes related to a KMPRM, for the purpose of this research (Flores-Rios, 2016) (Table 33). A third dimension regarding software processes or process areas of the SPRM was added, which should be positively impacted by the PA indicators, and for the scope of this research refers to CMMI-DEV 1.3.

Figure 9 shows how the measurement framework defines process capability. The process capability increases from the minimum level corresponding to *L1 Socialization*- which seeks to achieve communication and acquisition of TK- to the maximum level *L5 Knowledge Creation*, -that seeks to achieve an increase of new knowledge-. This new knowledge promotes the institutionalization of innovation culture in SDOs for the roles to generate continuous improvement in their processes as well as innovation in their products and services. All this amounts to greater EK++ to begin with a new spiral or cycle of knowledge creation in which Socialization starts with greater TK++.

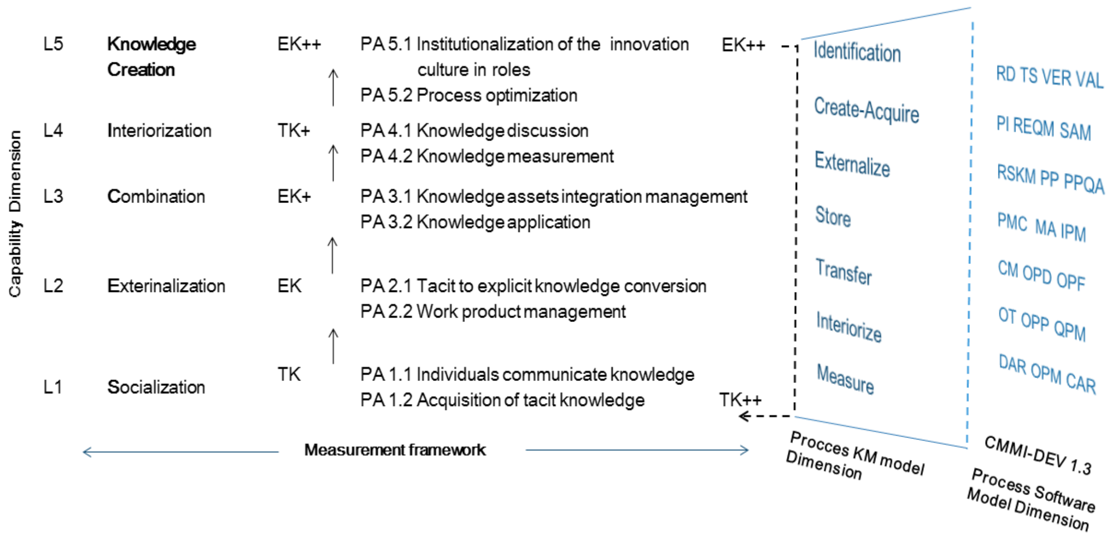


Figure 9. SECIKC-SE Capability assessment model towards an SPI initiative. Adapted from ISO/IEC 15504/02 (2010).

For the third dimension, in order to bring more detail (Table 66) with the SECIKC-SE model, a mapping was performed between SECIKC-SE indicators and CMMI-DEV 1.3 Process Areas and the Generic Goals (GG) by capability level. Figure 10 shows the mapping for each capability level, the 22 process areas, and the three GG: GG1 "To achieve the process specific goals," GG2 "To institutionalize a managed process," and GG3 "To institutionalize a defined process" (CMMI-DEV, 2010) also indicating the Generic Practices (GP).

Capability is assessed by measuring the achievement of each PA (PA 1.1, PA 1.2, PA 2.1, etc.) from the collection of objective evidence that provides the knowledge to rate each indicator characterizing it. For this model, objective evidence of PA achievement comes from affirmations (statements) of team members or managers who carry out the processes (ISO/IEC 15504/05, 2012). Considering that these affirmations can be questionnaires and that according to the assessment scope, only one type of objective evidence is required (CMMI-DEV, 2010), for this study to collect affirmations as objective evidence, a survey was used so participants could assess and rate each indicator. Additional to the rating, participants were asked to mention the work products (EK) or knowledge that they or other team members possess (TK) in such a way that justifies their rating.

L5	AP 5.1 Institutionalization of the innovation culture in the roles	OPP	OT	OPD	OPF	OPM	GP 2.1	GP 2.3	GG3.1	GG3.2			
	AP 5.2 Process optimization	OPP	OPM	CAR	MA	GP 2.1	GP 2.5	GP 2.8	GP 2.9	GP 2.10			
L4	AP 4.1 Knowledge discussion	OT	PMC	GP 2.5	GP 2.6	GG 3.2							
	AP 4.2 Knowledge measurement	OT	MA	OPP	QPM	GP 2.1	GP 2.5						
L3	AP 3.1 Knowledge assets integration management	CM	OPD	PI	IPM	PPQA	GP2.1	GP 2.2	GP 2.3	GP 2.4	GP 2.6		
	AP 3.2 Knowledge application	CM	OT	GP2.1	GP 2.3	GP 2.6	GG 3.2						
L2	AP 2.1 Tacit to explicit knowledge conversion	RD	TS	REQM	RSKM	VER	VAL	DAR	GP1.1				
	AP 2.2 Work product management	RD	TS	REQM	RSKM	VER	VAL	PP	OPF	PPQA	GP 1.1	GP 2.9	GP 3.2
L1	AP 1.1 Individuals communicate knowledge	OT	GP 2.5	GP 2.6	GP 2.7	GP 2.8							
	AP 1.2 Acquisition of tacit knowledge	OT	GP 2.5	GP 2.7	GP 2.8								

Figure 10. Capability mapping between SECIKC-SE indicators and CMMI-DEV 1.3 model (2010).

6.1.1 Rating scale of process attributes to achieve a capability level

To assess the achievement of the PA, it is necessary to assign a rating within an ordinal measurement scale (Table 35). PA ratings depend on the assessment of each indicator. The assessment of the SECIKC-SE indicators consisted of a 5-point Likert scale (5-Strongly Agree SA, 4-Agree A, 3-Neither disagree nor agree N, 2-Disagree D and 1-Strongly Disagree SD). Considering the four ratings scale applied for the ISO/IEC 15504/02 (2010) described in Table 9, an equivalence of the rating range was developed according to conformity percentages, therefore, the scale 5-SA is C (4.30-5), 4-A is A (2.60-4.29), 3-N is P (0.80-2.59) and 2-D y 1-SD are N (0-0.79). Assigning an equivalent percentage to the ordinal scale brings greater precision to a quantitative rating than the SCAMPI-MDD (2014) scale (Table 7).

Table 35. Rating scale to assess the degree of implementation of process attributes. Adapted from ISO/IEC 15504/02 (2010).

Acronym	Achievement of the defined process attributes		Percentage 15504/02	Percentage SECIKC-SE
N (SD-2, D-1)	Not achieved	There is little or no evidence of achievement of the defined attribute in the assessed process	0 to 5% of the scope	0-0.79

P (N-3)	Partially achieved	There is evidence of a sound systematic approach to the achievement of the defined attribute in the assessed process. Some aspects of achievement may be unpredictable.	>15% to 50% of the scope	0.80-2.59
L (D-4)	Largely achieved	There is evidence of a sound systematic approach to and significant achievement of the defined attribute in the assessed process. Performance of the process may vary by organization.	>50% to 85% of the scope	2.60-4.29
F (SA-5)	Fully achieved	There is evidence of a complete and systematic approach to and full achievement of the defined attribute in the assessed process. No significant weaknesses exist across the defined organization.	>85% to 100% of the scope	4.30-5

6.1.2 Process Capability level profile SECIKC-SE

The process capability level profile has been adapted from ISO/IEC 15504/02 (2010). In Table 36, capability levels are described, so that to reach a capability N1 *Socialization* the PA rating must be at least L. For capability levels 2 or higher the ratings of their PA may also be at least L or F, but the PA of the previous capability level must have obtained the maximum rating of F. Therefore, according to ISO/IEC 15504/04 (2004), the set of PA ratings defines a profile reflecting the result of an assessment of the set of processes within the scope.

6.2 Verifying compliance of SECIKC-SE capability assessment model with the ISO/IEC 15504

A requirement checklist was developed to verify compliance of the assessment model of SECIKC-SE with the requirements established in sections 6.3.2, 6.3.3, 6.3.4, and 6.3.5 from chapter 5 of the ISO/IEC 15504/02 (2011). Table 38 listed the five requirements for a process assessment model: 1) Purpose, 2) Scope, 3) Elements and indicators, 4) A mapping between the measurement framework and the SRPM, and 5) A mechanism to express results in a consistent manner; compliance of the rational assessment of SECIKC-SE, as well as the revisions made.

Table 36. Process capability level profile SECIKC-SE. Adapted from the ISO/IEC 15504/04 (2004).

Level	Capability Processes Process Attributes (PA)	Maximum PA rating for each capability level 1	2	3	4	5
L1 Socialization	AP 1.1 Individuals communicate knowledge	L	**F**	**F**	**F**	**F**
	AP 1.2 Acquisition of tacit knowledge	L	**F**	**F**	**F**	**F**
L2 Externalization	AP 2.1 Tacit to explicit knowledge conversion	-	L	**F**	**F**	**F**
	AP 2.2 Work product management	-	L	**F**	**F**	**F**
L3 Combination	AP 3.1 Knowledge assets integration management	-	-	L	**F**	**F**
	AP 3.2 Knowledge application	-	-	L	**F**	**F**
L4 Interiorization	AP 4.1 Knowledge discussion	-	-	-	L	**F**
	AP 4.2 Knowledge measurement	-	-	-	L	**F**
L5 Knowledge Creation	AP 5.1 Institutionalization of innovation culture in the roles	-	-	-	-	L
	AP 5.2 Process optimization	-	-	-	-	L

Table 37. Compliance of SECIKC-SE with the ISO/IEC 15504/02 (2010).

Requirements for the process assessment models	Compliance	Adaptations
1. A process assessment model must have a purpose.	The purpose of the SECIKC-SE model is to support the assessment of KM processes to determine their capabilities through five levels (L1 to L5) (Table 34).	
2. Scope		
A process assessment model must be related to at least one process of a SPRM	KMPRM by Flores-Rios (2016) Section 2.3	In this research instead of a SPRM there is a KMPRM
A process assessment model must be considered for one process or for all, as a continuous subset of levels (starting with 1) of the capability measurement framework for each process within its scope.	The SECIKC-SE model considers a set of KM Process and the capability dimension (Figure 9).	For the SECIKC-SE capability framework, the capability results from the combination of KM process indicators.
A process assessment model must clarify its scope (SPRM selected; selected processes from the SPRM; selected capability levels from the measurement framework).	The SECIKC-SE model selected 7 of the 8 KM processes considered by the (Flores-Rios, 2016) model in the process dimension, leaving out the evolution process. Also, the five capability levels of measurement framework were selected (Figure 9).	
3. Elements and indicators		
A process assessment model must be based on the set of indicators defined in the SPRM with purposes and results from all the processes within the scope and that demonstrate the achievement of the PA.	SECIKC-SE integrates a bidimensional view of the capability process through a set of indicators that measure the achievement of the PA (Figure 9)	In this version of the SECIKC-SE model, only objective evidence obtained from affirmations was assessed by project team members.
4. Correlation of the process assessment models with the SPRM *Instead of SPRM is KMPRM		
A process assessment model must map the purposes and results of the processes within the SPRM specified.	The purpose of the processes included in the SECIKC-SE assessment model is the same as the KMPRM.	The indicators used were mainly mapped from the Management Techniques process element of the KMPRM.

A process assessment model must map the PA of the assessment framework.	Every PA in the SECIKC-SE process measurement framework is used in the assessment model. The indicators characteristics of PA are measurable.	In this scope, Generic Practices, Generic Resources and Generic Work Products are not considered.
5. Expression of the results		
A process assessment model must provide a formal and verifiable mechanism to present results of an assessment as a set of qualifications of the PA of the process, for each selected process of the SPRM specified.	The results of the SECIKC-SE assessment are expressed as a set of ratings of the PA of each process within the scope of the assessment (Table 36).	

6.3 SECIKC-SE Assessment process

A documented assessment process was adapted from (ISO/IEC 15504/02, 2010; ISO/IEC 15504/03, 2004; ISO/IEC 15504/01; 2004) to conduct the SECIKC-SE assessment process and to ensure consistency and duplicity of ratings that determine improvements and capability levels (ISO/IEC 15504/05, 2012) (Table 37) (Figure 11). The documented process comprises the Planning, Execution, Results Generation, and Results Delivery activities. The roles and responsibilities are represented by a Sponsor, who is interested in obtaining the capability process profile of the organization and is responsible for providing human and material resources to conduct the assessment; the SPI Responsible, who requires the Report results to plan actions for process improvement; the Assessing team members, that can be any participant assessing the implementation of the indicator; and the Competent assessor who has the skills and experience to monitor and verify compliance of the process assessment. Finally, the input and output products integrated by the Organization's initial information, Assessment agreement, Assessment plan, Survey measurement instrument, and Result Report.

The SECIKC-SE capability assessment process model allows self-assessment or independent assessment of the knowledge process capability to diagnose and identify any improvement opportunities. In a self-assessment, the Sponsor and the Assessing team members are the organization's employees, and on an independent assessment, the assessor(s) are external to the organization (ISO/IEC 15504/03, 2004). During self-assessment, only one type of objective evidence is required, and this model uses affirmations (statements) adapted as SCAMPI C from (CMMI-DEV, 2010).

Table 38. SECIKC-SE assessment process.

Planning	
Roles	**Activities**
Competent assessor (internal or external) Sponsor SPI Responsible	● The organization's initial information is obtained (Organization's name, SDO ML, operation years, number of employees, project team members sample, roles, education level, and type of projects). ● Assessment agreements with the organization's sponsor are established considering the assessment scope regarding the processes to be assessed by KM presented in the survey measurement instrument; confidentiality; participant selection in the assessment considering the type of roles, employee seniority, and their active enrollment in projects within the CMMI-DEV certification. ● The assessment schedule is determined considering the supervision that will take place during the assessment and the results submittal.
Execution	
Assessing team members	● The project team members participate as assessors issuing their opinions on the level of implementation of the indicators through affirmations as objective evidence; they respond to the survey measurement instrument rating each of the indicators according to the rating scale (Table 35).
Competent assessor (internal or external)	● The Competent assessor verifies that all participants have responded to the survey and that each survey was correctly completed. ● Collecting data from the surveys and validate it.
Results generation	
Competent assessor (internal or external)	● Results are documented by providing general information such as the name of the organization, date of application and delivery of results, the name of the sponsor and SPI responsible, name of the competent assessor, a summary of the roles of participants and employee seniority profile. ● Based on the assessment of all participants, results are processed to obtain ratings by indicator and in turn measure PA achievement. The organization's capability process profile is generated from the set of PA ratings profile (Table 36).
Results delivery	
Competent assessor (internal or external) Sponsor SPI Responsible	● The report of the assessment results is submitted to the sponsor, SPI responsible, and assessment participants so that the organization is aware of the degree of process implementation and the capability process profile obtained. ● Any concerns presented are discussed and the development of an improvement action plan is encouraged according to the findings.

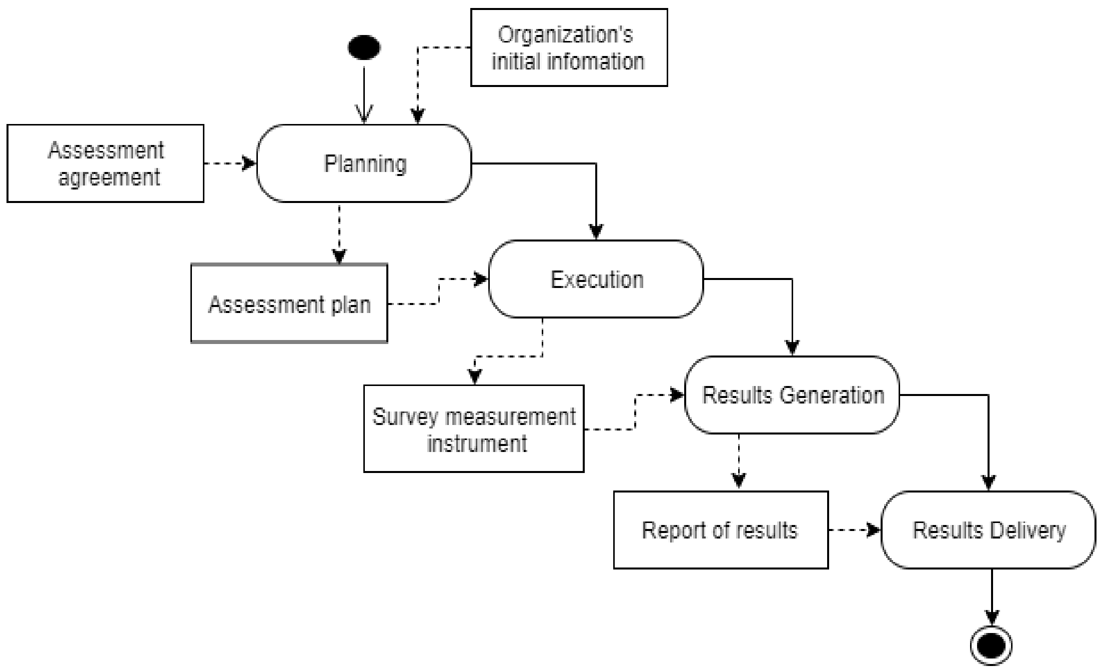


Figure 11. Assessment process activities. Adapted from ISO/IEC 15504/04 (2004).

6.4 Case study research method

Data collection

The case study research method was used because it tests the relevance of quantitative model proposals empirically (Choueinoglou et al., 2013). The SECIKC-SE assessment process was followed for the assessment (Figure 11). Therefore, following the activity plan, the initial information of the SDO certified in CMMI-DEV 1.3 in Mexico, particularly in Baja California (Table 1) was collected. Subsequently, SDOs were contacted and asked to be part of the case study, explaining the scope of the Measuring KM focused on SPI and SE processes and determined the assessment agreements.

From a total of 11 SDOs in Baja California, four agreed to participate, 3 (ML2), 1 (ML3). So to enhance the number of SDOs and include higher ML, other SDOs (ML 4 and ML5) were contacted so that 1 (ML5) was added. Table 39 shows the data collection taking into account the properties of SDOs: ML, years in operation, number of employees, project team members sample, Roles, degree of education, employee seniority and, Type of projects.

Afterwards, according to the assessment schedule of each SDO, execution activities began by administering the survey measurement instrument and verifying that all participants answered and completed it correctly. A total of 66 surveys were collected (Table 40).

Table 39. Data collection.

Attributes	SDO A	SDO B	SDO C	SDO D	SDO E
ML	2	2	2	3	5
Operation years	6-9	10-20	10-20	More than 20	More than 20
Staff number	7	19	24	35	More than 250
Project team members sample	6	13	21	16	10
Roles	Project leader, systems analyst, architecture designers, user interface designer, and programmers.	Product owner, Scrum Master, Project leader, systems analyst, architecture designers, user interface designer, programmers, and testers.	Project leader, architecture designers, user interface designer, programmers, testers, and responsible of preparing manuals.	Project leader, architecture designers, user interface designer, and programmers.	Project leader, architecture designers, user interface designer, and programmers.
Degree of education	Bachelor degree	Bachelor degree	1 Technician, Bachelor, and 2 Master degree	18 Bachelor degree	1 Technician, 8 Bachelor, and 1 Master degree
Employee seniority	17 % from 1 to 2 years, 33% from 3 to 5 years and 50% more than 5 years.	8 % less than 1 year, 8% from 1 to 2 years, 61% from 3 to 5 years and 23% more than 5 years.	52 % less than 1 year, 33% from 1 to 2 years, 5% from 3 to 5 years and 10% more than 5 years.	12 % less than 1 year, 44% from 1 to 2 years, 31% from 3 to 5 years and 13% more than 5 years.	10 % less than 1 year, 30% from 1 to 2 years, 20% from 3 to 5 years and 40% more than 5 years.
Projects	Custom software development	Custom software development	Custom software development	Custom software development	Custom software development

Table 40. Total sample collected.

SDO	Frequency	Percentage
A	6	9.09
B	13	19.70
C	21	31.82
D	16	24.24
E	10	15.15
Total	**66**	**100.00**

Research challenges

Maintaining direct contact with the SDO Responsible was the main challenge. Once the agreement was obtained, the time for answering the survey took some SDOs longer that what was scheduled, due to prior customer comittments. For this reason, some SDOs were not able to administer the survey to all employees in the company.

Hypotheses

Five hypotheses were formulated to validate the influence of the theoretical model SECIKC-SE on the knowledge conversion from TK to EK through five capability levels considering the origin knowledge flow from L1 Socialization to the next capability high level in a spiral flow until reaching L5 Knowledge creation (Table 41).

Scale design

The second version of the survey was applied with seven processes from the KM reference model with a total of 42 indicators (see Appendix Table 65). The Likert scale used was explained in subsection 6.1.1. To guarantee that the project team members understood the survey, the SDO assigned the SPI Responsible as point of contact to clarify any questions.

Table 41. Research hypotheses.

Interaction of knowledge capability level flows From	To	Hypotheses
L1 Socialization	L2 Externalization	**H1:** Socialization among project team members positively influences the externalization of tacit knowledge to create explicit knowledge
L2 Externalization	L3 Combination	**H2:** The externalization of project team members positively influences the combination of explicit knowledge to create new explicit knowledge
L3 Combination	L4 Interiorization	**H3:** The existing explicit knowledge in SDOs positively influences the interiorization of tacit knowledge of project team members to create new tacit knowledge in them
L4 Interiorization	L5 Knowledge Creation	**H4:** The interiorization of project team members positively influences knowledge creation in SDOs to create new tacit and explicit knowledge
		H5: Knowledge creation by project team members positively influences socialization to create new tacit knowledge

Reliability and validity

In order to ensure the scientific quantitative research of the SECIKC-SE model proposal, the internal consistency of the survey was measured across a reliability analysis using Cronbach's alpha (α) coefficient, obtaining a value of α= 0.964. The value of α for each PA construct was between 0.575 and 0.884 which is considered acceptable when is near 0.6 and above this (Table 42).

Next, an individual PA component reduction was executed to validate the common meaning of indicators into each PA factor, based on the content validity performed for the SECIKC-SE capability level constructs consistent with the characterization of the standards (ISO/IEC 15504/02, 2010; CMMI-DEV, 2010). To confirm the normalization of KMO factors a Bartlette's test of Sphericity was performed; KMO ranged from 0.583 to 0.798 and Bartlette's test of Sphericity was statistically significant (p=0.000). Hence, a factor analysis with the main component analysis method and varimax rotation was executed. Each PA was extracted in a single factor using eigenvalue greater than 1.

Table 42. Reliability constructs.

Construct	No. Items	α
PA 1.1	6	0.822
PA 1.2	3	0.575
PA 2.1	3	0.787
PA 2.2	3	0.789
PA 3.1	4	0.776
PA 3.2	4	0.749
PA 4.1	5	0.841
PA 4.2	4	0.884
PA 5.1	5	0.845
PA 5.2	5	0.910
Total	42	0.964

Table 43 shows the two factors related to L1 Socialization. *PA 1.1 Individuals communicate knowledge* as a measure of the degree to which tacit knowledge communicates and increases between individuals inside and out of the organization; it is integrated by 6 indicators taken from transfer process (5.5, 5.2, 5.3, 5.4) and acquisition process (2.1, 2.2). The range of variance explained among indicators was from 0.868 to 0.0813. The factor explained 53.948 of total variance; KMO (0.748) and ($p = 0.000$).

The *PA 1.2 Acquisition of tacit knowledge* is a measure of the degree to which individuals assess their own knowledge, their availability to share it and learn from others; it is composed by 3 indicators taken from the transfer process (5.1), acquisition process (2.4) and identification process (1.4). The range of variance explained among indicators was from 0.676 to 0.0824. The factor explained 54.753 of the total variance; KMO (0.712) and ($p = 0.000$).

Table 43. Factors PA 1.1 and PA 1.2.

L1 Socialization	Loading factor
PA 1.1 Individuals communicate knowledge	
1.1.1 Roles are aware that their knowledge can be shared (5.5 Transfer)	0.737
1.1.2 Existing explicit knowledge is distributed in electronic format (emails, intranet, information systems, etc.) (5.2 Transfer)	0.727
1.1.3 Constant communication among project team members (5.3 Transfer)	0.813
1.1.4 Communication between project team members and executives (5.4 Transfer)	0.746
1.1.5 There are ways to acquire knowledge from external sources (consultants, suppliers, clients, etc.) (2.2 Acquisition)	0.690
1.1.6 Knowledge acquisition strategies are defined and selected (training, forums, repositories, online courses, etc.) (2.1 Acquisition)	0.686
KMO	0.748
Bartlette Sig.	0.000
Accumulated variance explained	53.948
PA 1.2 Acquisition of tacit knowledge	
1.2.1 The knowledge that I possess is easily available to others (5.1 Transfer)	0.824
1.2.2 The knowledge that I usually acquire comes from the other roles with whom I interact (2.4 Acquisition)	0.676
1.2.3 Roles identify all their knowledge (I know what I know) (1.4 Identify)	0.712
KMO	0.583
Bartlette Sig.	0.000
Accumulated variance explained	54.753

Table 44 shows the two factors of L2 Externalization. *PA 2.1 Conversion from Tacit to explicit knowledge* measures the degree on which TK transforms into EK by the effectiveness of the process of document preparation required through software development processes regarding customer's needs, initially with the establishment of the project goals and requirements; this PA is composed by 3 indicators taken from the externalization process (3.1, 3.3) and identification process (1.5). The range of variance explained among indicators was from 0.0835 to 0.859. The factor explained 70.284 of the total variance; KMO (0.702) and (p = 0.000).

PA 2.2 Work product management measures the degree of the existence and control of EK (artifacts or documents) created during the software lifecycle and the resources implemented to support processes, as well as, the capture of success or failed experiences; it is integrated by 3 indicators taken from the transfer process (3.2, 3.4 and 3.5). The range of variance explained among indicators was from 0.863 to 0.808. The factor explained 70.357 of the total variance; KMO (0.697) and (p = 0.000).

Table 44. Factors PA 2.1 and PA 2.2.

L2 Exteriorization	**Loading factor**
PA 2.1 Tacit to explicit knowledge conversion	
2.1.1 There is a formalization to document the implicit goals of the project (3.1 Externalize)	0.835
2.1.2 Customer tacit requirements are related to specific project characteristics (subjective requirements to objective requirements) (3.3 Externalize)	0.821
2.1.3 The Project team has the right mix of skills and knowledge (1.5 Identify)	0.859
KMO	0.702
Bartlette Sig.	0.000
Accumulated variance explained	70.284
PA 2.2 Work product management	
2.2.1 Customer requirements are formally and systematically captured (3.2 Externalize)	0.863
2.2.2 Improvement ideas as well as lessons learned are captured in real time (3.4 Externalize)	0.844
2.2.3 The resulting documentation is verified and validated (3.5 Externalize)	0.808
KMO	0.697
Bartlette Sig.	0.000
Accumulated variance explained	70.357

L3 Combination is composed of two factors (Table 45). The *PA 3.1 Knowledge assets integration management* measures the degree on which EK converts into new EK through artifacts or document integration. For this, it is important for employees to combine skills and knowledge; this PA is integrated by 4 indicators taken from the store process (4.5, 4.4, 4.3, 4.6). The range of variance explained among indicators was from 0.693 to 0.847. The factor explained 59.875 of the total variance; KMO (0.753) and ($p = 0.000$).

PA 3.2 Application of knowledge assets measures the degree of which existing EK from knowledge databases is applied to perform the work; it is integrated by 4 indicators taken from the storage process (4.1), identification process (1.2, 1.1), and interiorization process (6.5). The range of variance explained among indicators was from 0.571 to 0.868. The factor explained 70.357 of the total variance; KMO (0.697) and ($p = 0.000$).

Table 45. Factors PA 3.1 and PA 3.2.

L3 Combination	**Loading factor**
PA 3.1 Knowledge assets integration management	
3.1.1 Knowledge is integrated in real time and documents are organized (4.5 Store)	0.847
3.1.2 There is a person responsible for storage and maintenance of knowledge assets (4.4 Store)	0.819
3.1.3 Procedures are documented to guide the work (4.3 Store)	0.725
3.1.4 Tools that allow integrating (combine) explicit knowledge are used (4.6 Store)	0.693
KMO	0.753
Bartlette Sig.	0.000
Accumulated variance explained	59.875
PA 3.2 Application of knowledge assets	
3.2.1 I know how to store the knowledge and experience that I possess and create (4.1 Store)	0.571
3.2.2 Roles know how to find the knowledge that is available (1.2 Identify)	0.868
3.2.3 Roles know what types or sources of knowledge they need to perform the work (Documented, personnel's knowledge) (1.1 Identify)	0.841
3.2.4 The existing information in the knowledge base of the organization for the practice of work is used (6.5 Interiorize)	0.757
KMO	0.740
Bartlette Sig.	0.000
Accumulated variance explained	59.009

L4 Interiorization is composed of two factors (Table 46). *PA 4.1 Knowledge discussion* is a measure of the degree on which EK is discussed since the beginning to the end of the project to reflect and create new TK; this PA is integrated by 5 indicators taken from the interiorization process (6.1, 6.2, 6.3, 6.4) and identification process (1.3). The range of variance explained among indicators was from 0.645 to 0.888. The factor explained 61.796 of the total variance; KMO (0.794) and ($p = 0.000$).

PA 4.2 Knowledge measurement is a measure of the degree of the implementation of indicators that helps to achieve the process goals within the established quantitative limits; this PA involves 4 indicators taken from the measure process (7.1, 7.2, 7.3, 7.4). The range of variance explained among indicators was from 0.790 to 0.926. The factor explained 74.661 of the total variance; KMO (0.798) and ($p = 0.000$).

Table 46. Factors PA 4.1 and PA 4.2.

L4 Interiorization	**Loading factor**
PA 4.1 Knowledge discussion	
4.1.1 Training is provided to the roles according to the work and requirements of the project (6.1 Interiorize)	0.673
4.1.2 Documents are used to start discussions at the beginning of the project for the roles to reflect on or create knowledge (6.2 Interiorize)	0.827
4.1.3 Documents are used to start discussions about the progress of the project for the roles to reflect on or create knowledge (6.3 Interiorize)	0.865
4.1.4 Documents are used to start discussions after the implementation of the project for the roles to reflect on or create knowledge (Interiorize 6.4)	0.888
4.1.5 Roles know which team members have experience in specific areas (1.3 Identify)	0.645
KMO	0.794
Bartlette Sig.	0.000
Accumulated variance explained	61.796
PA 4.2 Knowledge measurement	
4.2.1 There are indicators to measure knowledge in the organization (7.1Measure)	0.865
4.2.2 The organization measures and evaluates the knowledge of each employee (7.2 Measure)	0.926
4.2.3 Top management knows how much the staff has learned in the past year (7.3 Measure)	0.870
4.2.4 The stored knowledge is measured and/or quantified (explicit knowledge) documents, mail, and or systems (7.4 Measure)	0.790
KMO	0.798
Bartlette Sig.	0.000
Accumulated variance explained	74.661

L5 Knowledge creation incorporates two factors (Table 47). *PA 5.1 Institutionalization of the innovation culture in roles* measures the degree in which the SDO interiorizes TK to motivate and spread new knowledge that encourages roles to create innovative products and services; this PA is integrated by 6 indicators taken from the acquisition process (2.5, 2.6, 2.3, 2.7), the measure process (7.5) and the interiorization process (6.6). The range of variance explained among indicators was from 0.662 to 0.793. The factor explained 52.420 of the total variance; KMO (0.798) and (p = 0.001).

PA 5.2 Process optimization is a measure of the degree in which the SDO analyzes and implements actions to improve processes, based on their opinions of the results; this PA is integrated by 4 indicators taken from the measure process (7.6, 7.7, 7.8, 7.9). The range of variance explained among indicators was from 0.821 to 0.918. The factor explained 79.001 of the total variance; KMO (0.800) and (p = 0.000).

Table 47. Factors PA 5.1 and PA 5.2.

L5 Knowledge Creation	Loading factor
PA 5.1 Institutionalization of the innovation culture in roles	
5.1.1 Roles are motivated to create and/or generate new knowledge (2.5 Acquisition)	0.793
5.1.2 Roles know how to innovate, modify and update procedures and processes (2.6 Acquisition)	0.660
5.1.3 New knowledge is spread throughout the organization (7.5 Measure) (Nonaka, 1994)	0.673
5.1.4 Tools that boost innovation and knowledge creation are used (6.6 Interiorize)	0.767
5.1.5 Explicit sources of knowledge (standards, printed material, meeting records, manuals, etc.) are easy to acquire (2.3 Acquisition)	0.775
5.1.6 New innovative software products are created periodically (2.7 Acquisition)	0.662
KMO	0.798
Bartlette Sig.	0.000
Accumulated variance explained	52.420
PA 5.2 Process optimization	
5.2.1 Improvement goals of quantitative and qualitative processes are defined and documented	0.871
5.2.2 Results of knowledge measurements are analyzed (ISO/IEC 15504, 2011) (7.7 Measure)	0.821
5.2.3 Improvement actions are identified and implemented for best performance and quality of the measured processes (ISO/IEC 15504/02, 2010, CMMI-DEV, 2010) (7.8 Measure)	0.918
5.2.4 Results of the implementation of improvement actions are evaluated (ISO/IEC 15504/02, 2010) (7.9 Measure)	0.941
KMO	0.800
Bartlette Sig.	0.000
Accumulated variance explained	79.001

Testing the hypotheses of SECIKC-SE capability levels

To test the hypotheses (Table 41) of the SECIKC-SE model's influence from the lowest capability level to a higher level, a correlation and regression analysis was performed. The statistically significant level is ($p^{**} > 0.01$ and $p^{*} > 0.05$).

H1. Table 48 shows the PA 1.1 has significant correlated with PA 2.1 (0.757**) (p=0.000) and PA 2.2 (0.758**) (p=0.000). Likewise, PA 1.2 are significant with PA 2.1 (0.525**) (p=0.001) and PA 2.2 (0.446**) (p=0.001). The effect of regression analysis confirm the research hypothesis of the influence from L1 Socialization to L2 Externalization on Models 1 and 2 L1S-L2E (Table 49) the PA 1.1 factor significant influenced PA 2.1 (adjusted R^2=0.566) (p=0.000) and PA 2.2 (adjusted R^2=0.567) (p=0.000). Likewise, on Model 3 and 4 L1S-L2E (Table 49) PA 1.2 significant influenced PA 2.1 (adjusted R^2=0.258) (p=0.001) and PA 2.2 (adjusted R^2=0.186) (p=0.001).

Table 48. Correlation of L1 Socialization and L2 Externalization.

	PA 1.1	PA1.1.1	PA1.1.2	PA1.1.3	PA1.1.4	PA1.1.5	PA1.1.6	PA 1.2	PA 1.2.1	PA1.2.2	PA 1.2.3
PA 2.1	0.757**	0.464**	0.583**	0.677**	0.427**	0.547**	0.619**	0.525**	0.366**	0.344**	0.462**
Sig.	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.006	0.005	0.000
PA 2.2	0.758**	0.494**	0.642**	0.651**	0.453**	0.456**	0.584**	0.446**	.0413**	0.281*	0.284*
Sig.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.005	0.022	0.021

Table 49. Effect of L1 Socialization on L2 Externalization.

Model 1 L1S-L2E: Tacit-Explicit (PA 2.1 Tacit to explicit knowledge conversion)= β_0+ β_1PA1.1							
	β	t	Sig.	R^2	adjusted R^2	F	Sig.
	.757	6.151	.024	0.573	0.566	85.941	.000
Predictor variable: (Constant), PA 1.1 Individuals communicate knowledge							
Dependent variable: PA 2.1 Tacit to explicit knowledge conversion							
Model 2 L1S-L2E: Tacit-Explicit (PA 2.2 Work product management)= β_0+ β_1PA1.1							
	β	t	Sig.	R^2	adjusted R^2	F	Sig.
	.758	9.289	0.000	0.574	0.567	86.283	.000
Predictor variable: (Constant), PA 1.1 Individuals communicate knowledge							
Dependent Variable: PA 2.2 Work product management							
Model 3 L1S-L2E: Tacit-Explicit (PA 2.1 Tacit to explicit knowledge conversion)= β_0+ β_1PA1.2							
	β	t	Sig.	R^2	adjusted R^2	F	Sig.
	0.530	4.936	.000	0.281	0.258	12.325	0.000
Predictor variable: (Constant), PA 1.2 Acquisition of tacit knowledge							
Dependent variable: PA 2.1 Tacit to explicit knowledge conversion							
Model 4 L1S-L2E: Tacit-Explicit (PA 2.2 Work product management)= β_0+ β_1PA1.2							
	β	t	Sig.	R^2	adjusted R^2	F	Sig.
	0.446	2.727	0.000	0.199	0.186	15.882	0.000
Predictor variable: (Constant), PA 1.2 Acquisition of tacit knowledge							
Dependent Variable: PA 2.1 Work product management							

H2. The knowledge flow of L2 Externalization and L3 Combination (Table 50) was a significant correlated from PA 2.1 to PA 3.1 (0.661**) (*p*= 0.000) and PA 3.2 (0.774**) (p=0.000). On the other hand, PA 2.2 was significant with PA 3.1 (0.765**) (p=0.000) and PA 2.2 (0.707**) (*p*=0.000). The regression effect of the knowledge flow from L2 Externalization to L3 Combination on Models 1 and 2 L2E-L3C (Table 51) has significant influenced PA 2.1 to PA 3.1 (adjusted R^2=0.428) (p= 0.000) and PA 3.2 (adjusted R^2=0.593) (p=0.000). Likewise, on Model 3 and 4 L2E-L3C (Table 51) has significant influenced PA 2.2 to PA 3.1 (adjusted R^2=0.578) (p= 0.000) and PA 3.2 (adjusted R^2=0.492) (p=0.000). This leads to the confirmation of the research hypothesis.

Table 50. Correlation of L2 Externalization and L3 Combination.

	PA 2.1	AP 2.1.1	AP 2.1.2	AP2.1.3	AP 2.2.1	PA 2.2	AP2.2.2	AP2.2.3
PA 3.1	0.661**	0.647**	0.563**	0.476**	0.581**	0.765**	0.703**	0.642**
Sig.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PA 3.2	0.774**	0.670**	0.549**	0.724**	0.596**	0.707**	0.517**	0.670**
Sig.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 51. Effect of L2 Exteriorization on L3 Combination.

Model 1 L2E-L3C: Explicit-explicit (PA 3.1 Knowledge assets integration management)= β_0+ β_1PA2.1							
	β	t	Sig.	R^2	R^2 adjusted	F	Sig.
	0.661	7.050	0.000	0.437	0.428	49.697	0.000
Predictor variable: (Constant), PA 2.1 Tacit to explicit knowledge conversion							
Dependent variable: PA 3.1 Knowledge assets integration management							
Model 2 L2E-L3C: Explicit -Explicit (PA 2.1 Conversion tacit-explicit knowledge)= β_0+ β_1PA2.1							
	β	t	Sig.	R^2	R^2 adjusted	F	Sig.
	0.774	9.774	0.000	0.599	0.593	95.532	0.000
Predictors variable: (Constant), PA 2.1 Tacit to explicit knowledge conversion							
Dependent variable: PA 3.2 Application of knowledge assets							

Model 3 L2E-L3C: Explicit-Explicit (PA 3.1 Knowledge assets integration management)= β_0+ β_1PA 2.2							
	β	t	Sig.	R^2	R^2 adjusted	F	Sig.
	0.765	9.490	0.000	0.585	0.578	90.068	0.000
Predictor variable: (Constant), PA 2.2 Work product management							
Dependent variable: PA 3.1 Knowledge assets integration management							

Model 4 L2E-L3C: Explicit-Explicit (PA 3.2 Application of knowledge assets)= β_0+ β_1PA2.2							
	β	t	Sig.	R^2	R^2 adjusted	F	Sig.
	0.707	7.997	0.000	0.500	0.492	63.956	0.000
Predictor variable: (Constant), PA 2.2 Work product management							
Dependent variable: PA 3.2 Application of knowledge assets							

H3. The correlation of L3 Combination to L4 Interiorization (Table 52) was significant from PA 3.1 to PA 4.1 (0.629**) (p= 0.000) and PA 4.2 (0.472**) (p=0.000). As well as PA 4.1 (0.670**) (p=0.000) and PA 4.2 (0.441**) (p=0.000). The hypothesis of the influence of L3 Combination to L4 Interiorization was confirmed by the significant regression effect on Models 1 and 2 L3C-L4I (Table 53) PA 3.1 to PA 4.1 (adjusted R^2=0.386) (p= 0.000) and PA 4.2 (adjusted R^2=0.210) (*p*=0.000. Likewise, with respect to PA 3.2 the regression effect was significant on the Model 3 and 4 L3C-L4I (Table 53) PA 4.1 (adjusted R^2=0.441) (*p*=0.004) and PA 4.2 (adjusted R^2=0.182) (p=0.000).

Table 52. Correlation of L3 Combination and L4 Interiorization.

	PA 3.1	AP 3.1.1	PA 3.1.2	PA 3.1.3	PA 3.1.4	PA 3.2	PA 3.2.1	PA 3.2.2	PA 3.2.3	PA 3.2.4
PA 4.1	0.629**	0.559**	0.491**	0.483**	0.405**	0. 670**	0.221	0.567**	0.501**	0.716**
Sig.	0.000	0.000	0.000	0.000	0.001	0.000	0.075	0.000	0.000	0.000
PA 4.2	0. 472**	0.344**	0.230	0.543**	0.369**	0.441**	0.182	0.353**	0.255*	0.549**
Sig.	0.000	0.005	0.063	0.000	0.002	0.000	0.144	0.004	0.039	0.000

Table 53. Effect of L3 Combination on L4 Interiorization.

Model 1 L3C-L4I: Explicit-Tacit (PA 4.1 Knowledge discussion)= β_0+ β_1AP 3.1							
	β	t	Sig.	R^2	adjusted R^2	F	Sig.
	0.629	6.477	0.000	0.396	0.386	41.949	0.000
Predictor variable: (Constant), PA 3.1 Knowledge assets integration management							
Dependent variable: PA 4.1 Knowledge discussion							

Model 2 L3C-L4I: Explicit-Tacit (PA 4.2 Knowledge measurement)= β_0+ β_1AP 3.1							
	β	t	Sig.	R^2	adjusted R^2	F	Sig.
	0.472	4.280	0.000	0.223	0.210	18.317	0.000
Predictor variable: (Constant), PA 3.1 Knowledge assets integration management							
Dependent variable: PA 4.2 Knowledge measurement							
Model 3 L3C-L4I: Explicit-Tacit (PA 4.1 Knowledge discussion)= β_0+ β_1PA 3.2							
	β	t	Sig.	R^2	adjusted R^2	F	Sig.
	0.670	7.225	0.000	0.499	0.441	52.197	0.000
Predictor variable: (Constant), PA 3.2 Application of knowledge assets							
Dependent variable: PA 4.1 Knowledge discussion							
Model 4 L3C-L4I: Explicit-Tacit (PA 4.2 Knowledge measurement)= β_0+ β_1AP 3.2							
	β	t	Sig.	R^2	adjusted R^2	F	Sig.
	0.441	3.929	0.000	0.194	0.182	15.441	0.000
Variable predictor: (Constant), PA 3.2 Application of knowledge assets							
Variable dependent: PA 4.2 Knowledge measurement							

H4. The correlation of L4 Interiorization to L5 Knowledge creation (Table 54) was significant from PA 4.1 to PA 5.1 (0.749**) (p= 0.000) and PA 4.2 (0.499**) (p=0.000). The PA 4.2 was significant with PA 5.1 (0.536**) (p=0.000) and PA 5.2 (0.883**) (p=0.000). Hence, the research hypothesis was confirmed. The regression effect of L4 Combination to L5 Knowledge creation was significant on Models 1 and 2 L4I-L5KC (Table 55) PA 4.1 to PA 5.1 (adjusted R^2=0.426) (p= 0.000) and PA 4.2 (adjusted R^2=0.275) (p=0.000). Likewise, for PA 4.2 the influence was significant on Models 3 and 4 L4I-L5KC (Table 55) PA 5.1 (adjusted R^2=0.264) (p=0.000) and PA 5.2 (adjusted R^2=0.790) (p=0.000). Hence, the research hypothesis was confirmed.

Table 54. Correlation L4 Interiorization and L5 Knowledge creation.

	PA 4.1	AP 4.1.1	AP 4.1.2	AP4.1.3	AP 4.1.4	AP4.1.5	PA 4.2	AP4.2.1	AP4.2.2	AP4.2.3	AP4.2.4
PA 5.1	0.749**	0.584**	0.646**	0.570**	0.626**	0.525**	0. 536**	0.443**	0.477**	0.463**	0.474**
Sig.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
PA 5.2	0. 499**	0.541**	0.369**	0.399**	0.350**	0.366**	0.883**	0.796**	0.836**	0.730**	0.683**
Sig.	0.000	0.005	0.002	0.001	0.004	0.006	0.000	0.000	0.000	0.000	0.000

Table 55. Effect of L4 Interiorización on L5 Knowledge Creation.

Model 1 L4I-L5KC: Tacit-Knowledge Creation (PA 5.1 Knowledge discussion)= β_0+ β_1AP 4.1							
	β	t	Sig.	R^2	adjusted R^2	F	Sig.
	0.659	7.017	0.000	0.435	0.426	49.239	0.000
Predictor variable: (Constant), PA 4.1 Knowledge discussion							
Dependent Variable: PA 5.1 Knowledge discussion							
Model 2 L4I-L5KC: Tacit-Knowledge Creation (PA 5.2 Process optimization)= β_0+ β_1AP 4.1							
	β	t	Sig.	R^2	adjusted R^2	F	Sig.
	0.535	5.059	0.000	0.286	0.275	25.597	0.000
Predictor variable: (Constant), PA 4.1 Knowledge discussion							
Dependent variable: PA 5.2 Process optimization							
Model 3 L4I-L5KC: Tacit-Knowledge Creation (PA 5.1 Knowledge discussion)= β_0+ $\beta_1$4.2							
	β	t	Sig.	R^2	adjusted R^2	F	Sig.
	0.525	4.932	0.000	0.275	0.264	24.325	0.000
Predictor variable: (Constant), PA 4.2 Knowledge measurement							
Dependent variable: PA 5.1 Knowledge discussion							
Model 4 L4I-L5KC: Tacit-Knowledge Creation (PA 5.2 Process optimization)= β_0+ $\beta_1$4.2							
l	β	t	Sig.	R^2	adjusted R^2	F	Sig.
	0.891	15.661	0.000	0.793	0.790	245.276	0.000
Predictor variable: (Constant), PA 4.2 Knowledge measurement							
Dependent variable: PA 5.2 Process optimization							

H5. The correlation of Knowledge creation and Socialization (Table 56) was significant from PA 5.1 to PA 1.1 (0.725**) (p= 0.000) and PA 1.2 (0.370**) (p=0.002). PA 5.2 was significant with PA 1.1 (0.586**) (p=0.000) and PA 5.2 (0.369**) (p=0.002). The influence from L5 Knowledge creation to L1 Socialization (Table 52) was significant on the regression effect in Models 1 and 2 L5KC-L1S (Table 57), PA 5.1 to PA 1.1 (adjusted R^2=0.519) (p= 0.000) and PA 1.2 (adjusted R^2=0.123) (p=0.002). Likewise, with respect to PA 5.2 the influence was significant on the Models 3 and 4 L5KC-L1S (Table 57) PA 1.1 (adjusted R^2=0.333) (p=0.000) and PA 5.2 (adjusted R^2=0.123) (p=0.002).

Table 56. Correlation L5 Knowledge creation and L1 Socialization.

	PA 5.1	AP 5.1.1	AP 5.1.2	AP5.1.3	AP 5.1.4	AP5.1.5	AP5.1.6	PA 5.2	AP5.2.1	AP5.2.2	AP5.2.3	AP5.2.4
PA 1.1	0.725**	0.620**	0.437**	0.572**	0.545**	0.588**	0.368**	0.586**	0.484**	0.405**	0.614**	0.568**
Sig.	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.001	0.000	0.000
PA 1.2	0.370**	0.304*	0.415**	0.389**	0.295*	0.083	0.144	0.369**	0.364**	0.164	0.436**	0.335**
Sig.	0.002	0.013	0.001	0.001	0.016	0.505	0.250	0.002	0.003	0.187	0.000	0.006

Table 57. Effect of L5 Knowledge Creation on L1 Socialization

Model 1 L5KC-L1S: Knowledge Creation-Tacit (PA 1.1 Individuals communicate knowledge)= β_0+ β_1AP 5.1							
	β	t	Sig.	R^2	R^2 adjusted	F	Sig.
	0.725	8.433	0.000	0.526	0.519	71.115	0.000
Predictor variable: (Constant), PA 5.1 Institutionalization of the innovation culture in roles							
Dependent variable: PA 1.1 Individuals communicate knowledge							
Model 2 L5KC-L1S: Knowledge Creation-Tacit (PA 1.2 Acquisition of tacit knowledge)= β_0+ β_1AP 5.1							
	β	t	Sig.	R^2	R^2 adjusted	F	Sig.
	0.370	3.182	0.000	0.137	0.123	10.125	0.002
Predictor variable: (Constant), PA 5.1 Institutionalization of the innovation culture in roles							
Dependent variable: PA 1.2 Acquisition of tacit knowledge							

Model 3 L5KC-L1S: Knowledge Creation-Tacit (PA 1.1 Individuals communicate knowledge)= β_0+ β_1AP 5.2							
	β	t	Sig.	R^2	R^2 adjusted	F	Sig.
	0.586	5.788	0.000	0.344	0.333	33.505	0.000
Predictor variable: (Constant), PA 5.2 Process Optimization							
Dependent variable: PA 1.1 Individuals communicate knowledge							
Model 4 L5KC-L1S: Knowledge Creation-Tacit (PA 1.2 Acquisition of tacit knowledge)= β_0+ β_1AP 5.2							
	β	t	Sig.	R^2	R^2 adjusted	F	Sig.
	0.369	3.179	0.000	0.136	0.123	10.107	0.002
Predictor variable: (Constant), PA 5.2 Process Optimization							
Dependent variable: PA 1.2 Acquisition of tacit knowledge							

6.5 Research findings in the case study

6.5.1 SECIKC-SE Capability Level detail

During results generation, the data collected was processed to determine the measurement of the process capability level; statistical methods of frequencies and central tendency were used. The implementation degree for each indicator is obtained from the frequency and percentage in which each team member assessed them using the scales N (SD-2, D-1), P (N-3), L (D-4), and F (SA-5) (see Table 66 Appendix A). The rating of each indicator was defined using the mean as a unit of measure based on the frequencies given by equation (1). The measurements of the PA ratings are the mean of each indicator given by equation (2).

$$\text{Rating Indicador} = \mu \quad \left(\sum_{e1}^{n} \boldsymbol{I}\right) \qquad (1)$$

$$\text{Rating PA} = \mu \quad \left(\sum_{e1}^{n} \boldsymbol{PA}\right) \qquad (2)$$

L1 Socialization

Ratings for *PA 1.1 Individuals communicate knowledge* in all SDOs were L (Table 58) (Figure 12). The highest PA rating was found in SDO B (4.28) and the lowest in SDO D (3.50). The *1.1.3* indicator was the highest rated for SDO B (4.69) and SDO A (4.50). The *1.1.5* indicator was the lowest rated for SDO D (2.88), A (3.50), and E (3.20). The *1.1.4* indicator had the lowest rating for SDO B (3.77). The *1.1.1* indicator was the highest rated for SDO C (4.24), D (4.19), and E (4.50). The *1.1.2* indicator was the lowest rated for SDO C (3.76). The *1.1.4* indicator had the lowest rating for SDO A (3.50), D (2.88), and E (3.20).

Ratings for *PA 1.2 Knowledge acquisition* in all SDOs were L (Table 58) (Figure 12). The highest PA rating was found in SDO B and C (4.13) and the lowest in SDO C (3.73). The *1.2.3* indicator had the highest rating for SDO A (4.50), B (4.23), C (4.10) and E (4.30). The *1.2.1* indicator was the highest rated for SDO D (3.88) and E (4.30). The *1.2.3* indicator had the lowest rating for SDO A (3.67), B (4.00), C (3.29), and E (3.80). The *1.2.3* indicator was the lowest rated for SDO C (3.69).

Table 58. PA Ratings for L1 Socialization.

L1 Socialization	**A**	**B**	**C**	**D**	**E**	**Indicator mean**
PA 1.1 Individuals communicate knowledge						
1.1.1	4.50	4.38	4.24	4.19	4.50	4.36
1.1.2	4.17	4.23	3.76	3.44	4.20	3.96
1.1.3	4.50	4.69	4.19	3.88	4.20	4.29
1.1.4	4.33	3.77	4.10	3.56	3.60	3.87
1.1.5	3.50	4.31	3.81	2.88	3.20	3.54
1.1.6	4.33	4.31	4.10	3.06	4.00	3.96
Rating PA	**4.22**	**4.28**	**4.03**	**3.50**	**3.95**	**4.00**
PA 1.2 Acquisition of tacit knowledge						
1.2.1	3.83	4.15	3.81	3.88	4.30	3.99
1.2.2	3.67	4.00	3.29	3.88	3.80	3.73
1.2.3	4.50	4.23	4.10	3.69	4.30	4.16
Rating PA	**4.00**	**4.13**	**3.73**	**3.81**	**4.13**	**3.96**

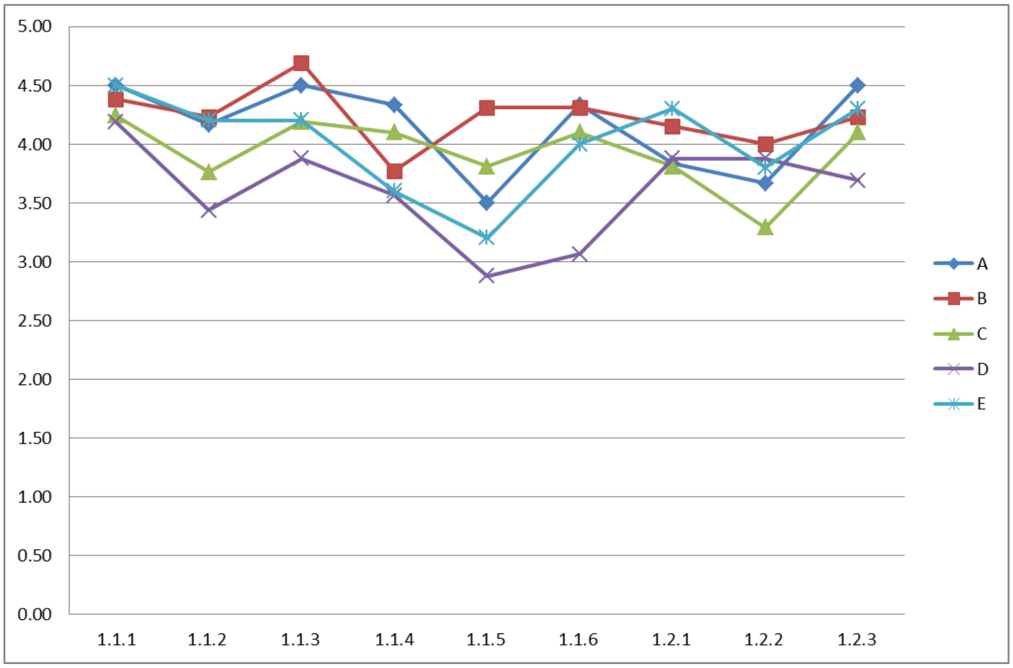


Figure 12 Ratings for indicators PA 1.1 and PA 1.2.

L2 Externalization

Ratings for the PA 2.1 *Tacit to explicit knowledge conversion* in all SDOs were L (Table 59, Figure 13). The highest PA rating was found in SDO B and C (4.44) and the lowest in SDO D (3.56). The *2.1.3* indicator had the highest rating for SDO A (4.67), however, the lowest rating for SDO B (4.31) and D (3.31). The *2.1.1* indicator was the highest rated for SDO B (4.54), C (4.05), D (3.75), and case E (4.11), and the lowest for SDO A (4.00).

Ratings for the PA 2.2 *Work product management* in all SDOs were L (Table 59, Figure 13). The highest PA rating was found in SDO B (4.18) and the lowest in SDO D (3.37). The *2.2.3* indicator was the highest rated for SDO E (4.60) and C (4.00). *2.2.1* had the highest rating for SDO A (4.33), B (4.46), and D (3.56). *2.2.2* was the lowest rated for all SDOs.

Table 59. PA Ratings for L2 Externalization.

L2 Externalization	A	B	C	D	E	Indicator mean
PA 2.1 Tacit to explicit knowledge conversion						
2.1.1	4.00	4.54	4.05	3.75	4.20	4.11
2.1.2	4.50	4.46	3.86	3.63	3.90	4.07
2.1.3	4.67	4.31	3.90	3.31	4.00	4.04
Rating PA	**4.39**	**4.44**	**3.93**	**3.56**	**4.03**	**4.07**
PA 2.2 Work product management						
2.2.1	4.33	4.46	3.95	3.56	4.10	4.08
2.2.2	3.83	3.77	3.48	3.06	3.70	3.57
2.2.3	4.17	4.31	4.00	3.50	4.60	4.11
Rating PA	**4.11**	**4.18**	**3.81**	**3.37**	**4.13**	**3.92**

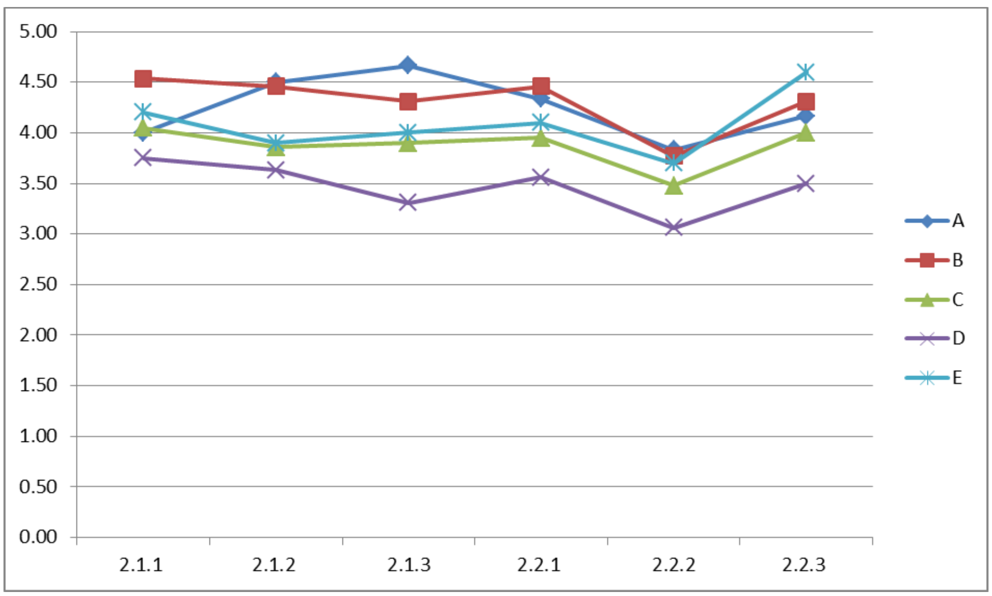


Figure 13 Ratings for the indicators PA 2.1 and PA 2.2.

L3 Combination

Ratings for the PA *3.1 Knowledge assets integration management* in all SDOs were L (Table 60) (Figure 14). The highest PA rating was found in SDO B (4.00) and the lowest in SDO D (3.40). The *3.1.3* indicator had the highest rating for SDO B (4.23), A (4.17), and E (4.20). The *3.1.1* indicator was the lowest rated for SDO D (3.13) and A (3.17). The *3.1.4* indicator had the highest rating for SDO E (4.20), A and C (4.00), and D (3.63); however, it was the lowest for SDO B (3.69). The *3.1.2* indicator was the lowest rated for SDO C (3.48) and E (3.70).

Ratings for PA *3.2 Application of knowledge assets* in all SDOs were L (Table 60) (Figure 14). The highest PA rating was found in SDO A (4.33) and the lowest in SDO D (3.61). The *3.2.3* indicator had the highest rating for SDO B (4.54) and A (4.50). The *3.2.4* indicator was the lowest rated for all SDOs. The *3.2.1* indicator had the highest rating for SDO C (3.81) and E (4.30). The 3.2.2 indicator was the highest rated for SDO C (4.29).

Table 60. PA Ratings for L3 Combination.

L3 Combination	A	B	C	D	E	Indicator mean
PA 3.1 Knowledge assets integration management						
3.1.1	3.17	3.92	3.62	3.13	3.80	3.53
3.1.2	3.33	4.15	3.48	3.38	3.70	3.61
3.1.3	4.17	4.23	3.90	3.44	4.20	3.99
3.1.4	4.00	3.69	4.00	3.63	4.20	3.90
Rating PA	**3.67**	**4.00**	**3.75**	**3.40**	**3.98**	**3.76**
PA 3.2 Application of knowledge assets						
3.2.1	4.33	4.23	3.86	3.81	4.30	4.11
3.2.2	4.33	4.15	4.29	3.75	4.10	4.13
3.2.3	4.50	4.54	4.24	3.50	4.20	4.20
3.2.4	4.17	3.92	3.81	3.38	3.60	3.78
Rating PA	**4.33**	**4.21**	**4.05**	**3.61**	**4.05**	**4.05**

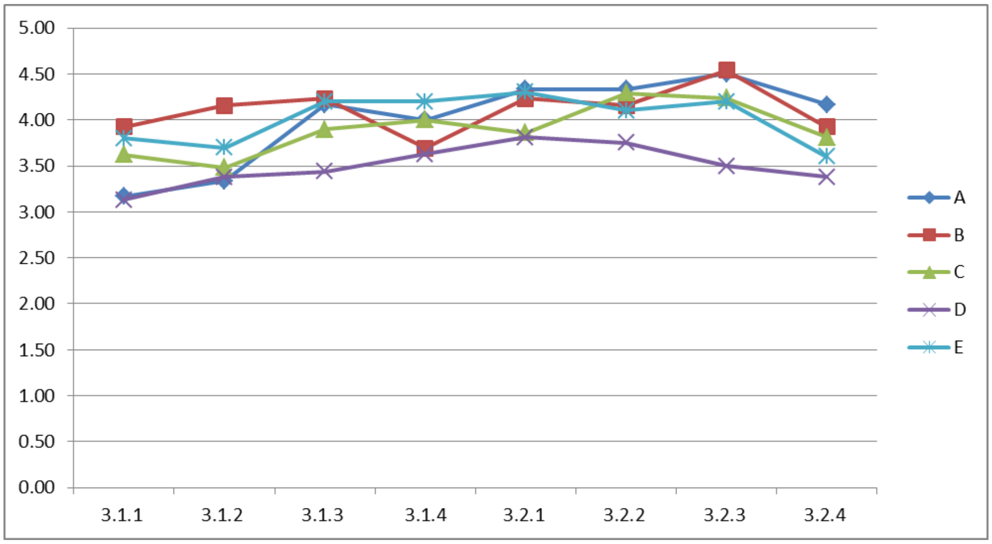


Figure 14. Ratings for indicators PA 3.1 and PA 3.2.

L4 Interiorization

Ratings for PA *4.1 Knowledge discussion* for all SDOs were L (Table 61, Figure 15). The highest PA rating was found in SDO A (4.27) and the lowest in SDO E (3.60) very close to SDO D (3.63). The *4.1.5* indicator was the highest rated for SDO B (4.62) and the rest of the SDOs. The *4.1.2* indicator was the lowest rated for SDO E (3.20), B (3.92), and C (3.76). The *4.1.1* indicator had the highest rating for SDO C (4.00) and the lowest for SDO A (4.00) and C (3.25). The *4.1.3* indicator had the lowest rating for SDO C (3.76). The *4.1.4* indicator had the highest rating for SDO A (4.50) tied with the *4.1.5* (4.50) indicator.

Ratings for PA *4.2 Knowledge measurement* for all SDOs were L (Table 61, Figure 15). The highest PA rating was found in SDO E (3.65) and the lowest in SDO C (3.17). The *4.2.2* indicator had the highest rating for SDO E (4.00), A (3.50), B (3.69), and D (3.38). The *4.2.1* indicator had the lowest rating for SDO C (2.95). The *4.2.3* indicator had the highest rating for SDO C (3.33) and the lowest for SDO B (2.54) and D (3.13). Finally, the *4.2.4* indicator had the lowest rating for SDO A (3.16) and E (3.40).

Table 61. PA Ratings for L4 Combination.

L4 Combination	A	B	C	D	E	Indicator mean
PA 4.1 Knowledge discussion						
4.1.1	4.00	4.46	4.00	3.25	3.90	3.92
4.1.2	4.17	3.92	3.76	3.88	3.20	3.79
4.1.3	4.17	4.15	3.76	3.56	3.50	3.83
4.1.4	4.50	4.08	3.81	3.56	3.40	3.87
4.1.5	4.50	4.62	4.00	3.88	4.00	4.50
Rating PA	**4.27**	**4.25**	**3.87**	**3.63**	**3.60**	**3.92**
PA 4.2 Knowledge measurement						
4.2.1	3.33	3.46	2.95	3.19	3.50	3.29
4.2.2	3.50	3.69	3.14	3.38	4.00	3.54
4.2.3	3.33	2.54	3.33	3.13	3.70	3.21
4.2.4	3.16	3.77	3.24	3.19	3.40	3.35
Rating PA	**3.33**	**3.37**	**3.17**	**3.22**	**3.65**	**3.35**

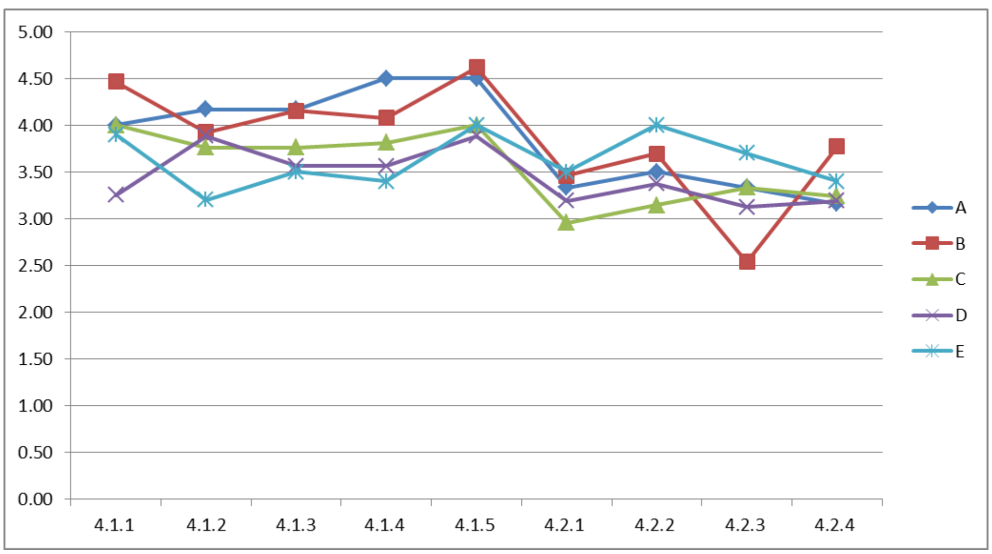


Figure 15. Ratings for the indicators PA 4.1 and PA 4.2.

L5 Knowledge Creation

Ratings for PA *5.1 Institutionalization of the innovation culture in roles* in all SDOs were L (Table 62, Figure 16). The highest PA rating was found in SDO A and C (3.78) and the lowest in SDO D (3.32). The *5.1.1* indicator had the highest rating for SDO C (4.24), A (4.17), and E (4.00). The *5.1.2* indicator had the highest rating for SDO D (3.63); however was the lowest rated for SDO B (3.77) and E (3.40). The *5.1.3* indicator had the lowest rating for SDO A (3.50), C (3.10), and D (2.81). The *5.1.4* indicator had the lowest rating for SDO A (3.50) and B (3.77). The *5.1.5* indicator had the highest rating for SDO B (4.00). The *5.1.6* indicator had the highest rating for SDO A (3.66) and the lowest for SDO B (2.85).

Ratings for PA *5.2 Process optimization* in all SDOs were L (Table 62, Figure 16). The highest PA rating was found in SDO A (3.87) and the lowest in SDO D (3.73). The *5.2.3* indicator had the highest rating for SDO A (4.16) and D (4.10). The *5.2.1* indicator had the highest rating for SDO B (3.69) and D (3.63). The indicator *5.2.2* was the highest rated for SDO D (3.40); while it was the lowest rated for SDO A (3.33) and C (3.14). The indicator *5.2.3* had the lowest rating for SDO D (3.25). The *5.2.4* indicator had the highest rating for SDO A (4.00) and E (3.90).

Table 62. PA Ratings for L5 Knowledge Creation.

L5 Knowledge Creation	A	B	C	D	E	Indicator mean
PA 5.1 Institutionalization of the innovation culture in roles						
5.1.1	4.17	3.92	4.24	3.25	4.00	3.92
5.1.2	4.00	3.77	3.71	3.63	3.40	3.70
5.1.3	3.50	3.38	3.10	2.81	3.70	3.30
5.1.4	3.50	3.77	3.76	3.50	3.50	3.61
5.1.5	3.83	4.00	4.19	3.44	3.70	3.83
5.1.6	3.66	2.85	3.43	3.31	3.30	3.31
Rating PA	**3.78**	**3.62**	**3.74**	**3.32**	**3.60**	**3.61**
PA 5.2 Process optimization						
5.2.1	4.00	3.69	3.29	3.63	3.50	3.62
5.2.2	3.33	3.08	3.14	3.06	3.40	3.20
5.2.3	4.16	3.62	3.52	3.00	4.10	3.68
5.2.4	4.00	3.62	3.48	3.25	3.90	3.65
Rating PA	**3.87**	**3.50**	**3.36**	**3.23**	**3.73**	**3.54**

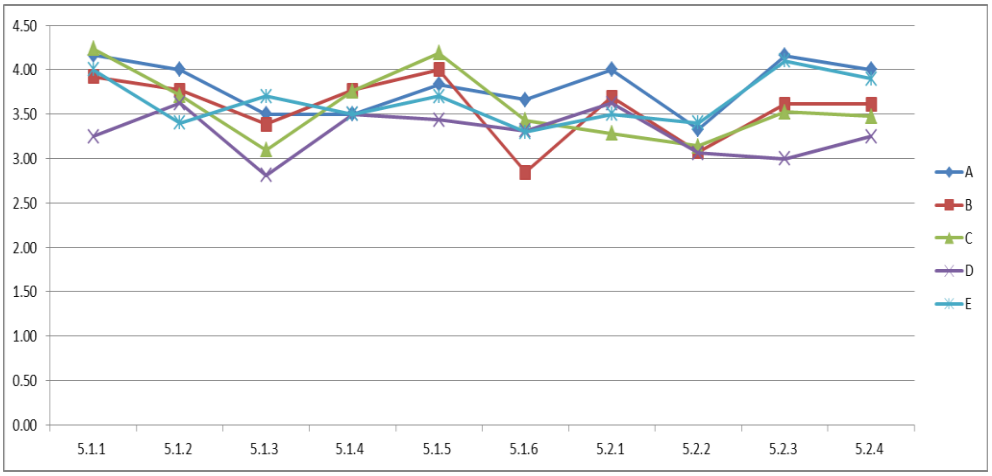


Figure 16 Ratings for the indicators PA 5.1 and PA 5.2.

6.5.2 Process capability level profile SECIKC-SE

Continuing with results generation, the capability profile was obtained according to section 6.1.2 (Table 36). The results of the SECIKC-SE capability profile for each SDO are presented in Table 63. It was revealed that capability of all SDOs corresponds to L1 Socialization. Since none of the ratings for *PA 1.1 Individuals communicate the knowledge* or *PA 1.2 Acquisition of tacit knowledge* were F, then there is no compliance with the guideline profile, which requires that both previous PA levels to be F in order to reach the next level.

Having a lower level does not mean that PA indicators of higher level could not achieve F, As SDO A and B on PA 2.1 and SDO A in PA 3.2. However, when the PA of previous levels has not reached F, there are still opportunities for improvement, in order to reduce the gap in such a way that SDOs can implement the practices that lead them to reach higher levels.

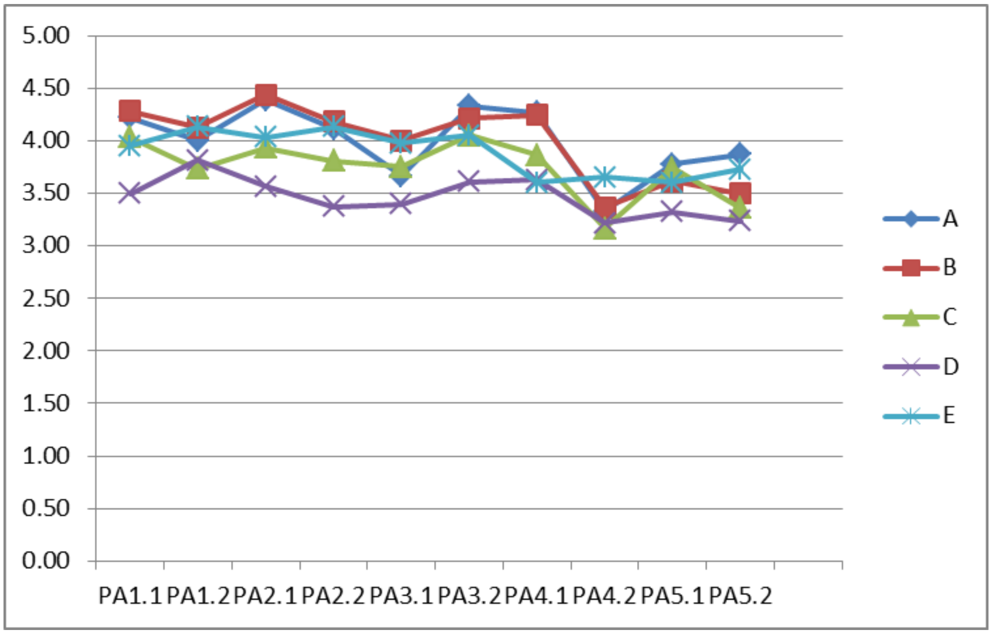
Figure 17a shows a behavior comparison among SDOs relating the PA ratings. SDO B obtained the highest ratings on PA 1.1 (4.28), PA 1.2 (4.13), PA 2.1 (4.44), PA 2.2 (4.18), and PA 3.1 (4.00); PA 3.2 (4.21) was close to SDO A (4.27) which had the highest rating. SDO A ranked second place also, close to SDO B in PA 1.1 (4.22), PA 2.1 (4.39); also obtained the highest rating in PA 3.2 (4.33), PA 4.1 (4.27), PA 5.1 (3.78) and PA 5.2 (3.87). SDO E ranked third place, despite obtaining the highest rating on PA 4.2 (3.65) and tied the rating in PA 1.2 (4.13) with SDO B. SDO C ranked fourth place, obtained the highest ratings on PA 4.1 (3.87) and PA 5.1 (3.74), and in PA 3.2 (4.05) was tied with SDO E. Finally, SDO D was ranked fifth place, but in PA 1.2 (3.81) was higher than SDO C (3.73) and in PA 4.1 (3.63) was higher than SDO E (3.60). Figure 17b shows the same information in a radial graph, notably SDO B had higher ratings on PA 1.1, PA 1.2, PA 2.1, PA 2.2, PA 3.1, PA 3.2, and PA 4.1 in relation to the others SDO. SDO B had higher ratings on PA 3.2, PA 5.1, and PA 5.2; SDO C had higher ratings than SDO D and E in PA 4.1 and higher ratings on PA 5.1 than SDO B, D, and E.

The detailed behavior of each SDO is presented in Figure 18. It can be seen that all five SDOs obtained the lowest ratings in PA 3.1, as well as, PA 4.2, PA 5.1 and PA 5.2. Furthermore, SDO C and D have the most incidences of lower ratings across L1 Socialization to L5 Knowledge creation, ranging from 3.22 to 4.05.

Table 63. Capability profile SECIKC-SE.

SDO	N1 Socialization				N2 Externalization				N3 Combination				N4 Interiorization				N5 Knowledge creation			
	PA 1.1		PA 1.2		PA 2.1		PA 2.2		PA 3.1		PA 3.2		PA 4.1		PA 4.2		PA 5.1		PA 5.2	
A	4.22	**L**	4.00	**L**	4.39	F	4.11	L	3.67	L	4.33	F	4.27	L	3.33	L	3.78	L	3.87	L
B	4.28	**L**	4.13	**L**	4.44	F	4.18	L	4.00	L	4.21	L	4.25	L	3.37	L	3.62	L	3.50	L
C	4.03	**L**	3.73	**L**	3.93	L	3.81	L	3.75	L	4.05	L	3.87	L	3.17	L	3.74	L	3.36	L
D	3.50	**L**	3.81	**L**	3.56	L	3.37	L	3.40	L	3. 61	L	3.63	L	3.22	L	3.32	L	3.23	L
E	3.95	**L**	4.13	**L**	4.03	L	4.13	L	3.98	L	4.05	L	3.60	L	3.65	L	3.60	L	3.73	L

a) PA ratings for each SDO.



b) PA ratings for each SDO.

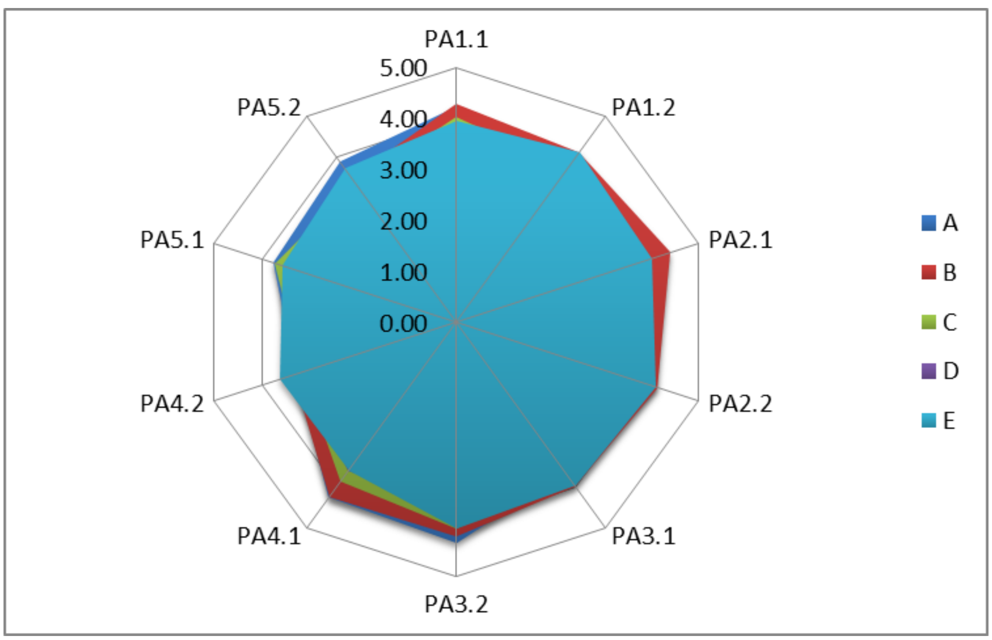


Figure 17. Comparison among SDO capability process profile.

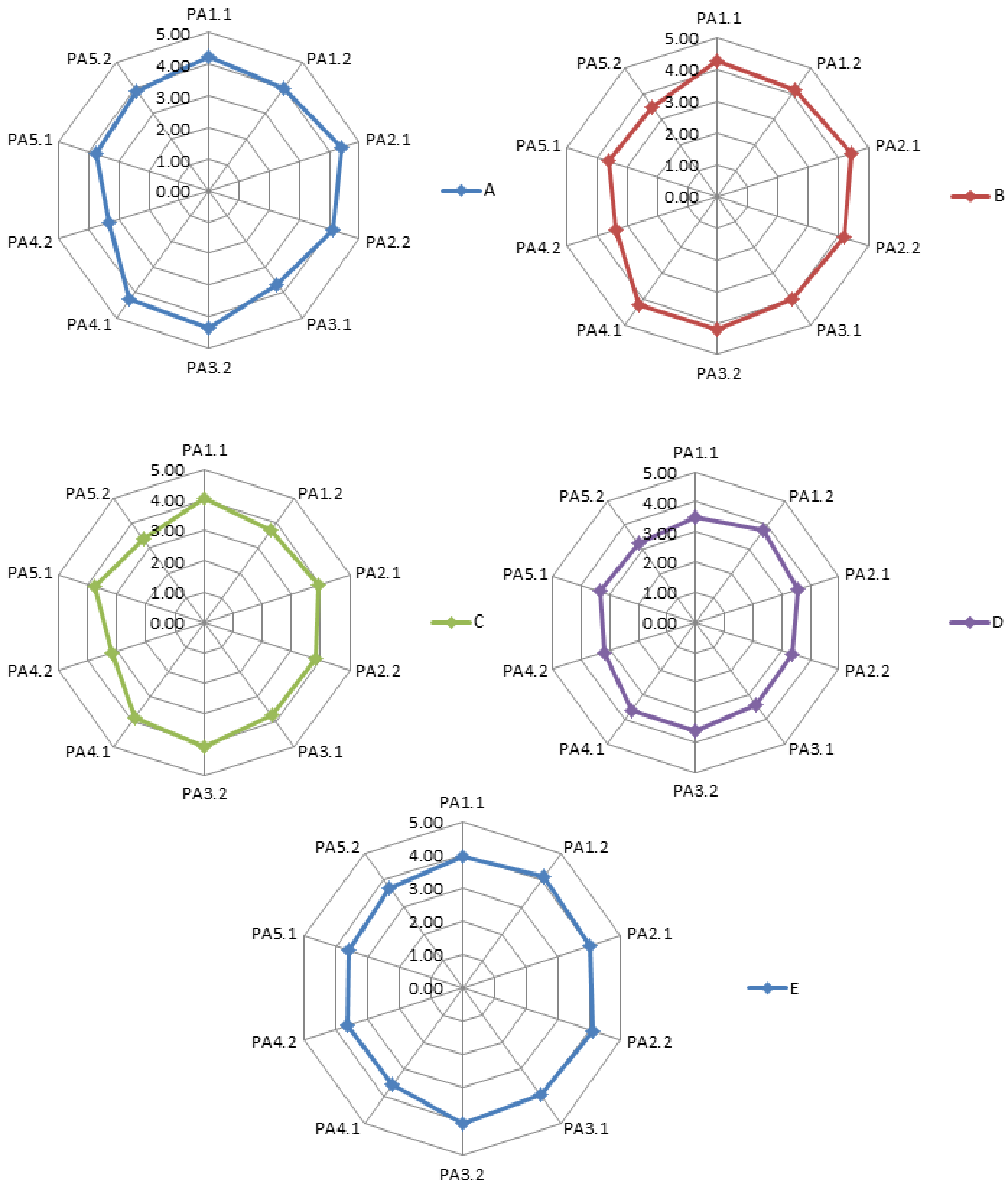


Figure 18. Capability process profile for each SDO.

Finally, during the results submittal, a Report with the results was submitted to all SDO Sponsors and SPI Responsibles. Most feedback comments were of approval of the results obtained. Socialization as a capability level gave them a new perspective about the importance of communicating and acquiring tacit knowledge among roles. Furthermore, SDOs certified in ML2 and ML3 realized that L5 Knowledge creation is a reachable goal. However, upon reflecting on the results of previous levels and specifically on L5, they also realized that the degree of implementation to motivate the creation of new knowledge was L, but the spread of new knowledge and the creation of innovative software products obtained a lower degree of implementation.

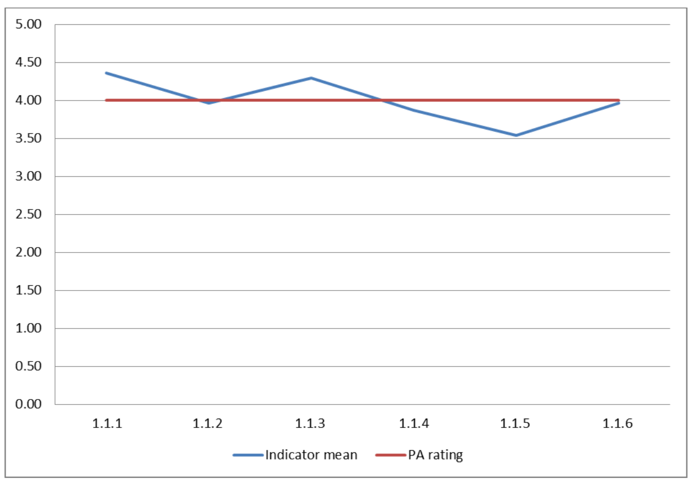
The SDO with (ML5) had strong opinions since they expected to achieve a higher level in knowledge processes. Some comments were: a) knowledge about goals and process indicators should be a concern for the person responsible for them or for management personnel; b) since all processes and products are finally managed, socialization among team members should be less; c) not all roles should be required to know everyone else's skills, and this knowledge should be a concern for the project leader; and d) self-assessment could be reinforced with an interview, similar to SCAMPI, to verify the objectivity of the team members' assessments. However, the scope of ML5 must include a deeper involvement of the team members in order to implement best practices in process areas as well as the necessary improvement measures. Similarly, other SDO leaders were asked for their opinion about the need for a direct interview with the assessing team members, and they stated they were confident about the assessment being objective.

6.6 Discussions

The quantitative validation of the content of the SECIKC-SE model from the factor analysis showed that the correlation of the measured indicators reasonably -i.e. statistically significant- explains the purpose of each of the ten factors. On the other hand, the five research hypotheses proved how the influence of knowledge flows from lower capability levels to high levels statistically is significant, so it was confirmed as an incremental capability model. The SECIKC-SE capability process assessment model and measurement framework supported by a set of KM and SE indicators characterized by capability levels established a comparable measurement between both disciplines. The use of quantitative scale ratings adapted from ISO/IEC 15504/02 (2010) provided higher precision and objectivity to measure the evidence than the scale provided by SCAMPI-MDD (2014).

The measurement results demonstrated that both TK and EK have achieved at least an L rating at all levels. There are three PA with F rating and no PA with N or P. However, all five SDOs reached *L1 Socialization*, so knowledge management practices implementation is not consistent with their maturity level. The discussion of the results of the degree in which each indicator influenced, was established taken as a comparison parameter over the degree of implementation above or below the mean rating achieved by PA (Table 58-62), and the existing gap to reach the upper limit scale rating (Table 35). In L1 Socialization, it was found that mainly in *PA 1.1 Individuals communicate knowledge* (4.00) (Figure 19a) there are weaknesses in the implementation of indicators *1.1.4* (3.87) and *1.1.2* (3.96) for TK to communicate internally between individuals and in the indicators *1.1.*5 (3.54) and *1.1.6* (3.96) to communicate externally to the organization. On the other hand, the indicators with the highest degree of implementation were *1.1.1* (4.36) and *1.1.3* (4.29). In *PA 1.2 Acquisition of tacit knowledge* (3.96) (Figure 19b), weaknesses were found in the acquisition of tacit knowledge from the interaction with other roles *1.2.2* (3.73), as well as access to knowledge owned by others *1.2.1* (3.99).

a) PA 1.1 indicators.



b) PA 1.2 indicators.

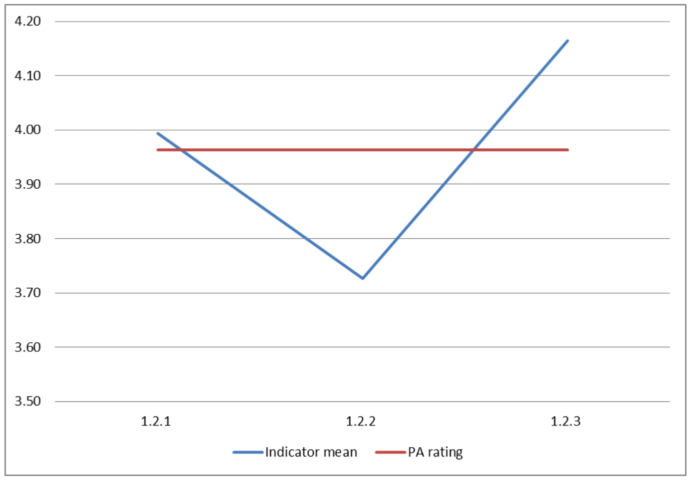
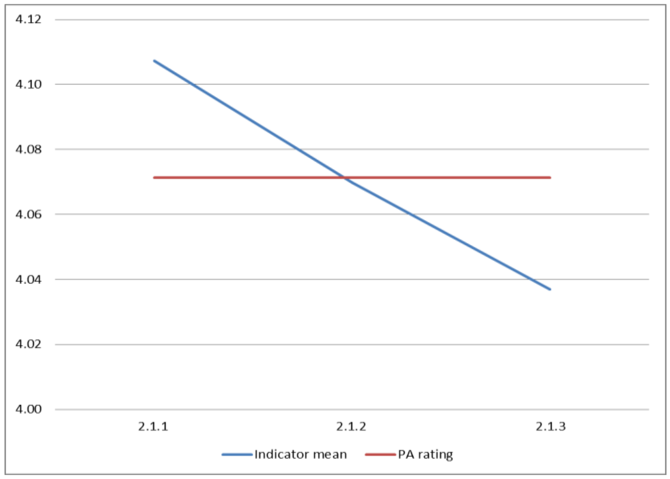


Figure 19. Comparison of PA 1.1 and 1.2 indicators based on the PA rating.

In L2 Externalization from TK to EK conversion, it was observed that in *PA 2.1 Tacit to explicit knowledge conversion* (4.07) (Figure 20a), the mean of all three indicators that integrated it was very close. The first two look to formalize the documentation of implicit knowledge *2.1.1* (4.11) and the third one is about project requirements and characteristics *2.1.2* (4.07). In particular, SDO A and B obtained a level F. This is assumed since all SDOs are certified in at least ML2 and must provide evidence of keeping specifications documented and managed. However, three of the SDOs, including one (ML3) and one (ML5), have a PA achievement of L. The higher achievement results in PA 2.1 in SDO A (4.39) and B (4.44) than PA in L1 Socialization, was deduced from the implementation of indicator *2.1.3*, regarding the assessment about the right combination of team members skills (4.04). Given that it is a characteristic of ML2 that project teams must follow the process even in times of crisis (Table 8) (CMMI-DEV 1.3, 2010). Analyzing the characteristics of these two studies, SDO A is composed of a small team with six members with well-defined skills. While SDO B was in the middle of an intense process of ML3 implementation, so their strategy was to assemble a team with the strongest combination of skills. In SDO C, 52% of employee seniority was less than one year with a rating of (3.90) which prevented the team members from realizing if they had the right combination of skills. In *PA 2.2 Work product management* (3.92) (Figure 20b), the indicator with the highest weakness in its implementation was *2.2.2* (3.57) due to the lack of best practices to document lessons learned in real time. The indicator *2.2.1* (4.08) about the formal and systematic capture of requirements was above the mean of the PA achievement, however, in SDO C (3.95) and D (3.56) it was the least implemented.

a) PA 2.1 indicators.



b) PA 2.2 indicators.

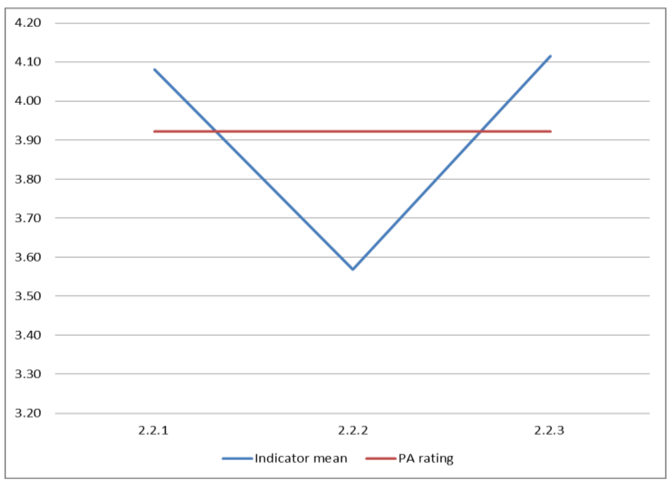
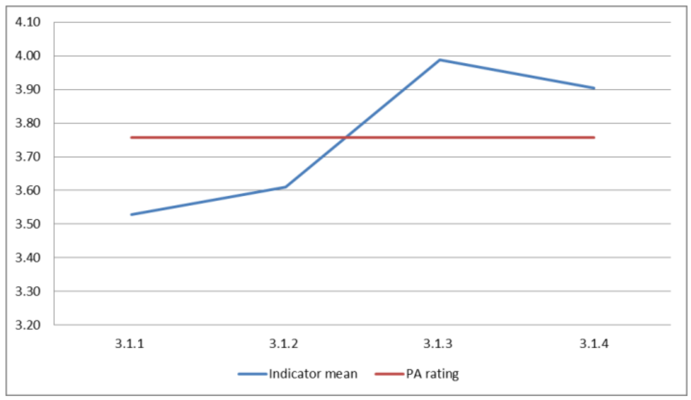


Figure 20. Comparison of PA 2.1 and PA 2.2 indicators based on PA rating.

In L3 Combination in *PA 3.1 Knowledge assets integration management* (3.76) (Figure 21a) it was observed that *3.1.1* aimed at the integration and organization of documents in real time obtained the lowest degree of implementation within the three SDOs A (3.17), C (3.62) and D (3.13). The next indicator with the lowest degree of implementation was 3.1.2 (3.61) about the existence of a person responsible for storing and maintaining the assets. This result was due to ratings in SDO A (3.33), C (3.48) and, D (3.38). On the other hand, the indicator *3.1.3* (3.99) on the existence of documented procedures to guide the work was the lowest in SDO D (3.44) and C (3.90). Especially in this indicator, comments such as "*No procedure is updated or documented, and I am not sure that they are documented or where to find them*" were received. Results for *PA 3.2 Knowledge application* (4.05) (Figure 21b) showed that indicator 3.2.4 regarding the application of existing knowledge in the knowledge bases in the practice of work (3.78) remained below the mean of the PA achievement. SDO A was the one with the highest implementation (4.17), while the indicator with the highest degree of implementation was 3.2.3 about the knowledge that roles have on the sources or types of knowledge necessary to perform the tasks (4.20). Thus, it shows a gap between knowing what types of knowledge to use and applying them in practice.

a) PA 3.1 indicators.



b) PA 3.2 indicators.

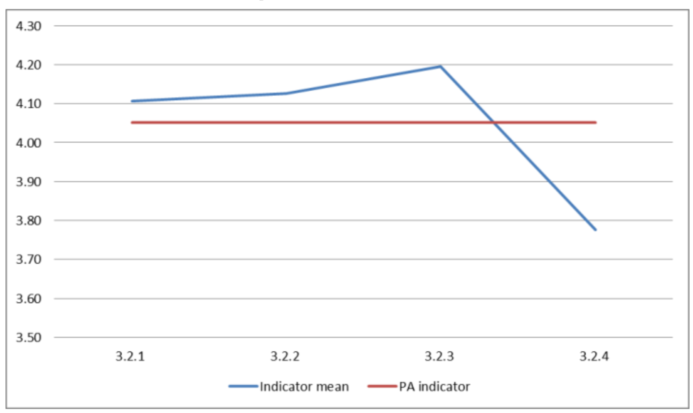
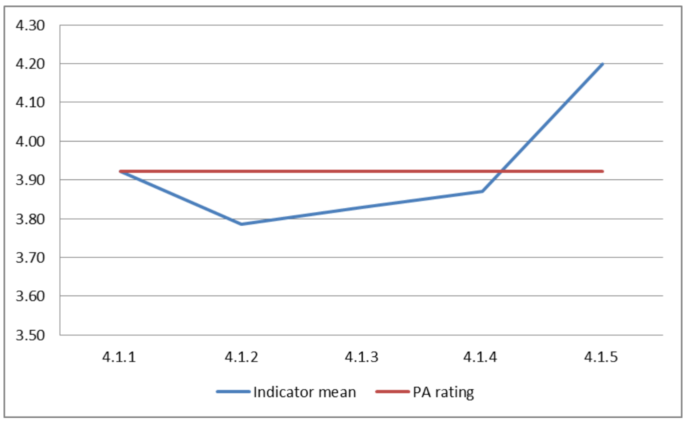


Figure 21. Comparison of PA 3.1 and PA 3.2 indicators based on the PA rating.

In L4 Interiorization, *PA 4.1 Knowledge discussion* (3.92) (Figure 22a) the indicator that presented a lower degree of implementation was *4.1.2* (3.79) followed by *4.1.3* (3.83) and *4.1.4* (3.87), all three indicators with the purpose to create discussions at the beginning, during and at the end of the project using the documentation prepared at each stage of the development cycle. This confirms the lack of application of the documents created to maintain traceability requirements. The SDO that presented less implementation in these three indicators were C, D, and E. In *PA 4.2 Knowledge measurement* (3.35) (Figure 22b), the indicator with the lowest degree of implementation was *4.2.3* (3.21) about if the top management knows how much the staff learned in the past year and the indicator *4.2.1* concerning the existence of the indicators to measure the knowledge of the organization (3.29). In contrast, indicator *4.2.2* concerning the measure and evaluation of knowledge for each member of the organization was the highest implemented (3.54). This means that these evaluations for project team members do not represent how SDOs evaluate how much they have learned and improved their daily activities. The degree of indicators implementation was lower than previous levels; for example, the indicator *4.2.1* (2.95). But it was denoted that the SDO (ML5) obtained the highest degree of implementation (3.65); however, due to their maturity, the degree of achievement could be higher, like SDO (ML3) that obtained an achievement (3.22).

a) PA 4.1 indicators.



a) PA 4.2 indicators.

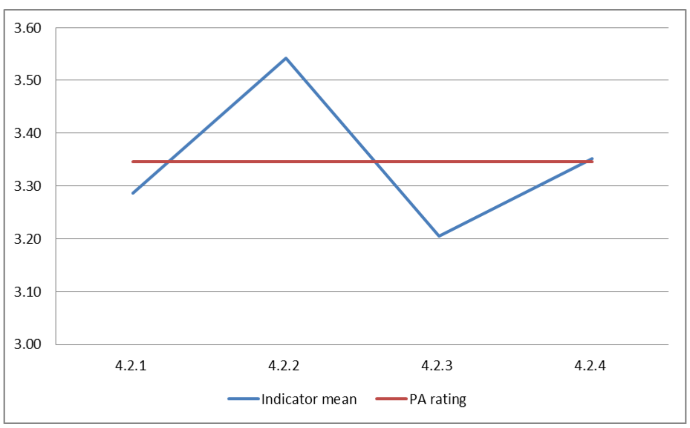
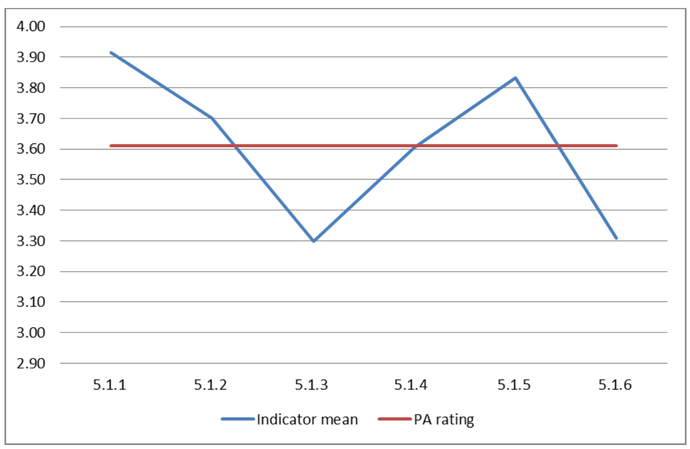


Figure 22. Comparison of PA 4.1 and 4.2 indicators based on the PA rating.

In L5 Creation of knowledge (Figure 23a) the *PA 5.1 Institutionalization of the culture of innovation in roles* (3.60), shows that the degree of implementation in SDOs was also low compared to previous levels except in PA 4.2. The indicator *5.1.3* Spread of new knowledge throughout the organization was the one with the lowest degree of implementation (3.30), followed very closely by *5.1.6* about new innovative software products that are created periodically (3.31). However, indicator *5.1.1* which covers the motivation to create new knowledge obtained the highest degree of implementation (3.92). This means that the motivation exists but is not addressed to create new innovative products. In *PA 5.2 Process optimization* (3.54) (Figure 23b) the indicator with the lowest degree of implementation was 5.2.2 about defining and documenting quantitative and qualitative process improvement goals (3.20); none of the SDOs implemented this indicator, even in SDO E (3.40) despite being ML5. The highest was 5.2.3 Improvement actions are identified and implemented for the best performance and quality of the measured processes (3.62).

a) PA 5.1 indicators.



b) PA 5.2 indicators.

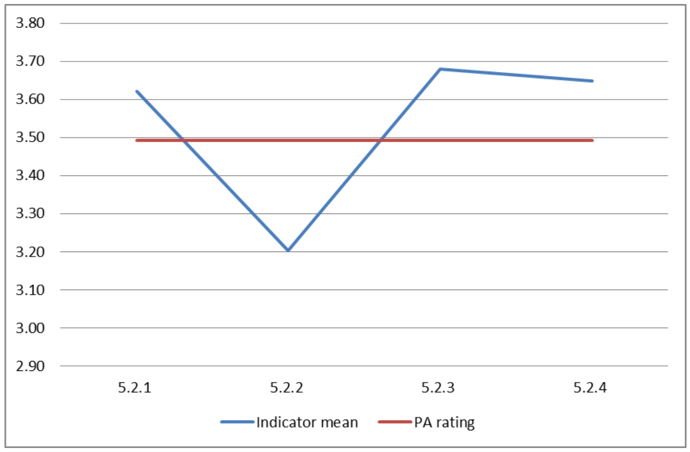


Figure 23. Comparison of PA 5.1 and PA 5.2 indicators based on the PA rating

In summary, according to the dependence of the lower capability levels to reach the higher levels, it was observed that the ratings of the higher levels are lower than those obtained in L1 (Figure 24), except PA 2.1 (4.07) and PA 3.2 (4.05) that were higher than PA 1.1 (4.00) and PA 1.2 (3.96). These were deduced due to the SDO, at least were (ML2), and they must submit evidence of the management of their products.

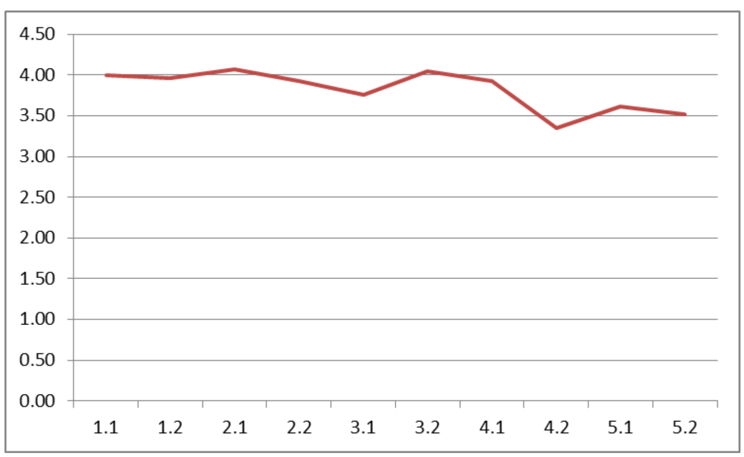


Figure 24. PA mean ratings among all five SDO.

Chapter 7. Conclusions and future work

7.1 Conclusions

Despite the implementation of SPI initiatives and the adoption of SPRM as a collection of best practices, as a strategy towards an incremental improvement in the processes capability, there are few CMMI-DEV certified SDOs in Mexico (SE, 2019; CMMI-Institute, 2019). In addition, there is a shortage of successful projects in the international market (Standish, 2017), which implies a lost opportunity for SDOs to reach high maturity levels that lead to quantitative management and optimization of their processes and projects that foster innovation.

The incremental path to improve capability processes confirms the nature of SDOs as knowledge-intensive organizations, which can be sustained by KM. In this sense, KM facilitates the management of both tacit and explicit knowledge, guaranteeing its reuse and creating new knowledge that encourages innovation. Thereby, in chapter two, the interdisciplinarity between KM and SE was described according to the theory of knowledge creation proposed by Nonaka (1994) based on the incremental path of knowledge flows between the four processes of the SECI model.

However, to confirm the effects of KM in SE, a quantitative measurement of knowledge is necessary to verify the degree of implementation of KM activities and the value added to the SDO. KMRPM were analyzed with a focus on SPI and their scope concerning the requirements of ISO/IEC 12774 standards for process definition and ISO/IEC 15504 related to process capabilities. For this reason, the proposal of Flores-Rios (2016) was selected because it includes both standards. In addition, it allows to integrate the SECI model (Nonaka, 1994) and a set of measurable indicators.

The application of the first version of the measurement instrument to the scholar software company case study, adjusting it to the four processes of the SECI model to measure the effects of knowledge flows to undergraduate students allowed testing the four research hypotheses related to the four modes of knowledge conversion (socialization-externalization, externalization-combination, combination-interiorization, interiorization-socialization). The results demonstrate the possibility to design a KM capability assessment model with the incremental knowledge path approach.

Conducting an SRL as a strategy to identify the most current forms of Knowledge Management with emphasis on quantitative assessment in software process improvement, revealed a shortage of studies that quantitatively assess the impact of KM in SE. The use of statistical techniques helps to measure this effect; however, it does not create a common view and interpretations of the results as the software assessment standards.

In correspondence between an incremental improvement path in the context of SE, and the incremental model from the theory of knowledge creation (Nonaka, 1994) within the context of KM, it was possible to establish a relationship with an incremental capability approach between both disciplines. This was supported by common attributes and indicators that characterized the five capability levels. Thus, a new process named Knowledge creation was added to the SECI model and a second version of the measurement instrument was designed.

As a result, it was now possible to adopt the ISO/IEC 15504/02 (2010) to develop the SECIKC-SE capability process assessment model, the measurement framework, and the assessment process. The determination of the SECIKC-SE capability process through five levels (L1 to L5), representing the degree of implementation of Socialization, Externalization, Combination, Interiorization, and Knowledge Creation allowed involving both types of knowledge, TK and EK.

The validation of the applicability of the SECIKC-SE model and its measurement framework through a case study research method and the execution of assessment activities (Figure 11), allowed for a successful empirical measurement of the degree of implementation of indicators in five SDOs. The use of affirmations (statements) as objective evidence to evaluate the indicators was not considered a weakness. First, because self assessments allow for using a single type of evidence and second, because the team members were the ones executing the processes; hence they were able to acknowledge the degree of implementation of the process indicators.

The capability in all five SDOs certified in CMMI-DEV 1.3 was L1 *Socialization*. The main weaknesses for PA 1.1 were indicators *1.1.4 Communication between project team members and executives*, and *1.1.2 Existing explicit knowledge is distributed in electronic format (emails, intranet, information systems, etc.)*. Likewise, the main weaknesses for PA 1.2 were indicators *1.2.1 The knowledge that I possess is really accessible to others* and *1.2.2 The knowledge that I usually acquire comes from the other roles with whom I interact*. Even though some SDOs have ML3 and ML5 CMMI-DEV certification none of them obtained an F rating in any L1 Socialization PA. Furthermore, capability results of the next levels (L2 to L5) indicated they depend on the support from previous levels (Figure 24).

Finally, considering the SECIKC-SE assessment was measured as an incremental path of capabilities characterized for the capability of SE standards concerning SPI, it was found that SDOs certified in CMMI-DEV 1.3 did not demonstrate sufficient management of the knowledge practices in correspondence to their maturity level. Therefore, the assessment results of the SECIKC-SE model provided SDOs with advantages and weaknesses to implement improvement actions to encourage innovation of products and services with focus on SPI.

7.2 Future work

The SECIKC-SE model allowed SDOs to perform a self-assessment by the project team members measuring the degree of implementation of indicators with the support of a single type of objective evidence, in this case, the affirmations (statements). Therefore, as future work, the plan is to extend the scope of the assessment using work products as objective evidence so that results can be corroborated with both types of evidence.

Additionally, implementing an independent assessment in which external assessors to SDOs can assess both types of objective evidence that extend and confirm the results of their self-assessments.

Likewise, it is planned to incorporate into the measurement framework the Generic Practices, Generic Resources, and Generic Work Products as PA indicators to extend the judgment of the degree of achievement of the PA.

It is desirable to increase the number of assessments to certified SDOs in CMMI-DEV 1.3 to have a better comparison of the results between SDOs with the same ML and between different ML, which help to validate the influence and correspondence with the SECIKC-SE capability levels.

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Appendix A

Table 64. First version of the measurement instrument

1	**Identify**
1.1	Roles know what types or sources of knowledge they need to perform the work (Documented, personnel's knowledge)
1.2	Roles know how to find the knowledge that is available
1.3	There is technology or support systems (hardware and software resources) in place to find the knowledge that I need to perform the activities
1.4	The roles involved know each other (who knows what)
1.5	The roles identify all their knowledge (I know what I know)
2	**Create/Acquire**
2.1	Knowledge acquisition strategies are defined and selected (training, forums, repositories, online courses, etc.)
2.2	There are ways to acquire knowledge from external sources (consultants, suppliers, clients, etc.)
2.3	Explicit sources of knowledge (standards, printed material, meeting records, manuals, etc.) are easy to acquire (2.3 Acquisition)
2.4	The knowledge that I usually acquire comes from the other roles with whom I interact
2.5	Electronic materials, procedures, manuals, online courses, etc. are generally used to acquire knowledge.
2.6	Roles are motivated to create and/or generate new knowledge
2.7	I can learn and find new ways of working
2.8	Roles know how to innovate, modify and update procedures and processes
3	**Externalization**
3.1	There is a formalization to document the implicit goals of the project
3.2	Customer requirements are formally and systematically captured
3.3	Customer tacit requirements are related to specific project characteristics (subjective requirements to objective requirements)
3.4	Improvement ideas as well as lessons learned are captured in real time
3.5	The work is reciprocally verified and validated
4	**Store**
4.1	Roles know how to store the knowledge and experience that they possess and create
4.2	I agree that knowledge must be stored
4.3	Roles are encouraged to capture knowledge assets (experiences, lessons learned, best practices, etc.) and have access to them
4.4	There is a person responsible for the storage and maintenance of knowledge assets
4.5	Customer evaluations, comments and complaints are recorded
5	**Transfer**

5.1	The knowledge that I possess is easily available to others
5.2	Existing explicit knowledge is distributed in electronic format (emails, intranet, information systems, etc.)
5.3	Roles are encouraged to share knowledge by building trust, granting incentives, time and available resources
5.4	Roles are aware that their knowledge can be shared
6	**Interiorize**
6.1	Roles are encouraged to take training courses.
6.2	Work products or procedures are reviewed to create knowledge or reflections by the roles
6.3	Tools that boost innovation and knowledge creation are used

Table 65. Second version of the measurement instrument

1	**Identify**
1.1	Roles know what types or sources of knowledge they need to perform the work (Documented, personnel's knowledge)
1.2	Roles know how to find the knowledge that is available
1.3	Roles know which team members have experience in specific areas
1.4	Roles identify all their knowledge (I know what I know)
1.5	The Project team has the right mix of skills and knowledge
2	**Create/Acquire**
2.1	Knowledge acquisition strategies are defined and selected (training, forums, repositories, online courses, etc.)
2.2	There are ways to acquire knowledge from external sources (consultants, suppliers, clients, etc.)
2.3	Explicit sources of knowledge (standards, printed material, meeting records, manuals, etc.) are easy to acquire (2.3 Acquisition)
2.4	The knowledge that I usually acquire comes from the other roles with whom I interact
2.5	Roles are motivated to create and/or generate new knowledge
2.6	Roles know how to innovate, modify and update procedures and processes
2.7	New innovative software products are created periodically
3	**Externalization**
3.1	There is a formalization to document the implicit goals of the project
3.3	Customer tacit requirements are related to specific project characteristics (subjective requirements to objective requirements)
3.2	Customer requirements are formally and systematically captured
3.4	Improvement ideas as well as lessons learned are captured in real time
3.5	The resulting documentation is reciprocally verified and validated
4	**Store**
4.1	I know how to store the knowledge and the experience that I possess and create
4.2	Procedures are documented to guide the work
4.3	There is a person responsible for the storage and maintenance of knowledge assets
4.4	Knowledge is integrated in real time and documents are organized
4.5	Tools that boost the integration of (combine) explicit knowledge are used
5	**Transfer**
5.1	The knowledge that I possess is easily available to others
5.2	Existing explicit knowledge is distributed in electronic fomat (emails, intranet, information systems, etc.)

5.3	Constant communication among project team members
5.4	Communication between project team members and executives
5.5	Roles know that their knowledge can be shared
5.6	New knowledge is spread throughout the organization (Nonaka)
6	**Interiorize**
6.1	Training is provided to the roles according to the work and requirements of the project
6.2	Documents are used to start discussions at the beginning of the project for the roles to reflect on or create knowledge
6.3	Documents are used to start a discussions about the progress of the project for the roles to reflect on or create knowledge
6.4	Documents are used to start discussions after the implementation of the project for the roles to reflect on or create knowledge
6.5	The existing information in the knowledge base of the organization for the practice of work is used
6.6	Tools that boost innovation and knowledge creation are used
7	**Measure**
7.1	There are indicators to measure the knowledge of the organization
7.2	The organization measures and evaluates the knowledge of each employee
7.3	Top management knows how much the staff have learned in the past year
7.4	The stored knowledge is measured and/or quantified (explicit knowledge) on documents, mail, and or systems
7.5	Improvement goals of quantitative and qualitative processes are defined and documented (ISO/IEC 15504)
7.6	Results of knowledge measurements are analyzed (ISO/IEC 15504)
7.7	Improvement actions are identified and carried out for best performance and quality of the measured processes (ISO/IEC 15504, CMMI-DEV)
7.8	Results of the implementation of improvement actions are evaluated (ISO/IEC 15504)

Table 66. Distribution of rating scale from all five SDOs and the mapping of indicators to CMMI-DEV 1.3

PA 5.1 Institutionalization of the innovation culture in roles	**N (DA-1,2)**	**%**	**P (N-3)**	**%**	**L (4-D)**	**%**	**F (5-TD)**	**%**	**Mapping CMMI-DEV 1.3**
5.1.1 Roles are motivated to create and/or generate new knowledge (2.5 Acquisition)	5	7.6	17	25.8	21	31.8	23	34.8	OT, OPM
5.1.2 Roles know how to innovate, modify and update procedures and processes (2.6 Acquisition)	3	4.5	28	42.4	20	30.3	15	22.7	OT, OPD, OPF, GP 2.1
5.1.3 New knowledge is spread throughout the organization (7.5 Measure) (Nonaka, 1994)	18	27.3	15	22.7	27	40.9	6	9.1	GG3.1, 3.2
5.1.4 Tools that boost innovation and knowledge creation are used (6.6 Interiorize)	3	4.5	31	47	17	25.8	15	22.7	GP 2.3
5.1.5 Explicit sources of knowledge (standards, printed material, meeting records, manuals, etc.) are easy to acquire (2.3 Acquisition)	5	7.6	15	22.7	26	39.4	20	30.3	OPP, GP 2.3
5.1.6 New innovative software products are created periodically (2.7 Acquisition)	13	19.7	26	39.4	19	28.8	8	12.1	OPM
PA 5.2 Process optimization									
5.2.1 Improvement goals of quantitative and qualitative processes are defined and documented (ISO/IEC 15504/02, 2010) (Measure 7.6)	8	12.1	22	33.3	23	34.8	13	19.7	MA, OPP, QPM, GP 2.1, GP 2.5
5.2.2 Results of knowledge measurements are analyzed (ISO/IEC 15504/02, 2010) (7.7 Measure)	15	22.7	26	39.4	17	25.8	8	12.1	MA, OPM, CAR
5.2.3 Improvement actions are identified and implemented for best performance and quality of the measured processes (ISO/IEC 15504/02, 2010, CMMI-DEV, 2010) (7.8 Measure)	10	15.2	22	33.3	17	25.8	17	25.8	OPM, CAR
5.2.4 Results of the implementation of improvement actions are evaluated (ISO/IEC 15504/02, 2010) (7.9 Measure)	11	15.2	21	47	20	30.3	15	22.7	OPP, CAR, GP 2.8, GP 2.9, GP 2.10

PA 4.1 Knowledge discussion	N (DA-1,2)	%	P (N-3)	%	L (4-D)	%	F (5-TD)	%	Mapping CMMI-DEV 1.3
4.1.1 Training is provided to the roles according to the work and requirements of the project (6.1 Interiorize)	6	9.1	11	16.7	31	47	18	27.3	OT, GP 2.5
4.1.2 Documents are used to start discussions at the beginning of the project for the roles to reflect on or create knowledge (6.2 Interiorize)	8	12.1	15	22.7	25	37.9	18	27.3	PMC, GP2.6, GG3.2
4.1.3 Documents are used to start a discussions about the progress of the project for the roles to reflect on or create knowledge (6.3 Interiorize)	6	9.1	3	17	4	26	5	17	PMC, GP2.6, GG3.2
4.1.4 Documents are used to start discussions after the implementation of the project for the roles to reflect on or create knowledge (Interiorize 6.4)	4	6.1	22	33.3	21	31.8	19	28.8	PMC, GP2.6, GG3.2
4.1.5 Roles know which team members have experience in specific areas (1.3 Identify)	4	6.1	10	15.2	23	34.8	29	43.9	
PA 4.2 Knowledge measurement									
4.2.1 There are indicators to measure the knowledge of the organization (7.1Measure)	13	19.7	28	42.4	18	27.3	7	10.6	MA, OPP, QPM, GP 2.1, GP 2.5
4.2.2 The organization measures and evaluates the knowledge of each employee (7.2 Measure)	11	16.7	21	31.8	20	30.3	14	21.2	OT, MA, OPP, QPM, GP 2.5
4.2.3 Top management knows how much the staff have learned in the past year (7.3 Measure)	19	28.8	18	27.3	19	28.8	10	15.2	OT, MA, OOP, QPM, GP 2.5
4.2.4 The stored knowledge is measured and/or quantified in (explicit knowledge) documents, mail, and or systems (7.4 Measure)	15	22.7	19	28.8	21	32.8	11	16.7	OT, MA, OPP, QPM, GP 2.5
PA 3.1 Knowledge assets integration management									
3.1.1 Knowledge is integrated in real time and documents are organized (4.5 Store)	8	12.1	24	36.4	21	31.8	13	19.7	CM, GP 2.1, GP 2.6, PI, IPM
3.1.2 There is a person responsible for the storage and maintenance of knowledge assets (4.4 Store)	8	12.1	24	36.4	18	27.3	16	24.2	CM, GP 2.4
3.1.3 Procedures are documented to guide the work (4.3 Store)	4	6.1	17	25.8	24	36.4	21	31.8	OPD, PPQA, GP 2.2

	N (DA-1,2)	%	P (N-3)	%	L (4-D)	%	F (5-TD)	%	Mapping CMMI-DEV 1.3
3.1.4 Tools that allow integrating (combine) explicit knowledge are used (4.6 Store)	5	7.6	22	33.3	26	39.4	13	19.7	GP 2.3
PA 3.2 Application of knowledge assets (Knowledge application)									
3.2.1 I know how to store the knowledge and the experience that I possess and create (4.1 Store)	4	6.1	12	18.2	27	40.9	23	34.8	CM, GP2.1, GP 2.6
3.2.2 Roles know how to find the knowledge that is available (1.2 Identify)	1	1.5	13	19.7	30	45.5	22	33.3	OT, GP 2.3, GP 2.1
3.2.3 Roles know what types or sources of knowledge they need to perform the work (Documented, personnel's knowledge) (1.1 Identify)	3	4.5	10	15.2	27	40.9	26	39.4	OT, GP 2.3, GP 2.1
3.2.4 The existing information in the knowledge base of the organization for the practice of work is used (6.5 Interiorize)	5	7.6	20	30.3	27	40.9	14	21.2	PMC, GP2.6, GG3.2
PA 2.1 Tacit to explicit knowledge conversion	**N (DA-1,2)**	**%**	**P (N-3)**	**%**	**L (4-D)**	**%**	**F (5-TD)**	**%**	**Mapping CMMI-DEV 1.3**
2.1.1 There is a formalization to document the implicit goals of the project (3.1 Externalize)	4	6.1	12	18.2	23	34.8	27	40.9	RD, TS, REQM, VER, VAL
2.1.2 Customer tacit requirements are related to specific project characteristics (subjective requirements to objective requirements) (3.3 Externalize)	1	1.5	18	27.3	27	40.9	20	30.3	RD, TS, REQM, RSKM, VER, VAL, DAR, PP, GP 1.1
2.1.3 The Project team has the right mix of skills and knowledge (1.5 Identify)	5	7.6	14	21.2	26	39.4	21	31.8	OT, IPM

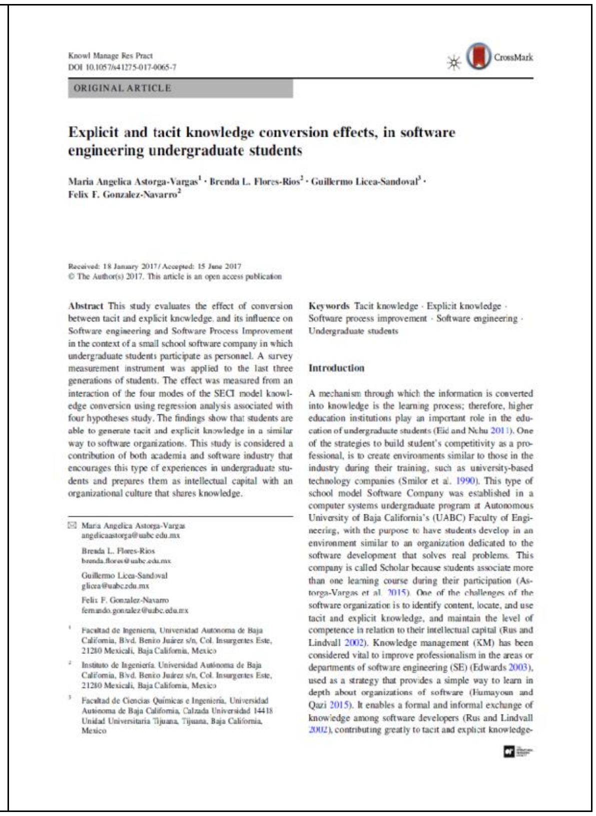
PA 2.2 Work product management	N (DA-1,2)	%	P (N-3)	%	L (4-D)	%	F (5-TD)	%	Mapping CMMI-DEV 1.3
2.2.1 Customer requirements are formally and systematically captured (3.2 Externalize)	3	4.5	15	22.7	24	36.4	24	36.4	RD, TS, REQM, RSKM, VER, VAL, DAR, PP, GP 1.1
2.2.2 Improvement ideas and lessons learned are captured in real time (3.4 Externalize)	7	10.6	27	40.9	21	31.8	11	16.7	OPF, GP 3.2
2.2.3 The resulting documentation is verified and validated (3.5 Externalize)	3	4.5	13	19.7	27	40.9	23	34.8	VER, VAL, PPQA, GP 2.9
PA 1.1 Individuals communicate knowledge									
1.1.1 Roles are aware that their knowledge can be shared (5.5 Transfer)	1	1.5	8	12.1	25	37.9	32	48.5	GP 2.6
1.1.2 Existing explicit knowledge is distributed in electronic format (emails, intranet, information systems, etc.) (5.2 Transfer)	6	9.1	12	18.2	27	40.9	21	31.8	GP 2.6
1.1.3 Constant communication among the project team members (5.3 Transfer)	3	4.5	8	12.1	24	36.4	31	47	GP 2.7
1.1.4 Communication between project team members and executives (5.4 Transfer)	6	9.1	15	22.7	27	40.9	18	27.3	GP 2.7
1.1.5 There are ways to acquire knowledge from external sources (consultants, suppliers, clients, etc.) (2.2 Acquisition)	12	18.2	16	24.2	24	36.4	14	21.2	GP2.7
1.1.6 Knowledge acquisition strategies are defined and selected (training, forums, repositories, online courses, etc.) (2.1 Acquisition)	9	13.6	10	15.2	23	34.8	24	36.4	OT, GP 2.5

PA 1.2 Acquisition of tacit knowledge	N (DA-1,2)	%	P (N-3)	%	L (4-D)	%	F (5-TD)	%	Mapping CMMI-DEV 1.3
1.2.1 The knowledge that I possess is easily available to others (5.1 Transfer)	3	4.5	14	21.2	31	47	18	27.3	GP2.7
1.2.2 The knowledge that I usually acquire comes from other the roles with whom I interact (2.4 Acquisition)	7	10.6	19	28.8	27	40.9	13	19.7	OT, GP 2.5
1.2.3 The roles identify all their knowledge (I know what I know) (1.4 Identify)	2	3	10	15.2	34	51.5	20	30.3	OT, GP 2.5

Annex A Publications

A.1 Explicit and tacit knowledge conversion effects in Software Engineering undergraduate students

Maria Angelica Astorga-Vargas, Brenda L. Flores-Rios, Guillermo Licea-Sandoval, Felix F. Gonzalez-Navarro. Explicit and tacit knowledge conversion effects in Software Engineering undergraduate students. Knowledge Management Research & Practice, Volume 15, Issue 3 – Springer, 2017. DOI 10.1057/s41275-017-0065-7. JCR. 1.013 (Figure 25).



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ORIGINAL ARTICLE

Explicit and tacit knowledge conversion effects, in software engineering undergraduate students

Maria Angelica Astorga-Vargas[1] · Brenda L. Flores-Rios[2] · Guillermo Licea-Sandoval[3] · Felix F. Gonzalez-Navarro[2]

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Abstract This study evaluates the effect of conversion between tacit and explicit knowledge, and its influence on Software engineering and Software Process Improvement in the context of a small school software company in which undergraduate students participate as personnel. A survey measurement instrument was applied to the last three generations of students. The effect was measured from an interaction of the four modes of the SECI model knowledge conversion using regression analysis associated with four hypotheses study. The findings show that students are able to generate tacit and explicit knowledge in a similar way to software organizations. This study is considered a contribution of both academia and software industry that encourages this type of experiences in undergraduate students and prepares them as intellectual capital with an organizational culture that shares knowledge.

Keywords Tacit knowledge · Explicit knowledge · Software process improvement · Software engineering · Undergraduate students

Introduction

A mechanism through which the information is converted into knowledge is the learning process; therefore, higher education institutions play an important role in the education of undergraduate students (Eid and Nuhu 2011). One of the strategies to build student's competitivity as a professional, is to create environments similar to those in the industry during their training, such as university-based technology companies (Smilor et al. 1990). This type of school model Software Company was established in a computer systems undergraduate program at Autonomous University of Baja California's (UABC) Faculty of Engineering, with the purpose to have students develop in an environment similar to an organization dedicated to the software development that solves real problems. This company is called Scholar because students associate more than one learning course during their participation (Astorga-Vargas et al. 2015). One of the challenges of the software organization is to identify content, locate, and use tacit and explicit knowledge, and maintain the level of competence in relation to their intellectual capital (Rus and Lindvall 2002). Knowledge management (KM) has been considered vital to improve professionalism in the areas or departments of software engineering (SE) (Edwards 2003), used as a strategy that provides a simple way to learn in depth about organizations of software (Humayoun and Qazi 2015). It enables a formal and informal exchange of knowledge among software developers (Rus and Lindvall 2002), contributing greatly to tacit and explicit knowledge-

✉ Maria Angelica Astorga-Vargas
angelicaastorga@uabc.edu.mx

Brenda L. Flores-Rios
brenda.flores@uabc.edu.mx

Guillermo Licea-Sandoval
glicea@uabc.edu.mx

Felix F. Gonzalez-Navarro
fernando.gonzalez@uabc.edu.mx

[1] Facultad de Ingeniería, Universidad Autónoma de Baja California, Blvd. Benito Juárez s/n, Col. Insurgentes Este, 21280 Mexicali, Baja California, Mexico

[2] Instituto de Ingeniería, Universidad Autónoma de Baja California, Blvd. Benito Juárez s/n, Col. Insurgentes Este, 21280 Mexicali, Baja California, Mexico

[3] Facultad de Ciencias Químicas e Ingeniería, Universidad Autónoma de Baja California, Calzada Universidad 14418 Unidad Universitaria Tijuana, Tijuana, Baja California, Mexico

Figure 25. Cover for KMRP Volume 15, Issue 3 - Springer, 2017, and first page of the paper

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A.2 Design of Experiments applied to a Software Engineering Project based on Knowledge Process

María Angélica Astorga-Vargas, Brenda L. Flores-Rios, Margarita Gil Samaniego, Juan Pablo García-Vázquez, Félix Fernando González-Navarro, Jorge E. Ibarra-Esquer, Mónica Cristina Lam Mora. Design of Experiments applied to a Software Engineering Project based on Knowledge Processes. IEEE Proceedings in 6th International Conference in Software Engineering Research and Innovation. CONISOFT 2018, Yucatán, México. (Figure 26).

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Design of Experiments applied to a Software Engineering Project based on Knowledge Processes

María Angélica Astorga-Vargas[1], Brenda L. Flores-Rios[2], Margarita Gil Samaniego[3], Juan Pablo García-Vázquez[4], Félix Fernando González-Navarro[5], Jorge E. Ibarra-Esquer[6], Mónica Cristina Lam Mora[7]
[1, 3, 4, 6, 7] Facultad de Ingeniería, [2, 5] Instituto de Ingeniería
Universidad Autónoma de Baja California
Mexicali, Baja California, México
{angelicaastorga,brenda.flores, margarita.gil.samaniego.ramos, pablo.garcia, fernando.gonzalez, jorge.ibarra, monica.lam}@uabc.edu.mx

***Abstract*— The systematic application of the Experimental Design plan from Design of experiments (DoE) is presented as an essential statistical method for experimentation in Software Engineering (SE). The objective is to correctly identify the factors that influence the degree to which the externalization of knowledge is generated in a software project based on knowledge, for which a factorial design was applied with two factors (a x b). Factor A, corresponds to Project teams and factor B, is related to Externalization strategies. The effect of the factors and their interaction on the response variable (externalization of knowledge) were checked from the test statistics of the analysis of the variance ANOVA, showing that only the factor B significantly influences the externalization measurement according to the sample under study.**

Keywords: Software engineering; Exteriorization; Design of experiments; Experimentation

I. INTRODUCTION

Most experiments in Science and Engineering require observation and experimentation to explain how and why they happen in that way within the process or system [1]. The methodology that supports to correctly answer the questions in experimentation is Design of Experiments (DoE) through the systematic application of statistics [2]. Well-designed experiments can lead to models of system performance also called empirical models [1]. However, despite the fact that DoE provides a quick and cost-effective method to understand and optimize products and processes [3], there are organizations that do not execute their experimentation with a pre-established statistical method [4].

In the software industry the experimentations is a recent practice compared to other disciplines, so, the challenge is the adaptation of experimental design according to the nature of Software Engineering (SE) [5]. In SE, experimental design is important to identify the key variables and their relationships [5]. Others authors consider that experimental design helps to build a reliable knowledge-based and therefore reduce uncertainty about theories, methods, and tools that are appropriate [6, 7].

On the other hand, SE is based on intensive knowledge of its processes [8, 9], therefore, one of the challenges in software development organizations is to identify the content, locate and use tacit and explicit knowledge, as well as maintaining the level of competence in relation to their intellectual capital [8]. There are organizations that believe that capturing or transferring tacit or explicit knowledge existing in individuals or knowledge base is an activity that does not add value, nor are they willing to invest in economic and technological resources [10]. In such a way, there is not enough dedication to externalize knowledge, that is, transform tacit knowledge into explicit knowledge [11]. In this sense, it is observed that the creation of knowledge can be affected not only by activities or good practices of the exteriorization process but also building work teams. Hence, Knowledge Management (KM) is used as a strategy to improve the professionalism of SE areas [12], to provide a simple way to learn with major depth about software development organizations [13], and allow the formal and informal exchange of types of knowledge among software developers [8] with tacit and explicit knowledge creation practices that support the Software Process Improvement (SPI) [9].

Taking into account the advantages of DoE in the experimentation, this investigation was guided by an experimental plan, applied in a study case of SE based on knowledge processes, specifically in exteriorization. The aim is to correctly identify the factors that influence the degree to which the externalization process is generated through the participation of 3 software project teams, applying the factorial design technique with two factors (a x b). The factorial design allows evaluating the individual effect and the interaction of several factors on one or more response variables [14].

The rest of the document is structured as follows: section 2 describes each of the steps that must be followed in an experimental DoE plan. Section 3 describes the development of experimentation. Section 4 presents the results of the experiment. Finally, section 5 presents the conclusions and the future work.

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Figure 26. Cover for IEEE Proceedings in 6th CONISOFT 2018, and first page of the paper

A.3 Technical reports

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A.4 Submission of literary creation to The National Institute of Copyright (INDAUTOR)

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