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ABSTRACT

The Capability Maturity Model (CMM) has obtained world-wide status as a premier process improvement framework. This influence has not gone unnoticed by the academic community who has utilized the CMM as a key construct representing a firm's IT project management and development capabilities. However, an examination of the current state of research reveals no consensus on how to best operationalize CMM-based process capability; therefore, this study seeks to start a dialog in the academic community about how CMM-based process capability should be conceptualized and measured. While the results do suggest that CMM-based process capability is multidimensional, and that a process structure rather than a level structure may be the most appropriate; the main intent of this research is to call attention to the need for greater rigor in the measurement and conceptualization of CMM-based process capability in the academic literature. The hope is this research represents a first step in developing a fully refined and validated CMM-based process capability measure.

Keywords

Capability Maturity Model (CMM), process maturity, measurement instrument

INTRODUCTION

The use of the Capability Maturity Model (CMM) as a framework for process improvement has reached a global level with firms spending billions of dollars toward the implementation of CMM-based processes and practices (Herbsleb, Zubrow, Goldenson, Hayes and Paulk, 1997). Large organizations such as Boeing (Yamamura and Wigle, 1997), Computer Science Corporation (McGarry and Decker, 2002), Hewlett-Packard (Myers, 1994), Hughes Aircraft (Humphrey, Snyder and Willis, 1991), Motorola (Diaz and Sligo, 1997), PRC Incorporated (Hollenbach, Young, Pflugrad and Smith, 1997), Raytheon (Dion, 1993; Haley, 1996), Schlumberger (Wohlwend and Rosenbaum, 1994), Tata Consultancy Services (Keeni, 2000) and Telcordia Technologies (Pitterman, 2000) have all formally adopted the CMM and have reported improvements in quality, cycle time, productivity, customer satisfaction and market share. CMM-based processes and practices have also proven to be quite scalable (Hadden, 1998). Small organizations such as DataStream Content Solutions (Dangle, Larsen, Shaw and Zelkowitz, 2005), Silicon & Software Systems (Kelly and Culleton, 1999), and Link (Guerrero, and Eterovic, 2004) have also applied the guiding principles of the CMM and are reporting similar benefits in terms of cost, efficiencies, and quality.

This possible relationship between CMM-based process capability and various process improvement outcomes has also drawn the interest of academia; however, a review of the literature shows a lack of consensus on how to operationalize this process capability construct. Therefore, much like the SERVQUAL measurement stream of research (a stream devote to the refinement and validation of the service quality construct), this research looks to spark an open dialog in the academic community about how best to measure CMM-based process capability. To aid such endeavors, this research examines how CMM-based process capability has been operationalized in the literature, identifies and compares four alternate methods of operationalizing CMM-based process capability, and provides direction for future research.

ORIGINS AND STRUCTURE OF CAPABILITY MATURITY MODEL

Based on quality management practices and principles, the Software Engineering Institute (SEI) created the Capability Maturity Model for Software (SW-CMM) for the U.S. Department of Defense. Originally the model was used as a means of factoring the contractor's software development capabilities into the military's contract award decision-making process. However, the CMM soon evolved into a framework for process improvement.

Over time the role of IT firms and departments expanded from software development, to systems development, to an array of IT services provisioning. As these responsibility evolved so did the CMM. In 2000 the SEI introduced the Capability Maturity Model Integration (CMMI) (Team, 2000). The CMMI combined previous system and software capability models, including the SW-CMM, into a single framework for developing enterprise-wide IT products and services.

The popularity of the CMM as a process improvement framework spawned process maturity models in other areas; for example, enterprise architecture (Ross, 2003), enterprise resource planning (Holland and Light, 2001), marketing (Hirschheim, Schwarz and Todd, 2006) and project management (Cooke-Davies and Arzymanow, 2003; Jugdev and Thomas, 2002).

Process Area	Specific Goals	Specific Practices
Project Monitoring and Control – provide an understanding of the project's progress so that appropriate corrective actions can be taken when the project's performance deviates significantly from the plan.	1. Monitor Project Against Plan	1. Monitor Project Planning Parameters 2. Monitor Commitments 3. Monitor Project Risks 4. Monitor Data Management 5. Monitor Stakeholder Involvement 6. Conduct Progress Reviews 7. Conduct Milestone Reviews
	2. Manage Corrective Action to Closure	1. Analyze Issues 2. Take Correction Action 3. Manage Corrective Action
	Generic Goals	**Generic Practices**
	1. Institutionalize as Managed Process	1. Establish an Organizational Policy 2. Plan the Process 3. Provide Resources 4. Assign Responsibility 5. Train People 6. Manage Configurations 7. Identify and Involve Relevant Stakeholders 8. Monitor and Control the Process 9. Objectively Evaluate Adherence 10. Review Status with Higher-Level Management
Process Area	**Specific Goals**	**Specific Practices**
Requirements Development - produce and analyze customer, product, and product-component requirements.	1. Develop Customer Requirements	1. Elicit Needs 2. Transform Stakeholder Needs, Expectations, Constraints, and Interfaces into Customer Requirements
	2. Develop Product Requirements	1. Establish Product and Product Component Requirements 2. Allocate Product Component Requirements 3. Identify Interface Requirements
	3. Analyze and Validate Requirements	1. Establish Operational Concepts and Scenarios 2. Establish a Definition of Required Functionality 3. Analyze Requirements 4. Evaluate Product Cost, Schedule and Risk 5. Validate Requirements with Comprehensive Methods
	Generic Goals	**Generic Practices**
	2. Institutionalize as Defined Process	1. Establish an Organizational Policy 2. Establish a Defined Process 3. Plan the Process 4. Provide Resources 5. Assign Responsibility 6. Train People 7. Manage Configurations 8. Identify and Involve Relevant Stakeholders 9. Monitor and Control the Process 10. Collect Improvement Information 11. Objectively Evaluate Adherence 12. Review Status with Higher-Level Management

Table 1 – Example of CMMI PA Model Structure (Process Areas, Goals, and Practices)

CMM Structure

The CMM is a process model that describes the characteristics of effective processes. The more recent CMM framework, the CMMI, describes a set of 22 processes referred to as process areas (PAs). Each PA consists of specific and generic goals which define the PA's objectives. Each PA goal is related to a cluster of (specific or generic) practices; when performed collectively these practices enable the achievement the stated PA goal. Table 1 provides two examples of the PA structure just described. Table 2 contains a list of all 22 CMMI PAs along with the number of specific and generic goals and practices associated with each PA.

Within the CMMI, PAs are classified into maturity levels. Level one (Initial) represents the least mature stage meaning project outcomes are less predictable and tend to involve more rework, defects, and schedule slippages. Level five (Optimizing) represents the highest level of process maturity meaning projects have little or no rework/scrap and predictable outcomes. Also within the CMMI framework, PAs are grouped into one of four process categories: engineering, project management, support, and process management. Table 1 shows both the level classification and process categorization for each PA. By institutionalizing these PAs it is proposed that an organization increases its ability to meet its cost, quality, schedule and performance objectives.

Process Area (PA)	Level	Process Category	Goals		Practices	
			Specific	Generic	Specific	Generic
Requirements Management	2	Engineering	1	1	5	10
Project Planning	2	Project Mgt.	3	1	14	10
Project Monitoring and Control	2	Project Mgt.	2	1	10	10
Supplier Agreement Management	2	Project Mgt.	2	1	7	10
Measurement and Analysis	2	Support	2	1	8	10
Process & Product Quality Assurance	2	Support	2	1	4	10
Configuration Management	2	Support	3	1	7	12
Requirements Development	3	Engineering	3	1	10	12
Technical Solution	3	Engineering	3	1	9	12
Product Integration	3	Engineering	3	1	9	12
Verification	3	Engineering	3	1	9	12
Validation	3	Engineering	2	1	5	12
Organizational Process Focus	3	Process Mgt.	2	1	7	12
Organizational Process Definition	3	Process Mgt.	2	1	5	12
Organizational Training	3	Process Mgt.	2	1	7	12
Integrated Project Management	3	Project Mgt.	2	1	8	12
Risk Management	3	Project Mgt.	3	1	7	12
Decision Analysis & Resolution	3	Support	1	1	6	12
Organizational Process Performance	4	Process Mgt.	1	1	5	12
Quantitative Project Management	4	Project Mgt.	2	1	8	12
Organizational Innovation & Deployment	5	Process Mgt.	2	1	7	12
Causal Analysis & Resolution	5	Support	2	1	5	12
		Total	*48*	*22*	*162*	*252*
		Grand Total	*70*		*414*	

Table 2: Capability Maturity Model Integration (CMMI) – Process Areas

EMPIRICAL RESEARCH USING A CMM-BASED PROCESS CAPABILITY MEASURE

Table 3 list various empirical studies in the IS literature incorporating a CMM-based process capability measure. An examination of the table reveals that the majority of studies adopting a unidimensional (i.e. single factor, variable or construct) representation preferred to measure CMM-based process capability using a level structure (i.e. either measure or group PAs by maturity level classification); with the exception of the following studies:

- Noushin (2003) used a binary structure for process capability which indicated if the organization was or was not using the CMM framework as part of their process improvement efforts.
- Harter, Krishnan and Slaughter (2000) used historical longitude data over a 12-year period to recalculate a single process capability measure at various time points during the product's development life-cycle.
- Krishnan and Kellner (1999) used a singular-aggregated process capability construct derived from individual process measures; however, a later study (Krishnan, Kriebel, Kekre and Mukhopadhyay 2000) using the same data set revealed that the singular-aggregated capability construct is better represented as two separate process capabilities constructs ("life-cycle" and "quality").

While the level structure has dominated the unidimensional representation, the process structure (i.e. either measure or group PAs by process category) is more prevalent in multidimensional (i.e. multiple factor, variable or construct) representations with the exception of Dekleva and Drehmer (1997). Studies involving the multidimensional representations also vary in the number of dimensions identified - from a low of two to a high of eleven. These differences may be a result of one of the following reasons:

- Some studies do not investigate the entire set of CMM processes or include additional processes (and practices) not strictly defined in the CMM. Krishnan et al. (2000) and Gopal, Mukhopadhyay and Krishnan (2002) only analyzed a subset of CMM process areas (i.e., requirements management, software product engineering, software configuration management, software product planning, training program, peer reviews, defect prevention, and software quality assurance). While Deephouse, Mukhopadhyay, Goldenson and Kellner (1995-1996) considered just eight processes of which only three (i.e., planning, process training, and design reviews) are defined process areas in the CMM framework. Dekleva et al.(1997) and Jiang, Klein, Hwang, Huang and Hung (2004) only measured practices associated with process areas up to maturity level 4.
- Some studies (Deephouse et al., 1995-1996; Gopal et al., 2002; Krishnan et al., 2000) choose to measure process capability by means of process area goals, while others (Dekleva et al., 1997; Jiang et al., 2004) use process area practices, and still others (McGuire, 1996) electing to use a mixture of both.
- Historically, not all goals and practices have mapped well to the "targeted" process area or maturity level. For example, Krishnan et al.(1999) performed a series of refinements to modify and clarify goal-based items to improve the reliability and validity of their mapping to the individual PAs. Using a Rasch psychometric model to fit process practices to maturity levels, Dekleva et al. (1997) found evidence supporting seven distinct levels, two more than the defined five levels of the CMM. In a more recent study by Jiang et al. (2004), analysis of 38 CMM-related process practices shows seven of the twelve Level 2 process area practices load on a factor they called "project management"; nine of the fourteen Level 3 process area practices, in addition to two of the Level 2 process area practices, load on a second factor they called "process engineering and organizational support"; and all twelve Level 4 process area practices plus two level 3 process area practices load on a final factor they called "product and process quality."

Article	Dimensions	Structure
Deephouse et al. (1995-1996)	Multidimensional	Process
Dekleva et al.(1997)	Multidimensional	Level
Herbsleb et al (1997)	Unidimensional	Level
McGuire (1996)	Multidimensional	Process
Krishnan et al.(1999)[1]	Unidimensional	Process
Ravichandran and Rai (1999)[2]	Unidimensional	Level
Harter et al. (2000)	Unidimensional	Both[3]
Krishnan et al.(2000)[1]	Multidimensional	Process
Parzinger and Nath (2000)	Unidimensional	Level
Gopal et al. (2002)	Multidimensional	Process
Patnayakuni and Rai (2002)[2]	Unidimensional	Level
Donald and Sandra (2003)	Unidimensional	Level
Noushin (2003)	Unidimensional	Level
Ravichandran and Rai (2003)[2]	Unidimensional	Level
Jiang et al. (2004)	Multidimensional	Both[3]

1. Papers using related or same data set
2. Papers using related or same data set
3. Containing elements of both process and level measures

Table 3 – CMM-Related Empirical Studies

RESEARCH MODELS

This research will now compare four different methods of operationalizing CMM-based process capability identified in the literature (see Table 4). The unidimensional representation is consistent with the CMM literature using process capability as a single construct. The SEI-Based Level Structure and SEI-Based Process Structure are both multidimensional representations derived directly from the level classification and process categorization used by the SEI (see Table 2). The fourth model, the Theory-Based Process Structure, is derived from the theoretical process structure identified in two separate empirical studies, Krishnan et al.(2000) and Gopal et al. (2002). These studies, using a subset of PAs from the CMM (excluding almost all higher level process areas), showed PAs to cluster on two theoretical process capabilities: "life-cycle" (also referred to as "technical") and "quality". Since this research investigates the full 22 process areas of the CMM, the process area mapping begun by the previous mentioned studies was extended based on Feigenbaum's (1956) theoretical framework to include life-cycle engineering, quality appraisal, quality prevention, and process adaptation[1].

UNIDIMENSIONAL REPRESENTATION	MULTIDIMENSIONAL REPRESENTATIONS		
	SEI-Based Level Structure	**SEI-Based Process Structure**	**Theory-Based Process Structure**
1. Requirements Management 2. Project Planning 3. Project Monitoring and Control 4. Supplier Agreement Management 5. Measurement and Analysis 6. Process & Product Quality Assurance 7. Configuration Management 8. Requirements Development 9. Technical Solution 10. Product Integration 11. Verification 12. Validation 13. Organizational Process Focus 14. Organizational Process Definition 15. Organizational Training 16. Integrated Project Management 17. Risk Management 18. Decision Analysis & Resolution 19. Organizational Process Performance 20. Quantitative Project Management 21. Organizational Innovation & Deployment 22. Causal Analysis & Resolution	***Level 2*** 1. Requirements Management 2. Project Planning 3. Project Monitoring and Control 4. Supplier Agreement Management 5. Measurement and Analysis 6. Process & Product Quality Assurance 7. Configuration Management ***Level 3*** 1. Requirements Development 2. Technical Solution 3. Product Integration 4. Verification 5. Validation 6. Organizational Process Focus 7. Organizational Process Definition 8. Organizational Training 9. Integrated Project Management 10. Risk Management 11. Decision Analysis & Resolution ***Level 4*** 1. Organizational Process Performance 2. Quantitative Project Management ***Level 5*** 1. Organizational Innovation & Deployment 2. Causal Analysis & Resolution	***Engineering*** 1. Requirements Management 2. Requirements Development 3. Technical Solution 4. Product Integration 5. Verification 6. Validation ***Project Management*** 1. Project Planning 2. Project Monitoring and Control 3. Supplier Agreement Management 4. Integrated Project Management 5. Risk Management 6. Quantitative Project Management ***Support*** 1. Measurement and Analysis 2. Process & Product Quality Assurance 3. Configuration Management 4. Decision Analysis & Resolution 5. Causal Analysis & Resolution ***Process Management*** 1. Organizational Process Focus 2. Organizational Process Definition 3. Organizational Training 4. Organizational Process Performance 5. Organizational Innovation & Deployment	***Life-Cycle Engineering*** 1. Requirements Management 2. Project Planning 3. Project Monitoring and Control 4. Requirements Development 5. Technical Solution 6. Integrated Project Management ***Quality Appraisal*** 1. Product Integration 2. Verification 3. Validation ***Quality Prevention*** 1. Supplier Agreement Management 2. Measurement and Analysis 3. Process & Product Quality Assurance 4. Configuration Management 5. Risk Management 6. Decision Analysis & Resolution 7. Quantitative Project Management 8. Causal Analysis & Resolution ***Process Adaptation*** 1. Organizational Process Focus 2. Organizational Process Definition 3. Organizational Training 4. Organizational Process Performance 5. Organizational Innovation & Deployment

Table 4 –Proposed Model Structures

METHODOLOGY

Construct Operationalization and Survey Development

Survey items to measure a firm's process capability were based on the process area definitions from the CMMI (Team, 2000); examples of these definitions are provided in Table 2. Using a 5-point Likert scale, respondents were asked the extent the process was formally defined in their organization (1-not defined to 5-very defined). The researchers elected to use measures at the process area level instead of the goal or practice level for several reasons. First, one objective of this research is to determine the dimensionality and structure of the CMM-based process capability construct; thus, measures at the process

[1] Activity names have been changed to reflect the more modern terms (e.g., new design control to life-cycle engineering, product control to appraisal quality, incoming material control to prevention quality, and special process studies to process adaptation).

area level are sufficient enough to accomplish this objective (this approach is conceptually similar to item-factor loading approach used with respect to the SERVQUAL construct). Second, though the structure of the CMMI framework previously described has a natural mapping of practices to goals and goals to process areas, past research using practice-based items (Dekleva et al., 1997; Jiang et al., 2004) and goal-based items (Krishnan et al., 1999) have noted reliability and validity issues when trying to associate these items with defined CMM process areas and/or maturity levels. Third, focusing on only the 22 process areas would keep the instrument at an acceptable size for the purpose of this research by alleviating undue complexity in both the data gathering and analysis processes (i.e., 414 items at the practice level and 70 at the goal level).

The validity of the survey instrument was assessed using eight respondents: two IS professionals and two IS researchers familiar with Capability Maturity Models, and two IS professionals and two IS researchers familiar with IS service provisioning. Feedback from their reviews resulted in minor changes in the survey's appearance and instructions. The complete instrument is available upon request from the authors.

Data Collection and Sample Characteristics

Data collection for this research was done over a nine-month period. In order to generate a diverse sample of new and traditional, large, well known IT service providers, as well as several small IT service providers, data collection efforts included the cooperation of two IT professional conferences, one IT industry consortium, and one regional IT professional organization. These efforts generated a total of 84 responses (62 useable). Multiple responses from the same organizational unit were averaged to provide a single measure for that organization unit. A final set of 60 data points were used for this study. Researchers were not allowed direct access to the complete member/attendee listserv of the partnering organizations due to confidentiality restrictions. However, by examining available resources, such as the service providers exhibiting at the two conferences, a response rate of 19.05% was conservatively estimated. Respondents consisted of owners/partners (8%), CEOs/presidents (8%), directors/VPs (18%), managers/supervisors (21%), engineers/analysts/developers (23%) and consultants/strategists (18%). They averaged 5.6 years of experience in their current organizations. Twenty-five companies had less than $100 million in sales with approximately the same number having less then fifty clients. Twenty companies did more than one billion dollars in sales with approximately the same number having more than one thousand clients.

ANALYSIS AND RESULTS

To determine the most likely dimensionality of the CMM-based process capability construct, this research follows a two-step procedures used in the SERVQUAL literature (Carman, 1990; Cronin and Taylor, 1992). The first step assesses the likelihood of a unidimensional construct; validation of a single construct structure would preclude further testing and provide support for the unidimensional structure. However, if the analysis reveals a multidimensional structure is more likely, a second analysis is conducted to assess the unidimensionality of the individual level/process factors within each of the three multidimensional representations.

Step 1: Dimensionality of entire CMM Scale

In this first step, a factor analysis was done using EQS to determine if the 22 items that make up the process capability measure load on a single factor. An OBLIMIN oblique factor rotation was used to allow for inter-correlations among dimensions and to facilitate easy interpretation. Results of the analysis reveal that a multiple factor structure is more likely (see Figure 1). It is also interesting to note that each of the three multidimensional representations consist of four dimensions and the results shows a four factor representation to be significant (i.e., eigenvalue is greater than one). Since a unidimensional representation was rejected, the second step of analysis was conducted.

Step 2: Dimensionality of the Individual Factors within each of the Multidimensional Structures

In the second step, each multidimensional representation was investigated separately. For each representation, a factor analysis was done using EQS to determine if the relevant process area items associated with an individual level/process dimension loaded on a single factor. Twelve separate factor analyses were conducted, four for each of the three multidimensional representations. For example, one of the factor analyses for the SEI-Based Process Structure was for the Engineering dimension which included process area item measures for Requirements Management, Requirements Development, Technical Solution, Product Integration, Verification and Validation (see Table 4 for a complete list of structures, dimensions, and process area). The results of all twelve analyses broken down by structure are provided in Figure 2.

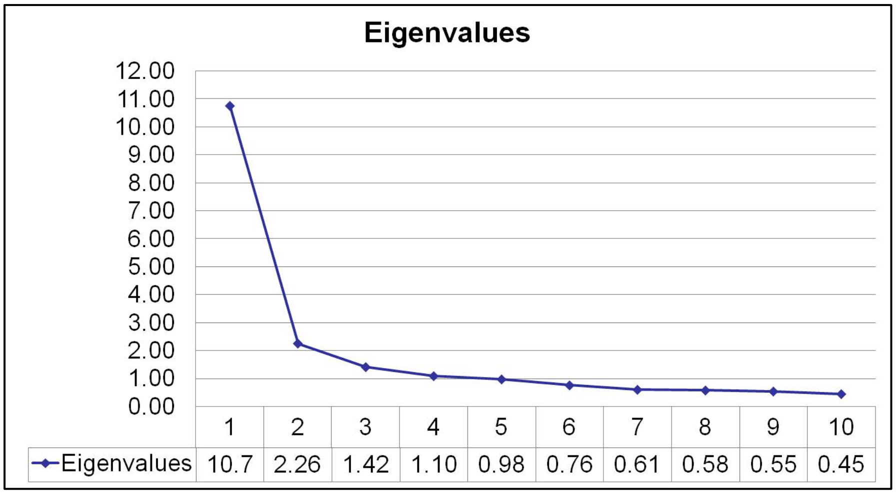

Figure 1: Step 1 - Dimensional Result

Examining the eigenvalues for the Level 3 dimension of the SEI-Based Level Structure, the results suggest the dimension contains more than one factor and that a two factor structure may be more appropriate. All the other Level dimensions of the SEI-Based Level Structure seem to be best represented by a single factor; though, the eigenvalue for the Level 2 dimension is very close to one – implying a possible two factor representation. All the process dimensions of the SEI-Based Process Structure seem to be best represented by a single factor; the same is true for all process dimensions in the Theory-Based Process Structure.

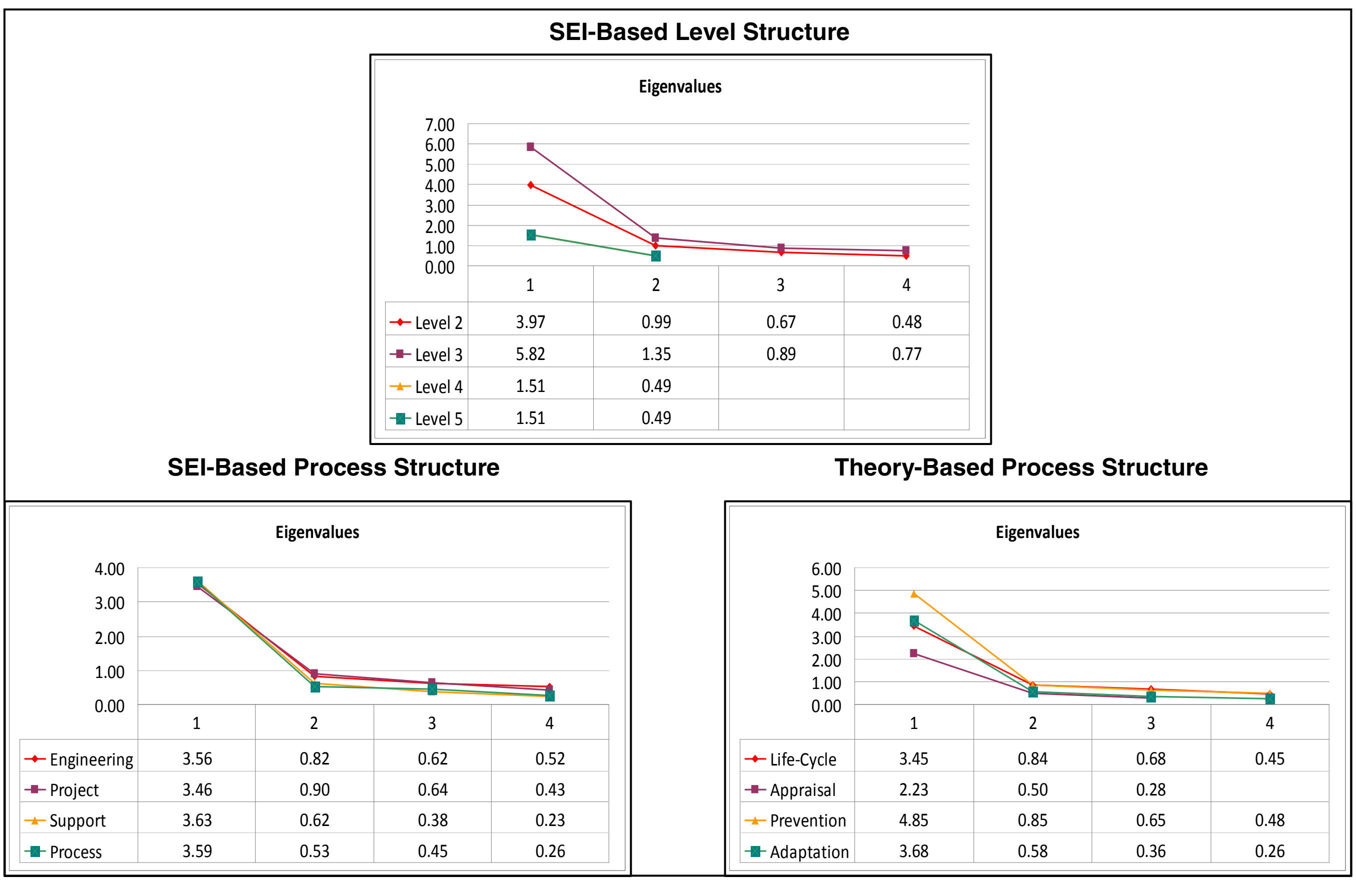

Figure 2: Step 2 - Individual Factor Results by Structure

DISCUSSION

The results indicate that CMM-based process capability construct, as operationalized in this research, is best represented using a multidimensional structure. The evidence also seems to suggest that a process-based multidimensional structure is slightly superior to the level-based multidimensional structure. While the result support a four-factor process structure, we do not have enough evidence to support which of the two four-factor process structures, the SEI-Based Process Structure or Theory-Based Process Structure, is best. But we do conjecture that with sufficient data it may be possible to provide support for one process structure over the other.

There are a several limitations associated with this study. First, the sample size is relatively small with 60 data points; however, sample size has been a limiting factor of most CMM-based empirical research given the median samples size of the studies listed in Table 3 is only 65.5 data points. Second, tests regarding response biases could not be conducted, but an examination of the respondents shows that approximately half of data points in the sample come from large and well known IS service providers; therefore, it is believed that the sample is representative of the IS industry.

The above results have several implications for academia and industry. For academia, research using a CMM-based process capability measures should conduct theory development with respect to a multidimensional process structure as oppose to a unidimensional capability structure or multidimensional level structure. It is possible that the process factors could have different theorized relationships with various process improvement outcomes; these relationships may vary in terms of magnitude, sign, and significance. For industry, these results seem to suggest that organizations may be developing capabilities around functional areas as oppose to the SEI's prescribed level development sequence.

This research represents only the beginning of a potentially large stream. Some potential areas include research comparing the use of practice, goal and process area measures; investigating the robustness of measures with respect to different industry, firm and product/service characteristics; and comparing the use of subjective measures with detailed objective measures and/or data collected by individual organizations or the Software Engineering Institute.

CONCLUSION

The intent of this research is not to provide a definite answer to the conceptualization and measurement of CMM-based process capability; rather, the intent of this research is to suggest that the time has come for greater rigor in the academia with respect to this construct. To this end this research presents a review of empirical studies incorporating measures of CMM-based process capability. Further, this research provides some evidence that a multidimensional process structure might be the most appropriate conceptualization of CMM-based process capability. Though several issues still remain, this research represents a first step in developing a fully refined and validated academic CMM-based process capability measure.

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