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Abstract

A survey instrument for measuring software process maturity is developed and validated. An empirical study of 362 software project managers is used to evaluate the performance of the survey instrument. The survey items factored into two dimensions—manageability and measureability—both of which were statistically reliable. The results also suggest that these dimensions possess convergent validity when compared to two other indicators of process maturity: a survey-based measure of software process customizability and self-reported CMM assessment level. The main implication of the study is that there are reliable and valid ways to measure software process maturity within the constraints of survey-based research designs.

Introduction

Software process maturity is one approach that organizations have undertaken as a way of improving the quality and predictability of their development efforts (Humphrey, 1988). From the perspective of the Software Engineering Institute's (SEI) Capability Maturity Model (CMM), software process maturity is defined as "the extent to which a specific process is explicitly defined, managed, measured, controlled, and effective" (Paulk, et al., 1993). The two ways that software process maturity is most often measured (Rahardja, 1996) are capability evaluation and internal assessment. Capability evaluation involves the use of qualified, outside auditors who classify the organization's maturity level in order to provide a risk assessment for potential customers. Internal assessment requires that the organization perform a self-audit by means of a CMM self-assessment questionnaire (Zubrow, et al, 1994) as a baseline for process improvement. Although each approach is appropriate for its purpose, neither approach is practical for researchers using a survey-based research design. The questionnaire, in particular, is too lengthy for researchers to use in a survey-based designs. Researchers who wish to study process maturity using survey methods are left with two choices: evaluate only organizations that have been CMM-assessed, or use a shorter instrument fit for a survey questionnaire. This paper evaluates two very recently developed measures used in survey-based studies. The purpose of this paper is to provide evidence to suggest that there are valid and reliable ways of estimating software process maturity for the purposes of survey-based research.

Literature Review

The software process maturity construct developed by the authors is based on the CMM's five-level maturity framework (Humphrey, 1988) in which each level represents a maturity state that is an evolutionary improvement from the prior level. The five maturity levels are initial, repeatable, defined, managed, and optimizing. The items that were developed for the authors' instrument were intended to capture software process characteristics at each of the levels of the framework. Items for four of the five levels were included, as no items were written for the first level. In the summer of 1998, a pilot study was conducted in order to assess the authors' maturity items for face validity, reliability, and construct validity. Some changes were made to the items as a result of the pilot study. It was thought that the questionnaire items might factor into four dimensions, with each dimension being made up of the items written to characterize that level of the framework. Initially, the pilot test on 39 software project managers and developers indicated that four factors were present in the data, but that some of the items meant to represent level 2 (repeatable) loaded on level 3 (defined) and vice-versa. The revised instrument contained ten items: four items intended to characterize level 2 (repeatable), two for level 3 (defined), three for level 3 (measured) and one for level 5 (optimizing).

Software process customizability represents another aspect of process maturity and is defined as "the extent to which an organization's software process is able to be tailored to the specific needs of individual projects" (Nidumolu and Knotts, 1998). This construct is based on the idea that higher levels of software process maturity are associated with having a well-defined software process that is easily adapted to a variety of different circumstances and situations, such as changes in personnel, the application domain, and technology. Nidumolu and Knotts developed and empirically validated a seven-item, Likert-scaled customizability construct.

The questions posed by this study deal with the usefulness of the two constructs. Are process maturity—as operationalized by the authors—and process customizability different constructs? If so, are they

positively correlated, as one would expect of two similar constructs based on the same underlying concept? And, do these measures provide a parsimonious estimate of maturity level as defined by the SEI's CMM?

Method

In the fall of 1998, a Web-based survey was then administered to members of the Information Systems SIG of the Project Management Institute (PMI), a professional organization devoted to the advancement of project management knowledge. This second study was part of a larger study designed to examine technology deployment in software development teams, using recently adopted visual application development tools. The respondents were software project managers working in a variety of different types of organizations. A total of 362 completed surveys were received and analyzed.

The author's ten-item instrument using five-point Likert-scaled items, ranging from strongly disagree (one point) to strongly agree (five points), was the basis of the author's maturity construct. The customizability items used by Nidumolu and Knotts (1998), also using five-point Likert scales, were included in the survey instrument without modification.

In addition, each of the respondents was asked to report the most recent CMM-assessment level for their organization, if applicable. CMM assessment is based on an objective evaluation of activities that fall under 18 key process areas related to maturity (Paulk, et al., 1993).

Results

A summary of the data analyzed is listed in Table 1. The minimum and maximum possible mean scores ranged from 1.0 to 5.0. Higher scores indicate higher levels of the construct.

A factor analysis was performed to assess the convergent and discriminant validity of the constructs. A three-factor model explained 68% of the variance in the data set. The items factored into three constructs with factor loadings greater than 0.5 and no cross-loadings. All seven customizability items loaded into a single factor. The authors' maturity level construct loaded into two factors. The items that loaded into the first factor were items designed to assess an organization's compliance with levels 2 and 3 of the Capability Maturity Model, namely that software projects were well-managed and controlled (level 2—repeatable), and that the organization's software process was well-defined (level 3—defined). The items that loaded into the second factor were items assessing an organization's compliance with levels 4 and 5 of the CMM, namely the extent to which the software process was quantitatively measured and managed (level 4—measured) and continuously optimized using quantitative feedback (level 5—optimized). These two factors were retained and subsequently termed *manageability* and *measurability*. Respondents clearly differentiated between the idea of defining and managing a software process from the idea of measuring and optimizing the process quantitatively. All of the reliability coefficients were above Nunnally's (1978) suggested range of .6 to .8 for research in a new area.

Table 1 – Process Maturity Construct Summary

Construct	N	Items	Mean	Standard Deviation	Reliability Coefficient
Manageability	328	6	3.31	.91	.91
Measureability	332	4	2.83	1.01	.92
Customizability	335	7	3.69	.76	.93

Having found evidence that the constructs were reliable and were measuring different things, an analysis was performed on each of the pairs of constructs to examine the extent to which the pairs of constructs were correlated. The results indicated that each of the pairs of constructs was correlated. All of the Pearson coefficients, which ranged from .529 to .691, were statistically significant beyond the .01 level (see Table 2).

Table 2 - Correlation Coefficients

Pairs of Dimensions	Pearson Coefficient
Manageability-Measureability	.691
Customizability-Manageability	.674
Customizability-Measureability	.529

As an additional test of convergent validity, each of the three maturity constructs were compared with the self-report of CMM-level obtained in the survey. A total of 52 organizations reported CMM assessments of 1 (N=21), 2 (N=21), or 3 (N=10), as none of the organizations had achieved a level 4 or 5 assessment.

A one-way analysis of variance test was performed to determine whether the mean values for each of the three maturity constructs differed with respect to self-reported CMM-level. With respect to manageability and measureability, the mean values for these constructs

increased with increasing CMM-level (see Table 3). The ANOVA produced statistically significant F-statistics for both measureability and manageability at the .01 level, which indicated that at least one CMM-level group differed from the other two groups. Tukey post-hoc HSD tests indicated that level 1 groups differed significantly from the level 2 and level 3 groups, as expected. However, the difference between level 2 and level 3 groups was not statistically significant.

Table 3 – Maturity Constructs vs. CMM-Level

Construct	CMM Level	N	Mean	Standard Deviation
Manageability	1	21	3.07	.76
Manageability	2	21	3.86	.83
Manageability	3	10	4.08	.73
Measureability	1	21	2.36	.57
Measureability	2	21	3.33	1.22
Measureability	3	10	3.58	1.14
Customizability	1	21	3.61	.80
Customizability	2	21	4.04	.87
Customizability	3	10	3.83	.91

The ANOVA for customizability did not produce a statistically significant F-statistic, so it could not be concluded that the three CMM-level groups differed with respect to customizability.

Discussion

The results of the factor analysis and scale reliability analyses indicate that there are at least three separate and distinct dimensions of maturity. Each of these measures is reliable, and, as expected of closely related constructs, they are all statistically significantly correlated. These analyses provide evidence of convergent and discriminant validity.

The ANOVA and post-hoc Tukey HSD tests both lent some support to the notion that the manageability and measureability dimensions were able to differentiate between level 1 (initial) and 2 (repeatable) and level 1 and level 3 (defined). However, there was no statistically significant evidence to suggest that these dimensions could distinguish between levels 2 and 3. Customizability was not found to be a statistically significant indicator of CMM-assessed maturity level for this data set, based on the results of the ANOVA. Manageability and measureability, therefore, were better estimators of CMM-level, for this data set.

Conclusions

The evidence suggests that there are reliable and valid ways to measure software process maturity in survey-based designs. However, there are several different aspects of maturity, and researchers should be careful about which aspects of maturity are appropriate for their research. If an organization wishes to assess itself, the CMM questionnaire is probably the best way, since it focuses on the objective performance of activities and is directly associated with the target objective—CMM-based process improvement. But, for researchers interested in assessing maturity level in relation to antecedents and outcomes, the measures presented here may provide a realistic way to assess maturity level for both CMM and non-CMM organizations in survey-based designs.

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