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A PROCESS IMPROVEMENT MODEL BASED ON QUANTITATIVE MANAGEMENT FOR SMALL AND MEDIUM SIZED SOFTWARE ORGANIZATIONS

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Abstract
Nowadays, software process improvement (SPI) is a way for strengthening the productivity and the competitiveness even for small and medium sized organizations, not to mention for large sized ones. However, it is a fact that small and medium sized organizations have limited amounts of the required resources and times to reach high maturity of maturity of models such as CMMI. In addition, there is very little research on quantitative process management approaches, suitable for small and medium sized organizations. In this paper, we propose a simple process improvement model based on quantitative management which might be used by small and medium sized organizations, and show an example applied it for a development team of a small sized organization.

Keywords:
Software Process Improvement (SPI), Capability Maturity Model Integration (CMMI), Customer Satisfaction

1. INTRODUCTION

Software process improvement (SPI) is a systematic approach by which software organizations can increase effectiveness and efficiency of their processes to raise up their products [2]. CMMI, developed by the Software Engineering Institute (SEI) to describe the principles and practices as the base of software process maturity, consists of 5 levels, and out of the five levels, Levels 4 & 5 reflects the high maturity of the organization, where the concept of a process performance model exists as the base of high maturity. CMMI 4 level involves to manage the key processes of the organization quantitatively and statistically, that is, 1) using statistical and quantitative techniques to find or correct issues of important practical activities and to predict achievements of goals in quality and process performance capabilities, 2) measuring variations of performance capabilities to manage the progresses based on them [1].

In the entire world, most of software organizations are small and medium sized, not large sized, and such small and medium sized ones play great roles in the software industry. Significant amounts of software are being produced by small firms with 1 ~ 50 developers [28]. In 2001, small and medium sized organizations account for 77% and 69% in Europe and America respectively [4, 33]. And the Bureau of Statistics of a country in Southeast Asia reports in 2017 that their small and medium sized organizations reach upward of 97.3% in total [6, 7].

Most software organizations, which have not implemented any methodologies for software process improvements, appropriate large costs for production and maintenance, and are not on the same level with the organizations that pose process improvement methods and nudged out in competition [8, 9, 10].

At this present, in relation to software engineering and software development, studies admit that there is a drastic distinction between the small, medium sized organizations and the large ones in their operations [11, 12].

High maturity in software development involves statistically controlling the performance of critical sub processes and using the predictability thus gained to manage projects with better planning precision and monitoring control [24].

There are proposed many study cases and methods that might be used by small and medium sized organizations to improve their processes, but there is little research on managing processes quantitatively to reach CMMI level 4 in such organizations.

The main contributions of our work are as follows:

- We propose a concise process improvement model based on quantitative management, which might be used in small and medium sized organizations, and demonstrate an effectiveness of the model through an application case. This new improvement model is a combination of the DMAIC (Define, Measure, Analyze, Improve, Control) model [23] and the multiple linear regression analysis.
- For the analysis technique, we describe the detailed formulas so that the analysis may be conducted without inquiring the application of Mathematical statistics to their process improvement initiatives in small and medium sized organizations.

The rest of the work is as follows. Section 2 gives an overview of literature on SPI and quantitative process management in small and medium sized organizations, and Section 3 presents a model for quantitative process management in medium sized organizations. Section 4 describes the issues, which might be encountered during applying the model, through an application case, and Section 5 concludes the paper.

2. RELATED WORK

There are some international standards such as CMMI, ISO 9001 and ISO 15504 (also called as SPICE), which are used extensively to improve software processes. Maturity Models such as CMMI mention statistical and quantitative methods, techniques and tools which may be used to support a high maturity of project managements, but do not provide their details, usages and available types. Thus, in such situations there is a lack of knowledge about how to select and apply statistical and quantitative methods, techniques and tools to support SPIs. In addition, small and medium sized organizations understand that SPI is very important for them, but they typically are short of knowledge and resources for implementation of SPIs. And there are many studies on SPI, but they mostly are associated with large organizations, and there are not many in connection with small and medium ones [13., 14].

Michael et al. [2] aim to identify and characterize evaluation strategies and measurements used to assess the impact of different

SPI initiatives, and select 148 papers published between 1991 and 2008, and classify them according to SPI initiative, applied evaluation strategies and measurement perspectives, and assess potential confounding factors interfering with the evaluation of the improvement effort.

Cristina C. et al. [24] aim to identify various methods, techniques and tools which can assist in high-maturity software project management, and by conducting a systematic literature mapping, identify 108 papers describing 153 contributions. And they describe the contributions identified, classifying them by their type, their software technology maturation phase, the method by which they were evaluated, the development methods and characteristics which they support, and the process/indicator areas to which they were applied.

Muhammad A. A. et al. have identified a total of 20 barriers for outsourcing software development activities, have performed organization types (client and vendor), organization size (small, medium, large) and experts' levels (junior, intermediate, and senior) based analysis to provide a clear understanding of the RE (Requirements Engineering) barriers in the three different context, and have developed a theoretical framework by mapping the identified barriers into six score knowledge areas of software process improvement [3].

Measurement of software processes is a substantial component in ensuring that process artifacts meet quality requirements and that predictable performance and high capability are attained. In this way, it is considered that software measurement is essential in improving software processes and products because efforts for SPI deal with wrong issues if processes (or artifacts) are not measured and evaluated [15].

Empirical results show that software measurement is an indispensable component for each SPI program or improvement effort and is an important factor for success of the work [16]. The feedbacks, collected from evaluation of software measurements and improvement efforts, provide at least two benefits: 1) giving insight into the results to stimulate and justify efforts for the work, 2) enabling to assess SPI strategies [17]. However, in the same instant, it is difficult to establish and implement the measurement plans which would provide a relevant and helpful information to make decisions [18]. There is little consensus about what to measure and how to measure, and it is considered that doing have not a systematic and reliable approach is a contributing factor to high failure of the improvement initiatives [19].

Organizations should have a strong definition for metrics across the organization, the ability to capture the metrics and analysis the metrics is the base even before getting into high maturity [21].

Process Performance Model (PPM) helps to pro-actively predict the outcomes and take preventive actions [22].

Zhang et al. [5] provide a concrete implementing scheme for organizations to proceed to high maturity improvement, based on the quantitative process management and persistent process improvement of CMMI and the model for process implementation and improvement with DMAIC [23].

Usama et al. propose an approach, i.e. BBSPI (Blockchain-Based Software Process Improvement) to perform SPI for the SMEs, and affirm that the BBSPI can reduce the time, cost, resources and helps to manage knowledge used to perform SPI [27]. Muhammad et al. present a new software development life cycle model, "AZ-Model", for software development by introducing new activities during software development life cycle, and assert that the model overcomes the limitations of traditional models and impacts the production of a quality product in a time-box [29].

Anu et al. [30] have developed a process modeling technique called LAPPI that documents current 'as-is' processes and have said that small-to-medium sized software development organizations can use LAPPI to highlight where improvements are needed in support services.

Carlos et al. [5] propose a framework "FQMaP" which allow incorporating practices and techniques that support quantitative management of software development processes in small software development organizations.

Venkatesh et al. [20] present a customer satisfaction model design and describe an instance which they apply the model to predict the customer satisfaction of 15 projects of their company.

In the next session, we describe a process improvement model which might be used by small and medium sized organizations.

3. A PROCESS IMPROVEMENT MODEL BASED ON QUANTITATIVE MANAGEMENT

We propose a DMAIC type of a process improvement model on quantitative management. The model consists of the steps, shown in Fig. 1.

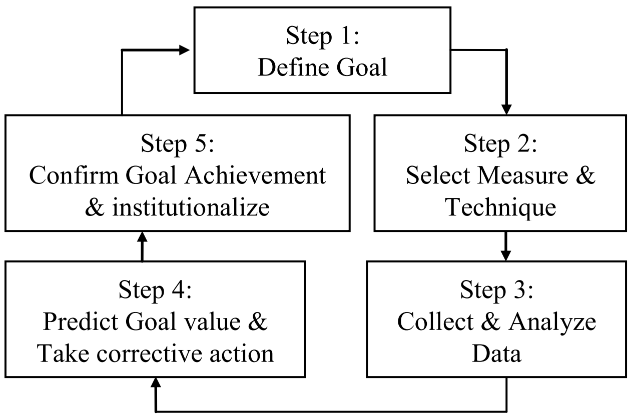

Fig.1. The improvement model

- Step 1: Define a quality or performance goal to be improved through quantitative managements. For example, the goal may include improving of customer satisfactions, decreasing of costs, and so on.
- Step 2: Select measures which may impact on achievement of the goal. For example, if the goal is improvement of customer satisfaction, then schedule variation, effort variation and default leakage may be defined as measures.

And choose an analysis technique. For example, the multiple linear regression models may be selected as an analysis technique, as in [20]:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_p x_p .$$

In this model, y is an independent variable (e.g. customer satisfaction score), $x_1, x_2, ...x_p$ are dependent variables (e.g. schedule variation, effort variation and default leakage …) and $\beta_0, \beta_1, \beta_2, ...\beta_p$ are regression coeffiicients.

Step 3: Collect measurement data and conduct analysis.

The data of the independent variable and the dependent variables are collected. Then, it is important that should satisfy for ensuring the uniqueness of solutions of the following regression equation (3), and, moreover, according to the central limit theorem, should be considerably great for increasing the approximation rating of the regression expression (1).

Table.1. Measurement data

№	Dependent Variables				Independent Variable y_i
	x_{i1}	x_{i2}	…	x_{ip}	
1	x_{11}	x_{12}	…	x_{1p}	y_1
2	x_{21}	x_{22}	…	x_{2p}	y_2
…					
N	x_{N1}	x_{N2}	…	x_{Np}	y_N

Then calculate the regression coefficients:

$$\hat{y} = \hat{\beta}_0 + \hat{\beta}_1 x_1 + \hat{\beta}_2 x_2 + ... + \hat{\beta}_p x_p \tag{1}$$

where

$$Y = \begin{pmatrix} y_1 & y_2 & \cdots & y_N \end{pmatrix}^T$$

$$X = \begin{pmatrix} 1 & x_{11} & x_{12} & ... & x_{1p} \\ 1 & x_{21} & x_{22} & ... & x_{2p} \\ ... & ... & ... & ... & ... \\ 1 & x_{N1} & x_{N2} & & x_{Np} \end{pmatrix} \tag{2}$$

$$\hat{\beta} = \begin{pmatrix} \hat{\beta}_0 \\ \hat{\beta}_1 \\ ... \\ \hat{\beta}_p \end{pmatrix} = (X^T X)^{-1} X^T Y \tag{3}$$

3.1 CORRELATION ANALYSIS

First, calculate the correlation coefficients between the independent variable $Y = (y_i), i = \overline{1, N}$ and the kth dependent variables $X_k = (x_{ik}), i = \overline{1, N}$:

$$r_{YX_k} = \frac{1}{N-1} \sum_{i=1}^{N} (\frac{x_{ik} - \overline{x_k}}{s_{X_k}})(\frac{y_i - \overline{y}}{s_Y}) \tag{4}$$

where

$$\overline{y} = \frac{1}{N} \sum_{i=1}^{N} y_i \tag{5}$$

is the mean of Y,

$$\overline{x_k} = \frac{1}{N} \sum_{i=1}^{N} x_{ik} \tag{6}$$

is the mean of X_k,

$$s_Y = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (y_i - \overline{y})^2} \tag{7}$$

is the standard deviation of Y and

$$s_{X_k} = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_{ik} - \overline{x_k})^2} \tag{8}$$

is the standard deviation of X_k.

Next, in general, if the correlation coefficient is positive, then the independent variable increases as the dependent variable increases, and if the correlation coefficient is negative, then the independent variable decreases as the dependent variable increases.

And when the absolute value of a correlation coefficient is nearly zero, conclude the dependent variable to be nearly unrelated to the independent variable, turn back to Step 2, and select the measures again.

3.2 ANALYZE A COEFFICIENT OF DETERMINATION OF THE REGRESSION MODEL

First, calculate the coefficient of determination:

$$R^2 = SR / ST \tag{9}$$

where

$$ST = \sum_{i=1}^{N} (y_i - \overline{y})^2 \tag{10}$$

is the total variation,

$$SR = \sum_{i=1}^{N} (\hat{y}_i - \overline{y})^2 \tag{11}$$

is the regression variation and

$$\hat{y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_{i1} + \hat{\beta}_2 x_{i2} + ... + \hat{\beta}_p x_{ip} \tag{12}$$

is the regression value of the independent variable Y.

Next, analyze the coefficient of determination R^2.

In general, if the coefficient of determination R^2 is more than 0.8 (i.e., 80%), then it may be concluded that the regression model is adequate in principle. If not so, turn back to Step 2 and add some dependent variables to the model or select them again.

3.3 TESTING THE USABILITY OF MODEL [26]

First, identify the hypothesis and calculate the required values to testing.

$$H_0 \text{ (Null hypothesis: } \beta_1 = \beta_2 = ... = \beta_p = 0 \tag{13}$$

H_a (Alternative hypothesis): At least one of the β parameters (except β_0) is nonzero, (14)

$$\text{RR: } F > F_\alpha(p, N-(p+1)) \tag{15}$$

where $(1-\alpha)$ is a significance level,

$$F = \frac{R^2 / p}{(1-R^2)/(N-(p+1))} \tag{16}$$

is F-static and

$$F_\alpha(p, N-(p+1)) \tag{17}$$

is F-distribution value.

Next, analyze it.

If the inequality in Eq.(15) holds, then we may conclude that the regression model is useful, in other words, that it may be confident at $(1-\alpha)$ significance level. If not so, turn back to Step 2 and select dependent variables again.

Step 4: Predict a goal value for the future and take corrective actions to achieve the goal.

First, calculate the confidence intervals (at confidence coefficient $(1-\alpha)$) for the mean of the kth dependent variables X_k based on t-distribution. [26]

$$(\bar{x}_k - t_{\alpha/2}\frac{s_{x_k}}{\sqrt{N}}, \bar{x}_k + t_{\alpha/2}\frac{s_{x_k}}{\sqrt{N}}) \tag{18}$$

where

$$\bar{x}_k = \sum_{i=1}^{N} x_{ik} / N \tag{19}$$

is the mean of x_k,

$$s_{x_k} = \sqrt{\sum_{i=1}^{N}(x_{ik} - \bar{x}_k)^2 / (N-1)} \tag{20}$$

is the standard deviation of x_k and $t_{\alpha/2}$ is t-distribution value with $(N-1)$ degree of freedom.

Next, calculate the prediction intervals (at coverage probability $(1-\alpha)$) for the next measurement value X_{N+1k} of the kth dependent variables X_k based on t-distribution:

$$(\bar{x}_k - t_{\alpha/2}\frac{s_{x_k}}{\sqrt{1+\frac{1}{N}}}, \bar{x}_k + t_{\alpha/2}\frac{s_{x_k}}{\sqrt{1+\frac{1}{N}}}) \tag{21}$$

In general, the prediction interval is wider than the corresponding confidence interval.

Now, being accordant to the meaning (up or down) of the independent variable and the correlation coefficients between the independent variable and the dependent variables, choose the dependent variable values x_{Gk} and set the corresponding independent variable value

$$\hat{y}_G = \hat{\beta}_0 + \hat{\beta}_1 x_{G1} + \hat{\beta}_2 x_{G2} + ... + \hat{\beta}_p x_{Gp} \tag{22}$$

as the goal to be achieved in the future. At this time, avoid choosing the values out of the above intervals if possible.

Then take corrective actions to achieve the goal.

Step 5: Confirm Goal Achievement and institutionalize.

After some months, first, measure the independent variable and the dependent variables and conclude whether the independent variable value has reached the goal value set before or has been improved.

And if it has been improved, then make it a rule to do keep the processes even in future.

4. AN APPLICATION CASE

In this section we describe our experience of quantitative process management implemented in a small sized software organization according to the above model.

4.1 GOAL DEFINITION

A goal may be defined at organization or at project.

We targeted for the project "Developping and Providing A Computer Vaccine" and, with PM and members of this project team, agreed that aiming at improving customer satisfaction for this project, we would apply the above model to the project. The project is a long-term ongoing project which has provided domestic users with the computer vaccine for more than 20 years.

4.2 SELECTION OF DEPENDENT VARIABLES & TECHNIQUE

In collaboration with the project members, we selected requirements implementation, requirements change, test & review, designer capability, coding capability, tester capability as the dependent variables which can have impacts on the customer satisfaction score. These variables are defined as follows.

- Requirements implementation (x_1) = the number of the implemented requirements / the number of the confirmed requirements, where a requirement is an opinion or feedback, a new virus report from users of users of the computer vaccine via the computer vaccine service website or a new function from inside of the project,
- Requirement change (x_2) = the number of the changed requirements / the number of the confirmed requirements,
- Test and review (x_3) = the number of resolved issues / the number of submitted issues from testing and reviewing, and
- Designer capability (x_4) = the average term of development + the average term of design of the designers,
- Coding capability (x_5) = the average term of development + the average term of design of the coding members,
- Tester capability (x_6) = the average term of development + the average term of test of the testers.

For the customer satisfaction scores, we put a questionnaire (Table.2) before users of the computer vaccine and decided the score from their answers.

Table.2. Questionnaire

Question	Answer
1. Functionality satisfaction How satisfactory would you feel on the product from the viewpoint of functionality? (Easy-use, accuracy, and so forth)	
2. Performance satisfaction How satisfactory would you feel on the product from the viewpoint of performance? (Processing speed, virus kinds, and so forth)	
3. Quality satisfaction	

How satisfactory would you feel on the product from the viewpoint of quality? (Error, user interface, manual, installing, usage, and so forth)	

In the above table, Users answered one of the 5 ratings, i.e., “very high”, “high”, “usual”, “low” and “very low” to each question, and the scores were respectively 10, 8, 6, 4 and 2.

Customer satisfaction score (y) = 0.3×Functionality satisfaction + 0.2×Performance satisfaction + 0.5×Quality satisfaction.

And we decided to use the multiple regression in statics.

4.3 COLLECTION AND ANALYSIS OF DATA

We and members of the project collected data (requirements implementation (x_1), requirements change (x_2), test & review (x_3), designer capability (x_4), coding capability (x_5), tester capability (x_6), customer satisfaction score (y)) from the histories that have been recorded and logged while developing and providing the computer vaccine for the last five years. The data were as follows.

Table.3. Measurement data (collected)

№	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	y_i
1	0.83	0.09	0.9	13	12	16	8.7
2	0.94	0.06	0.97	25	17	22	8.983
3	1	0.02	0.98	20	16	24	9
4	0.85	0.06	0.96	8	9	18	8.802
5	0.99	0.01	0.9	15	11	13	8.8
6	0.84	0.02	0.88	22	5	21	8.6
7	0.87	0.05	1	12	7	22	8.871
8	0.82	0	0.86	22	11	14	8.719
9	0.89	0.02	0.95	25	13	14	8.887
10	0.87	0.07	1	7	5	19	8.842
11	0.91	0.06	0.93	9	13	24	8.857
12	0.83	0.01	0.86	24	5	16	8.714
13	0.85	0.05	0.98	23	7	16	8.854
14	0.89	0.07	0.88	14	5	13	8.7
15	0.87	0.02	0.86	6	9	14	8.708
16	0.84	0.03	0.93	5	14	25	8.788
17	0.91	0.06	0.96	8	6	14	8.8
18	0.8	0.08	0.89	5	19	16	8.715
19	1	0.06	0.92	25	11	10	8.94
20	0.84	0.04	0.94	15	8	14	8.782
21	1	0.02	1	7	20	14	9
22	0.82	0.1	0.86	18	19	14	8.7
23	0.91	0.04	0.92	23	9	13	8.79
24	0.98	0.02	0.99	19	10	13	8.9
25	0.91	0.06	0.94	15	7	23	8.859
26	0.92	0.01	0.87	22	19	14	8.7
27	0.86	0	0.93	21	17	11	8.8
28	0.84	0.08	0.95	19	13	17	8.83
29	0.81	0.01	0.89	6	10	18	8.6
30	0.8	0.04	0.9	22	5	16	8.72
31	0.98	0.05	0.94	17	17	22	8.9
32	0.83	0.1	0.85	14	6	13	8.6

First, the correlation coefficients between the independent variable (customer satisfaction) and the dependent variables were calculated:

$$r = \begin{pmatrix} r_{YX_1} \\ r_{YX_2} \\ r_{YX_3} \\ r_{YX_4} \\ r_{YX_5} \\ r_{YX_6} \end{pmatrix} = \begin{pmatrix} 0.735 \\ -0.063 \\ 0.809 \\ 0.155 \\ 0.340 \\ 0.236 \end{pmatrix}$$

And the regression coefficients were estimated:

$$\hat{\beta} = \begin{pmatrix} \hat{\beta}_0 \\ \hat{\beta}_1 \\ \hat{\beta}_2 \\ \hat{\beta}_3 \\ \hat{\beta}_4 \\ \hat{\beta}_5 \\ \hat{\beta}_6 \end{pmatrix} = \begin{pmatrix} 6.7329 \\ 0.6580 \\ 0.2188 \\ 1.4608 \\ 0.0029 \\ 0.0043 \\ 0.0016 \end{pmatrix}$$

And then the coefficient of determination R^2 was calculated:

$$ST = \sum_{i=1}^{N} (y_i - \bar{y})^2 = 0.3740 ,$$

$$SR = \sum_{i=1}^{N} (\hat{y}_i - \bar{y})^2 = 0.3390 ,$$

$$R^2 = SR / ST = 0.8847 .$$

That is, the coefficient of determination was 88.47(%), thus relatively high. However, the correlation coefficient $r_{YX_2} = -0.0603$ for the 2nd dependent variable (requirements change) and the correlation coefficient $r_{YX_4} = 0.155$ for the 4th dependent variable (designer capability) were less in absolute value. Thus, we decided to eliminate the two dependent variables from the model.

Table.4. Measurement data (eliminated)

№	x_{i1}	x_{i3}	x_{i5}	x_{i6}	y_i
1	0.83	0.9	12	16	8.7
2	0.94	0.97	17	22	8.983
3	1	0.98	16	24	9
4	0.85	0.96	9	18	8.802
5	0.99	0.9	11	13	8.8

6	0.84	0.88	5	21	8.6
7	0.87	1	7	22	8.871
8	0.82	0.86	11	14	8.719
9	0.89	0.95	13	14	8.887
10	0.87	1	5	19	8.842
11	0.91	0.93	13	24	8.857
12	0.83	0.86	5	16	8.714
13	0.85	0.98	7	16	8.854
14	0.89	0.88	5	13	8.7
15	0.87	0.86	9	14	8.708
16	0.84	0.93	14	25	8.788
17	0.91	0.96	6	14	8.8
18	0.8	0.89	19	16	8.715
19	1	0.92	11	10	8.94
20	0.84	0.94	8	14	8.782
21	1	1	20	14	9
22	0.82	0.86	19	14	8.7
23	0.91	0.92	9	13	8.79
24	0.98	0.99	10	13	8.9
25	0.91	0.94	7	23	8.859
26	0.92	0.87	19	14	8.7
27	0.86	0.93	17	11	8.8
28	0.84	0.95	13	17	8.83
29	0.81	0.89	10	18	8.6
30	0.8	0.9	5	16	8.72
31	0.98	0.94	17	22	8.9
32	0.83	0.85	6	13	8.6

Then, repeating the above calculations,

$$r = \begin{pmatrix} r_{YX_1} \\ r_{YX_3} \\ r_{YX_5} \\ r_{YX_6} \end{pmatrix} = \begin{pmatrix} 0.7350 \\ 0.8090 \\ 0.3395 \\ 0.2361 \end{pmatrix},$$

$$\hat{\beta} = \begin{pmatrix} \hat{\beta}_0 \\ \hat{\beta}_1 \\ \hat{\beta}_3 \\ \hat{\beta}_5 \\ \hat{\beta}_6 \end{pmatrix} = \begin{pmatrix} 6.8021 \\ 0.7054 \\ 1.4186 \\ 0.0041 \\ 0.0008 \end{pmatrix},$$

$$ST = \sum_{i=1}^{N} (y_i - \overline{y})^2 = 0.3740,$$

$$SR = \sum_{i=1}^{N} (\hat{y}_i - \overline{y})^2 = 0.3200,$$

$$R^2 = SR / ST = 0.8555.$$

That is, the coefficient of determination R^2 was 85.55(%) and still high.

Next, we did significance testing for the model. By the formula

$$N = 32, p = 4, F = \frac{R^2 / p}{(1 - R^2) / (N - (p+1))} = 39.957$$

And at $\alpha = 0.05$

$$F_\alpha(p, N - (p+1)) = 5.76.$$

So the inequality held as follows:

$$F > F_\alpha(p, N - (p+1)).$$

Thus we could reject the null hypothesis and be 95% significantly confident that the model was useful.

4.4 GOAL VALUE PREDICTION AND CORRECTIVE ACTIONS

We calculated the mean of the dependent variable, the means and the standard deviations of the dependent variables according to the Eq.(5), Eq.(19) and Eq.(20).

$$\overline{y} = 8.7957,$$

$$\begin{pmatrix} \overline{x}_1 \\ \overline{x}_3 \\ \overline{x}_5 \\ \overline{x}_6 \end{pmatrix} = \begin{pmatrix} 0.8844 \\ 0.9247 \\ 11.094 \\ 16.656 \end{pmatrix},$$

$$\begin{pmatrix} s_{x_1} \\ s_{x_3} \\ s_{x_5} \\ s_{x_6} \end{pmatrix} = \begin{pmatrix} 0.0635 \\ 0.0467 \\ 4.8484 \\ 4.1474 \end{pmatrix}.$$

When $\alpha = 0.05$ and the degree of freedom is $(N-1)$,

$$t_{\alpha/2} = 1.645.$$

Thus, by the formula in Eq.(18), the confidence intervals were

x_1: (0.8624, 0.9064),

x_3: (0.9085, 0.9409),

x_5: (9.414, 12.774),

x_6: (15.219, 18.093).

And, by the formula in Eq.(21), the prediction intervals were

x_1: (0.7618, 1.0070),

x_3: (0.8346, 1.0148),

x_5: (1.7360, 20.452),

x_6: (8.651, 24.661).

Because values of the first two dependent variables range between 0 and 1, for the prediction intervals the upper limits of the two dependent variables should be 1. Thus, the prediction intervals were corrected as follows:

x_1: (0.7618, 1.000),

x_3: (0.8346, 1.000),

x_5: (1.7360, 20.452),

x_6 : (8.651, 24.661).

With the project members including the PM, we chose the dependent variable values x_{G_k} to be reached.

$$\begin{pmatrix} x_{G_1} \\ x_{G_3} \\ x_{G_5} \\ x_{G_6} \end{pmatrix} = \begin{pmatrix} 0.97 \\ 1.0 \\ 21 \\ 24 \end{pmatrix}$$

And we set a goal to reach

$$\hat{y}_G = \hat{\beta}_0 + \hat{\beta}_1 \times 0.97 + \hat{\beta}_3 \times 1.0 + \hat{\beta}_5 \times 21 + \hat{\beta}_6 \times 24 = 9.009$$

in the near future.

Then the project members discussed and decided the corrective actions for reaching the chosen dependent variable values x_{G_k}.

4.5 CONFIRMATION OF GOAL ACHIEVEMENT AND INSTITUTIONALIZATION

After 3 months since then, the project members measured the 4 dependent variables (requirements implementation (x_1), test & review (x_3), coding capability (x_5), tester capability (x_6)) and the independent variable (customer satisfaction score (y)). It turned out as follows.

$$\begin{pmatrix} x_{M_1} \\ x_{M_3} \\ x_{M_5} \\ x_{M_6} \\ y_M \end{pmatrix} = \begin{pmatrix} 0.969 \\ 0.988 \\ 20.4 \\ 23.7 \\ 8.994 \end{pmatrix}$$

And the prediction value of the customer satisfaction based on the regression model would been

$$\hat{y}_M = \hat{\beta}_0 + \hat{\beta}_1 \times 0.969 + \hat{\beta}_3 \times 0.988 + \hat{\beta}_5 \times 20.4 + \hat{\beta}_6 \times 23.7 = 8.988$$

And the actual measurement value $y_M = 8.994$ did not reach the goal value $\hat{y}_M = 9.009$, however the actual value was not only much high than the previous mean $\bar{y} = 8.796$ but also very close to the previous max value $y_{max} = 9.00$.

Therefore, we could conclude that the customer satisfaction has been improved. And we could affirm that it is essential to increase requirements implementation (x_1), test & review (x_3), coding capability (x_5) and tester capability (x_6) in the computer vaccine project.

5. DISCUSSION

The model we proposed in this study is an approach to process improvement initiatives performed in small and medium sized organizations.

As mentioned in the articles [31], [32], most of the small and medium sized organizations do not perform process improvement due to cost and time involved in the organizations. Also, there is little research on managing their processes quantitatively to reach CMMI level 4 in small and medium sized organizations.

Therefore, our main aims of this research are to:

- Define a concise process improvement model which might be used to manage their processes quantitatively and improve them in small and medium sized organizations.
- Describe an application of the defined model step-by-step.

We applied the proposed model to develop and provide the computer vaccine in our organization and could increase customer satisfaction of the processes from 8.796 up to 8.994. And the results of this study are compared with those of the study [20] as follows.

Table.5. Comparison with the study [20] from some aspects

№	Aspect	The study [20]	This study
1	Process improvement model	Not mentioned	DMAIC type [23]
2	Analysis technique	Multiple linear regression model	Multiple linear regression model, with detailed formulas, equations, and expressions
3	Prediction and Analysis of Goal	By regression expression	By Regression expression
4	Setting and Confirmation of Goal	Not mentioned	Using Regression expression, confidence intervals, and, prediction intervals
5	Customer Satisfaction Improvement	Not mentioned	From 8.796 up to 8.994

However, our results aren't being generalized to other cases. We applied the proposed model to process improvement of only one project and for the analysis technique we descried the simplest multiple linear regression, but not put knowledge of Mathematical statistics to good use, including polynomial regression, exponential regression, and so on.

6. CONCLUSION

In this study, we proposed a process improvement model based on quantitative management, which looks suitable for small and medium software organizations, and considered an example in which the model is applied to a project of our organization.

In the course of this, we encountered some challenges. First, the organization lacked in basic knowledge of mathematical statistics, on that ground, in the early days the goal was not achieved and appeared unrelated to predictions and the corrective actions. Next, the project members did not show activeness for applying the model to their project, on that ground, it was difficult to collect the data.

And, from what we have experienced, software organizations can develop and use a statistic program of this caliber well within their power, without purchasing commercial programs, only so it will helpful to process improvement initiatives of their organizations.

Importantly, for small and medium software organizations, studies on process improvement including quantitative managements should not be mere theories, and it seems necessary to research and develop simple and practical process improvement models, fitting in with their actual conditions under which they have limited amounts of resources and times.

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