Controlling a Software Development Process by Predicting the Effect of Improvements

Hachiro HONDA*, Masashi AISO**, and Keiichi SUZUKI*

Abstract

We have established a continuous quality improvement process by applying the Capability Maturity Model Integration (CMMI) method to our software development activities. The process consists of the following steps: (1) analyzing the key performance indicators of each development phase, (2) predicting the effect of improvements based on the analysis, and (3) monitoring and controlling the quality and cost. In upgrading from the CMMI level 4 to level 5, we focused on improvement of quality in the early development phases and achieved three times better quality in system tests.

1. Introduction

Fujifilm has been providing high-functionality, high-performance products in diverse fields including medical services with software playing an enabling role in these activities. In recent years, with the progress of IT innovation and the trend for larger and more complex software systems, software development capabilities have become even more important, requiring the improvement of software development management and quality control techniques.

Under such circumstances, to achieve an improvement of quality, cost and delivery (QCD), the Software Research & Development Center of FUJIFILM Corporation and FUJIFILM Software Co., Ltd. (hereinafter “we”) have jointly been conducting software development process improvement activities based on the Capability Maturity Model Integration (CMMI) model1 accepted worldwide.

In March, 2010, as an imaging unit development organization for X-ray image diagnosis systems (hereinafter the “medical console development organization”), we reached the CMMI Level 4 rating (hereinafter “L4”) and published our achievement in a research and development report, Introduction and Practice of Statistical Project Management Technique in Software Development2. Now, we are announcing that we have reached the highest CMMI Level 5 rating (hereinafter “L5”) by further improving our process management techniques.

Activities to improve our development processes from L4 to L5 included the following: data analysis of the organization; prediction of the effects of improvements; and the establishment of quality and cost monitoring/control techniques. In this paper, we will describe those activities in the light of improvement targets and the aim of improvement activities; our approach to process improvement activities; the confirmation of the effects of improvements; and the results of the acquired control techniques.

2. The improvement targets and the aim of improvement activities

We first clarified our improvement targets and the aim of improvement activities from business-oriented viewpoints and shared them within the organization.

(1) Process improvement targets from the viewpoint of business

In the past process improvement activities that brought us L4, we already reduced our development cost by more than 50%. In the latest improvement to acquire L5, focusing on making continuous process improvement take root throughout the organization, we set our target as the raising of productivity by 5% while improving work quality from L4.

(2) Our thought to cost reduction and the aim of improvement activities

Quality improvement and cost (workload) reduction are often regarded as contrary goals. However, the result of the statistical, organizational baseline analysis that we established to achieve L4 revealed that, by improving the quality of upper processes, corrective action workload can be reduced and this decreases overall cost. Therefore, in our improvement activities for L5, we targeted the improvement of the quality of upper processes.
3. Our approach to process improvement activities

To achieve our new target, improving productivity by 5%, we set our control target values for each process based on the organizational result data analysis and improvement prediction, and took action to improve all processes up to monitoring.

(1) Predicted values for improvements

i) Data analysis of the organization and extraction of improvements

All the projects of the medical console development organization involved in the current improvement activities were of product upgrades. Therefore, as the reference values for improvement analysis, we consulted the defects of the previous versions detected during system tests at the final test phase and those discovered on the market.

a) We created a fishbone diagram (i.e., Ishikawa diagram) for each project for the major factors of the above described defects and analyzed their root causes (Fig. 1).

b) We then created a tree chart from the root causes identified in a) and developed improvement plans. After assessing their effects and feasibility by giving them points, we selected several improvements to be executed from those having the highest scores (Fig. 2).
ii) Combination of improvements

The impact of each independent improvement may not be large. However, after summing up the individual effects of multiple improvements weighted in accordance with their scale, the total impact can be significant. According to that idea, we developed a tool to visualize the total impact of overall improvements for each process via an estimation based on the past statistical data (Table 1). The results given in the Total % row of the table revealed that, as we intended, defects in lower processes can be reduced by prior correction of those in upper processes.

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<tbody>
<tr>
<td>Improvement A</td>
<td>11%</td>
<td>11%</td>
<td>11%</td>
<td>-17%</td>
<td>-17%</td>
<td>-17%</td>
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<tr>
<td>Improvement B</td>
<td>-16%</td>
<td></td>
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<tr>
<td>Improvement C</td>
<td>6%</td>
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<tr>
<td>Improvement D</td>
<td>-4%</td>
<td>-2%</td>
<td>-15%</td>
<td></td>
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<tr>
<td>Improvement E</td>
<td>-5%</td>
<td>-7%</td>
<td>-14%</td>
<td>-17%</td>
<td>-28%</td>
<td>-39%</td>
</tr>
<tr>
<td>Total (%)</td>
<td>6%</td>
<td>15%</td>
<td>-4%</td>
<td>-17%</td>
<td>-28%</td>
<td>-39%</td>
</tr>
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Table 1 Degree of quality improvements.

iii) Simplified prediction of impact achieved by improvements

Normally, a t-test is used to assess a mean difference. However, following its regular procedures every time requires a considerable length of time for verification. Therefore, we created another tool that enables the simple confirmation of the results of improvements (Table 2). With this tool, it is possible to predict instantaneously whether the results of the executed improvement are statistically significant.

| Significance level $\alpha$ | 5% |
| Degrees of freedom $\phi$ | 23 |
| Pooled variance $V$ | 146.17 |
| Statistic $|t_0|$ | 2.77 |
| $|t_0| \\geq t (\alpha, \phi)$ ? | Yes (significantly different) |

Table 2 Simplified version of t-Test.

iv) Predicted values employed

To verify, in advance, whether the overall results of multiple improvements can reach the targets of the organizational process improvement activities and whether the impact is significantly different, we repeated steps ii) and iii) above and employed the final improvement plans. Table 3 shows, as an index for the improvement of the quality of software, the target defect density (the number of defects per thousand lines of code [i.e., kloc]) in system tests for L5 set based on the results for L4.

<table>
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<th>Target process</th>
<th>System test</th>
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<td>Improvement target for defect density</td>
<td>-48% from L4</td>
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Similarly, Table 4 shows the target total corrective action workload (hours per kloc) from system design to system test.

Table 4 Estimation of expected improvements in performance.

<table>
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<th>Improvement target for total corrective action workload from system design to system test</th>
<th>Total corrective action workload</th>
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<tr>
<td>-46% from L4</td>
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</table>

(2) Monitoring of the impact of improvements

Results data were monitored as described in i) to iii) below to check whether they would remain within the predicted control range. Methods i) and ii) were developed for L4 and iii) was newly added for L5.

i) In-process quality monitoring in each project

In each project, defect verification was conducted for all processes from system design respectively by subsystem (Fig. 3). In monitoring, if any results deviate from the predicted control range, the cause was identified and corrective measures were taken. In the current development by the medical console development organization, however, monitoring results were stable without any deviation other than falling below the lower limit observed in some components reused from existing software. Therefore, no corrective measures or resetting of the target values was necessary.

Fig. 3 Quality control graph in a process.

ii) Monitoring of total quality with a prediction model

In all processes of each project, cumulative defects were monitored with the dedicated prediction model to check whether they would remain within the control range (Table 5). By doing so, the quality targets can be reviewed when deviation is predicted. In the current development, monitoring results were stable with no deviation from the control range. Therefore, no resetting of the prediction model was necessary.

Table 5 Quality monitoring by our prediction model.
iii) Monitoring of results data for organizational improvement impact

We verified, weekly, the changes in result data for the quality and productivity (total corrective action workload) of the overall medical console development organization. With a tool developed for this monitoring, by entering the quality data of each subsystem of the involved multiple projects, it is possible to confirm whether the organizational target values remain within the control range (Fig. 4).

4. Verification of the impact of improvements

After completing development in all projects, we verified the results of activities described in 3. Our approach to process improvement activities.

(1) Verification of the impact of quality improvements

Table 6 shows the actual results for the prediction of quality improvement. In the system test process that requires more workload for correction than others, defect density decreased by 69% on average from that of L4 and it was confirmed that quality was significantly improved. The standard deviation for L5 was 0.35 of the value for L4 and the stability was thus improved. This is because the number of defects detected in system tests greatly decreased as a result of various improvement activities.

In addition, we conducted a t-test to assess defect density in system tests for both L4 and L5 and found the significance level was 5%. Improved quality was thus proved statistically, too (Fig. 5).

(2) Confirmation of the impact of improvements on total corrective action workload

Table 7 shows the actual results for the prediction of total corrective action workload. The quality of upper processes was increased and corrective action workload in system tests was decreased by reforming the software structure as one of those improvements. As a result, the total corrective action workload (i.e., the summation of the products of defect density and the number of hours required for correction in all processes from system design) was reduced from L4 by 62% on average and the impact of improvements was confirmed. Because the predicted values were an estimation of the minimum possible impact, the actual results turned out to be better than expected. The standard deviation for L5 was 0.84 of the value for L4 and the stability was thus improved. This is because, as a result of improvement activities, the time spent on analysis became shorter and more stable.

In addition, we conducted a t-test to assess total corrective action workload and found the significance level was 5%. Improved productivity (corrective action workload) was thus proved statistically, too (Fig. 6).

(3) Impact on business

The results of those improvement and monitoring activities reveal that development workload was reduced by
6% on average (Fig. 7), which exceeded the 5% set as the improvement target for productivity. Thus, the activities contributed to the reduction of development cost.

In defect density, quality at system test for L5 increased to three times that for L4 (Fig. 8).

**5. Control techniques acquired via improvement activities**

Via process improvement activities after receiving L4, we have established the following new control techniques covering prediction to monitoring.

- Techniques for the prediction of the impact of improvements
  - A technique for the prediction of the total impact of multiple improvements was established.
  - A technique for the advance prediction of statistical impact on quality and productivity was established.
- A control technique that allows the control of activities from the setting of overall organizational targets to their monitoring.

**6. Conclusion**

Since 2002, based on the CMMI models, we have been carrying out software development process improvement activities. On this occasion, we further introduced the high maturity models to the medical console development organization, via which we have established a control technique that enables a sequence of activities including organizational data analysis, comprehensive prediction of the total impact of multiple improvements and monitoring of quality and cost.

In official CMMI appraisal in December, 2011, we reached the highest Level 5 rating (optimizing stage) of its Version 1.3. In the meantime, we were also able to contribute to the reduction of development cost by achieving the target set for the improvement of productivity.

Our improvement activities are still in progress. In the future, we will apply the know-how and systems that brought L5 to the medical console development organization to improve software development processes company-wide and thereby increase the level of all our development organizations.

**References**


(“CMMI” referred to in this paper is a registered trademark of Carnegie Mellon University, U.S.A. That is an index developed by the Software Engineering Institute of the university to rate the process maturity of development organizations into five levels.)