

Performance Results of CMMI[®]-Based Process Improvement

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August 2006

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CMU/SEI-2006-TR-004
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Software Engineering Process Management

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Executive Summary

Organizations throughout the world have successfully invested in CMMI-based process improvement. This report presents quantitative evidence from 35 organizations, several of which are larger enterprises with more than one constituent organization. The process improvement efforts in these organizations include both small and large organizational units that do business in a variety of sectors and domains. They apply CMMI model practices to software engineering, systems engineering, and other engineering disciplines. While most of the results come from higher maturity organizations, notable improvements also have been achieved by lower maturity organizations. All of the organizations in the report explicitly attribute their achievements to guidance provided by CMMI.

Performance results are categorized and summarized by cost, schedule, productivity, quality, customer satisfaction, and return on investment (ROI). These categories include a wide variety of measures, each selected by the participating organizations to demonstrate improvements in areas of importance to their particular business goals and objectives. While the specific measures and results differ among organizations, the overall results provide ample proof of concept about the potential of CMMI-based process improvement.

Median percent improvements over time in the first five categories and the median improvement in ROI are summarized in Table 1. Further discussion of these results is followed in the report by 10 short case descriptions. The descriptions provide more detail about individual organizations, their process improvement journeys, and the measured performance gains as a consequence of their CMMI-based process improvement.

Table 1: Performance Improvements over Time by Category

Performance Category	Median Improvement
Cost	34%
Schedule	50%
Productivity	61%
Quality	48%
Customer Satisfaction	14%
Return on Investment	4.0 : 1

The movement to CMMI-based improvement has been accompanied by credible quantitative results for all six performance categories. Many organizations have achieved improvements in product quality and customer satisfaction at the same time that they have achieved higher productivity, cost performance, and schedule performance. Better quality may not always be

free, but it can occur with better project performance as a result of disciplined process improvement.

Abstract

There is a widespread demand for factual information about the impact and benefits of process improvement based on Capability Maturity Model[®] Integration (CMMI) models. Much has been learned since the Software Engineering Institute (SEI) published a special report on this topic over two years ago. There now is evidence that process improvement using the CMMI Product Suite can result in improvements in schedule and cost performance, product quality, return on investment, and other measures of performance outcome.

This technical report summarizes much of the publicly available empirical evidence about the performance results that can occur as a consequence of CMMI-based process improvement. In addition, the report contains a series of brief case descriptions that were created with collaboration from representatives from 10 organizations that have achieved notable quantitative performance results through their CMMI-based improvement efforts.

The report is meant for members of engineering process groups, middle and first-line management, and other potential process improvement participants who wish to learn more about how CMMI can contribute to measurable improvements. It also may be useful for executives and senior managers who are faced with decisions about the allocation of scarce resources for improvement efforts.

1 Introduction

Many organizations throughout the world have invested in CMMI-based process improvement. Many of these organizations have achieved and sometimes surpassed their improvement goals. The achievement of process capability and maturity level goals is an important benchmark of success; however, it is not enough. Organizations undertake process improvement to achieve business-related performance goals.

There now is ample evidence that process improvement using the CMMI Product Suite can result in marked improvements in schedule and cost performance, product quality, return on investment, and other measures of performance outcome. This document summarizes much of the publicly available empirical evidence about the performance results that can occur as a consequence of CMMI-based process improvement.

In some instances, the movement to CMMI-based improvement has been accompanied by marked jumps in performance. In other instances, the improvement in performance has continued in patterns comparable to what the organizations experienced with the CMMI source models and other improvement frameworks. In all of the instances reported here, the organizations have attributed their successes to the guidance for improvement that is included in CMMI.

The results presented in this report come from a variety of sectors including the telecommunications, financial, manufacturing, and defense industries. Many of the results come from higher maturity organizations; however, there also are some impressive results from lower maturity organizations. Similarly, most results come from larger organizational settings, but a few are from smaller settings.

At the time of this document's publication, almost all of the evidence presented here was available on the CMMI Performance Results Web site at <http://www.sei.cmu.edu/cmmi/results.html>. The Web site also included much more information than could be discussed in detail here. Other information was provided initially for use in this document.

1.1 CMMI-Based Improvement

Perspectives vary on what constitutes CMMI-based improvement. CMMI models contain content that is presented differently or did not exist in its source documents, and CMMI provides guidance about integrating improvement efforts across multiple disciplines.

Organizations craft their process assets and improvement efforts in a variety of ways. Many have relied heavily over the years both on CMMI and its source models. Others have incorporated other improvement frameworks, many of which have a shared heritage with CMMI in Total Quality Management (TQM).

Regardless of the other process improvement frameworks which organizations may have used in addition to CMMI, all of the evidence reported here comes from organizations that explicitly attribute their performance results to guidance provided by CMMI. In a few instances, the evidence comes from organizations that already had adopted practices that later became part of CMMI.

1.2 Intended Audience and Structure of the Report

This technical report is meant to be useful for members of engineering process groups, middle and first-line management, and other potential process improvement participants who wish to learn more about how CMMI can contribute to measurable improvements in organization and project performance and product quality. It also may be useful for executives and senior managers who are faced with decisions about the allocation of scarce resources for improvement efforts.

Section 2 of this document contains a brief discussion of the approach used for demonstrating the impact on project performance and product quality of CMMI-based process improvement. It is based on a section of the same name in the report titled *Demonstrating the Impact and Benefits of CMMI: An Update and Preliminary Results* [Goldenson 03].

Section 3 summarizes the results to date and provides a more detailed breakdown of results by performance categories: cost, schedule, productivity, quality, customer satisfaction, and return on investment. The section also includes some brief comparisons of results by maturity level, model, and organization scope.

Section 4 contains a series of brief case descriptions that were created with collaboration from representatives from 10 organizations that have achieved notable quantitative performance results through their CMMI-based improvement efforts. A summary and conclusions are in Section 5.

2 Demonstrating Impact on Performance

Organizations differ in their business goals and strategic objectives as well as the products and services that they provide. They differ in how they implement CMMI-based process improvement and in the ways they measure their resulting progress and performance.

Process improvement based on CMMI models may be demonstrated in several ways. Some organizations have established new processes or changed existing processes as a result of guidance found in the CMMI Product Suite. Others have broadened the organizational scope of their improvement efforts, through the integration of systems, software, hardware, and related disciplines. Process changes also sometimes predate the transition to CMMI models, especially for those organizations that were among the first to have been appraised at the higher maturity levels of CMMI. Some organizations, especially those that had used the Electronics Industry Alliance System Engineering Capability Model (EIA/IS 731) or the early Systems Engineering CMM[®] had already established processes that were subsequently included in CMMI. Not all of their experiences can be attributed to CMMI adoption, but their results certainly show the importance of the practices that are articulated in CMMI models.

Analytic approaches also differ. Some organizations make comparisons over time, across maturity levels, or relative to other major process milestones. Others focus on selected project or organizational processes that they have mapped to CMMI model practices. Similarly, many measures of performance can be used to demonstrate the impact of CMMI-based process improvement. Organizations often describe CMMI benefits in different ways, and they use the measures that make the most sense given their particular business goals.

Figure 1 is a high-level depiction of the impact of process improvement. It is used in this document for CMMI-based improvement; however, the same depiction can be applied elsewhere. The costs of process improvement are illustrated in the upper left. Some of these may be planned investments for process improvement; others may be expenses directly or indirectly related to process improvement. Process capability and organizational maturity are depicted in the center box. Organizations improve their processes in order to realize other benefits, and they use process capability and organizational maturity to evaluate and compare their results. The box on the right illustrates the kinds of benefits that organizations most frequently seek to attain as a result of their process improvement efforts. The costs and benefits also can be combined to calculate ROI or related measures, as shown in the box on the bottom of the figure.

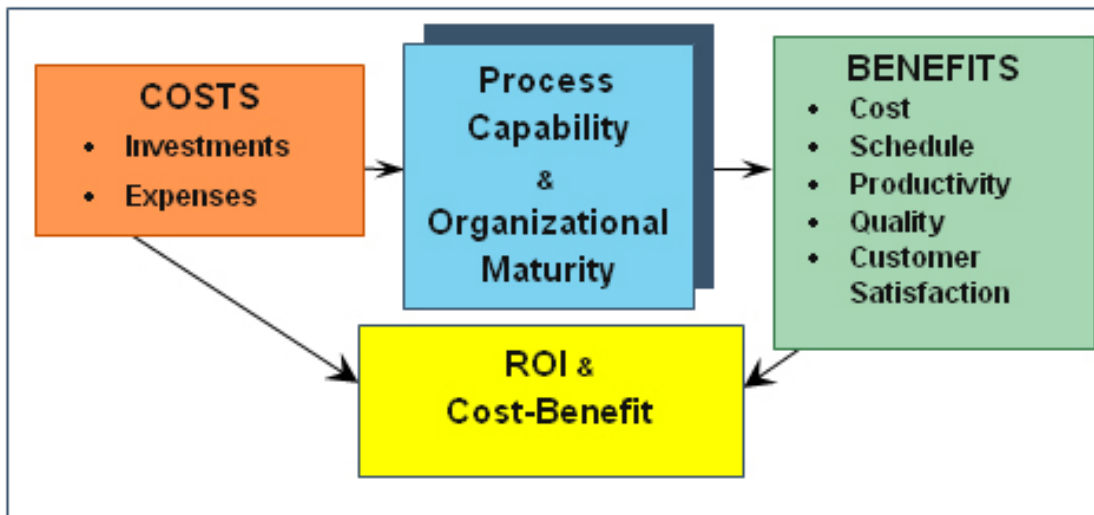


Figure 1: High-Level Model of CMMI Impact

The performance measures are classified into six broad categories for this report. As shown in the detail in Figure 1, potential benefits of process improvement might accrue with respect to cost, schedule, productivity, quality, and customer satisfaction. The sixth category is return on investment and related measures, as shown in the bottom box. Improvements in the six categories can contribute to additional business goals, for example, market share, reduced time to market, lower cost products, and higher quality products.

Organizations typically seek to optimize some combination of the five primary classes of benefits; each of these benefits can be refined to include a number of more specific measures. For example, one organization may be more interested in reducing the costs of its products and services while another may be concerned about having more predictable project costs or schedules. Other refinements of the five basic categories might include shorter cycle times, improved reliability, reductions in rework and concomitant effort, enhanced functionality, maintainability, and reduced cost over the life of the product.

As shown in the box at the bottom of Figure 1, ROI and related cost-benefit measures constitute the sixth category of performance measures. Organizations frequently are concerned about ROI measures, for which they need to track data that shows related costs and benefits.

Other possible performance measures, such as market share, business growth, profitability, and employee morale, per se do not map well to the simple benefits classification presented in Figure 1. Such measures are discussed in the case descriptions in Section 4.

3 Performance Results

Section 3.1 contains a high-level review of the quantitative performance results that were available at the time this document was published. Additional guidance for interpreting those results is found in Section 3.2. Section 3.3 follows with a more detailed breakdown by performance category, including some brief comparisons by maturity level.

3.1 Summarizing Performance Results

The quantitative performance results in Table 2 are from a total of 35 organizations, some of which are enterprises with more than one constituent organization. 30 of them have results that can be expressed as change over time. These results are expressed either as percentage change from an earlier baseline prior to the CMMI-based process improvement or as ratios of return on investment (ROI). The results are summarized by the six performance categories discussed in Section 2 of this document: cost, schedule, productivity, quality, customer satisfaction and return on investment. Most of the organizations have provided multiple results, sometimes several in the same performance category.

Table 2: CMMI Performance Results Summary

Performance Category	Median Improvement	Number of Data Points		Lowest Improvement	Highest Improvement
Cost	34%	29		3%	87%
Schedule	50%	22		2%	95%
Productivity	61%	20		11%	329%
Quality	48%	34		2%	132%
Customer Satisfaction	14%	7		-4%	55%
Return on Investment	4.0 : 1	22		1.7 : 1	27.7 : 1

Note: The performance results in this table express change over varying periods of time.

The summary results in Table 2 and the rest of this document provide substantial evidence about the performance results that are possible by adherence to CMMI-based processes. The median results in every category of the table are notable, as are both the high and low ends of the distributions.

The results in Table 2 come from several sources. Most of these sources are public reports, typically conference presentations and published papers by individuals from CMMI-appraised organizations. These sources can be seen in Appendix A. The table also includes the results provided by the organizations with which the authors have collaborated in preparing the brief case descriptions in Section 4. In almost all instances, the results have been corroborated through direct communication with members of the participating organizations; three of which have chosen to remain anonymous.

A large number of performance results are not included in the table because they could not be expressed as change over time. These results are equally interesting and valid although not as easily summarized. They have been included in Section 3.3, where the results are discussed by performance category.

3.2 Interpreting the Results

As mentioned in Section 2, the six performance categories are quite broadly defined. They combine data points from a wide variety of cases, ranging from pilot projects about the results associated with particular processes to major organization-wide improvement initiatives covering the full scope of CMMI. The CMMI-based improvements also occasionally occur simultaneously with other factors such as increased reuse, personnel changes, or the introduction of other new technologies.

The specific measures used by the various reporting organizations also differ. For example, as shown in Table 3, the cost category includes reductions in cost, cost performance, and related measures of discrepancy between estimates and actual results. Similar differences for schedule, productivity, and ROI are shown in Table 4, Table 5, and Table 6. There are no tables for the quality and customer satisfaction categories. Quality measures are almost always expressed as defects although the specific measures vary depending on the information needs of the reporting organizations (e.g., phase of injection, phase of discovery, or total density). Award fees and customer survey data are the only common measures of customer satisfaction.

As more evidence becomes available, the SEI will refine the existing categories and begin classifying the respective data points separately wherever possible. The variety in each of the categories does highlight the multiplicity of techniques used by organizations to measure their processes and products, and the wide variety of ways they use to present the results relevant to their organizations.

Table 3: Variety in Measures of Cost

Reductions in	
Costs (general category)/Cost of delivery	Cost of quality/Cost of poor quality
Overhead rate	Costs of rework/Defect find & fix costs
Number/Cost of process staff	Software unit costs
Variation in cost performance index (CPI)	
Savings in or due to	
Implementing hardware processes	
Improved	
Budget estimation accuracy	Average cost performance index (CPI)

Table 4: Variety in Measures of Schedule

Reductions in	
Variation in schedule	Schedule performance index (SPI)
Number of days late	Days variance from plan
Slippage of project delivery	
Improved or increased	
Cycle time	Average schedule performance index (SPI)
Proportion of milestones met	Estimation accuracy

Table 5: Variety in Measures of Productivity

Lines of code per labor hour	Number of releases per year
Source statements per month	Testing rates
Function points per full time equivalent staff	Time comparisons by build
Software production (general category)	

Table 6: Variety in Measures of Return on Investment

Example benefits and costs avoided	Examples of improvement investment
Rework avoided due to fewer defects	Quality activities
Improved productivity	Automation
Increased revenue due to shorter cycle time	Process improvement in general

While it would be helpful to have a common set of measures for benchmarking and comparison, valuable conclusions still can be drawn from the results summarized here. Consistent results about the same general classes of phenomena that are based on different measurements and data analytic procedures, such as those found in this document, are highly unlikely to occur by chance alone [Campbell 66, Cook 79]. These results provide ample

proof of concept about the potential of CMMI-based process improvement. Of course, proof of concept is not the same thing as a guarantee of success, and these same results may not be repeatable in different organizations.

Much of the evidence seen throughout the history of model-based process improvement is limited to positive results. Organizations rarely are willing to discuss their problems and disappointments publicly. Some of the source documents examined for this report do show a failure to fully reach performance goals; however, some of these organizations also report progress toward meeting those goals. Only one data point in Table 2 is a negative number, and it shows a slight change in what remains an excellent level of customer satisfaction.

Most of the quantitative performance results summarized in this report come from CMMI maturity level 4 and 5 organizations. It takes time to establish a measurement capability, determine what quantitative measures may be useful in a particular organizational context, and accumulate data.

Results showing improvements also are available from lower maturity organizations (defined here as maturity levels 1, 2, and 3). The initial improvements experienced by these organizations may appear to be comparably high; however, individual results should not be over generalized out of context. Percentages based on initially low values leave more room for improvement. Particular processes and measures also differ, and the lower maturity organizations from which quantitative results are available may very well be atypical and exemplary. The important thing to note here simply is that there is proof of concept that lower maturity organizations also can achieve important performance gains through CMMI-based process improvement.

Many organizations that successfully improve their processes may achieve performance results that are comparable to those described in this document. Nevertheless, more quantitative work remains to be done to investigate the circumstances under which the necessary process capabilities can be improved and sustained.

3.3 Further Detail

This section provides further detail about each of the six performance categories. A separate figure for each category provides a better sense of the range of differences within that category than can be seen in Table 2. Each figure shows the full distribution of the changes over time in its respective category. All but one of the figures display results for both lower and higher maturity organizations. With the addition of the Measurement and Analysis process area at maturity level 2 in CMMI, more results from lower maturity organizations may become available.

Remember also that the performance categories used in this report include a wide variety of measures because organizations use the measures that make the most sense for their individual information needs and business objectives. This can be seen in the example assertion statements and further discussion that follows for each of the six performance categories. The assertion statements are summary descriptions of the measures and results provided by the organizations in this report. Source information for all of the assertions can be found in Appendix A. Additional detail and more examples can be found on the CMMI Performance Results Web site at <http://www.sei.cmu.edu/cmml/results.html>.

3.3.1 Cost

The cost category covers instances where organizations report changes in the cost of final or intermediate work products, changes in the cost of the processes employed to produce the products, and general savings attributed to model-based process improvement. It also includes increased predictability of costs incurred and other measures of variation.

Figure 2 shows 5 data points on cost performance improvements over time from lower maturity organizations and 24 data points from organizations that have achieved maturity level 4 or 5. The performance results from the lower maturity organizations sometimes may appear to exceed those found in the higher maturity organizations; however, the magnitude of the percentage changes should not be over-generalized. Relatively small changes from initially low baselines can appear to be quite high when stated in percentage terms. The individual processes also differ, as do the measures of the performance results.

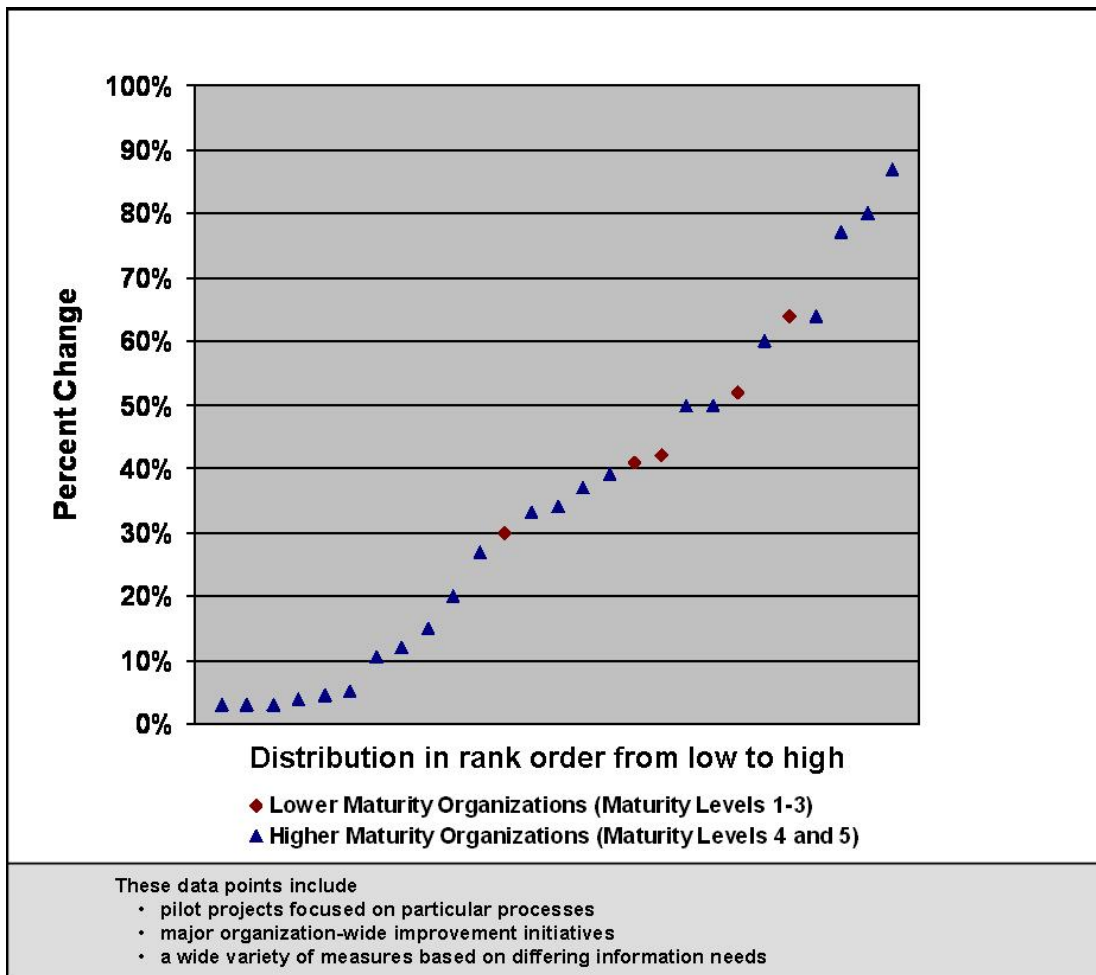


Figure 2: Changes Over Time in Cost

Table 7 includes selected assertion statements that describe the kinds of cost predictability and performance gains that have been achieved through CMMI-based process improvement. The first three table entries are from lower maturity organizations.

The statement in the first row of the table describes cost savings due to improved hardware engineering practices at a medium-sized aerospace company that had implemented CMMI. The statement in the second table row describes the results from an IT company that had just begun its use of model-based process improvement yet significantly reduced its cost of quality in one year. As seen later in this technical report, this company’s improvement in cost performance was accompanied by measured improvement in productivity and return on investment.

Table 7: Summary Benefits and Impact—Cost

#	Result	Organization
1	\$2.1 Million in savings in hardware engineering processes in an organization moving toward CMMI maturity level 3	Anonymous 1

#	Result	Organization
2	Used CMMI Measurement and Analysis process area to significantly reduce cost of quality in one year	Anonymous 2
3	Costs dropped 52 percent from a baseline prior to SW-CMM maturity level 2 as the organization moved toward CMMI maturity level 3	DB Systems GmbH
4	On-budget delivery improved from over 90 percent to nearly 100 percent as the organization moved from SW-CMM maturity level 3 to CMMI maturity Level 5	IBM Australia Application Management Services
5	Substantially improved cost variance over three causal analysis and resolution cycles in a CMMI maturity level 5 organization with PSP SM -trained engineers	Northrop Grumman IT, Defense Enterprise Solutions
6	CMMI maturity level 3 site reduced its costs of rework by 42 percent over several years	Raytheon Corp Anonymous site
7	Reduced cost of poor quality from over 45 percent to under 30 percent over a three year period as the organization moved from SW-CMM maturity level 5 towards CMMI maturity level 5	Siemens Information Systems Ltd.
8	Estimation accuracy improved by 72 percent on average in three technical areas from 1996 through 2004 On average, 63 percent of that improvement occurred as the organization moved from SW-CMM maturity level 5 to CMMI maturity level 5	Siemens Information Systems Ltd.
9	\$95K in savings attained by reduced rework effort through early detection of memory leaks in a CMMI maturity level 5 organization	Tata Consultancy Services
10	Additional 3 percent increase in both code reuse and related material reuse as the organization moved from SW-CMM maturity level 4 to CMMI maturity level 5	The Boeing Company

The second anonymous company had begun to work toward SW-CMM maturity level 2 when CMMI was first released. Management was reticent to adopt CMMI right away; however, the organization's consultant used the CMMI Measurement and Analysis process area to base the company's improvement effort on quantitative evidence. The value of doing this was evident to the company's management by the time of its SW-CMM assessment.

The statement in row three of Table 7 is from DB Systems GmbH, a major IT provider for the transport and travel industry. As seen in Figure 3, 20 percent of the drop in costs at DB Systems GmbH came as the organization moved to SW-CMM maturity level 2 while an additional 32 percent was achieved as the organization approached CMMI maturity level 3.

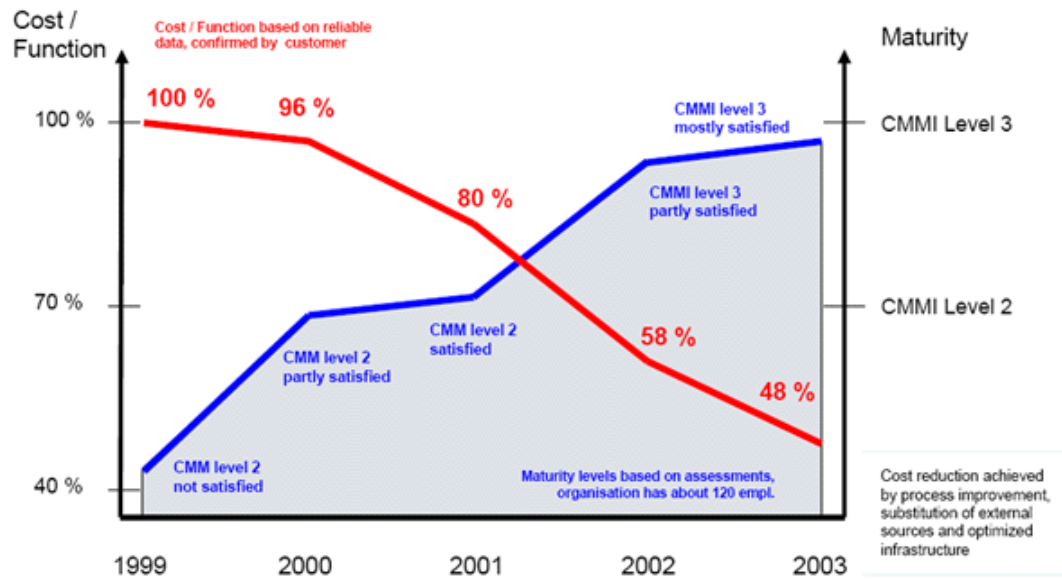


Figure 3: Cost Savings at DB Systems GmbH

Results from Northrop Grumman Information Technology, Defense Enterprise Solutions also are particularly compelling. Expanding on the fifth statement in Table 7, Figure 4 shows the changes between estimated and actual costs for the development of a firm-fixed price inventory tracking system over a three and a half year period. The project went through three causal analysis and resolution cycles to improve its peer review processes. During that time the organization completed five major builds of comparable difficulty. Its process changes were accompanied by a sizable improvement in cost performance. In build 1, the Northrop Grumman IT project substantially underestimated its costs. By build 6, the organization was able to complete the work for substantially less cost than initially estimated.

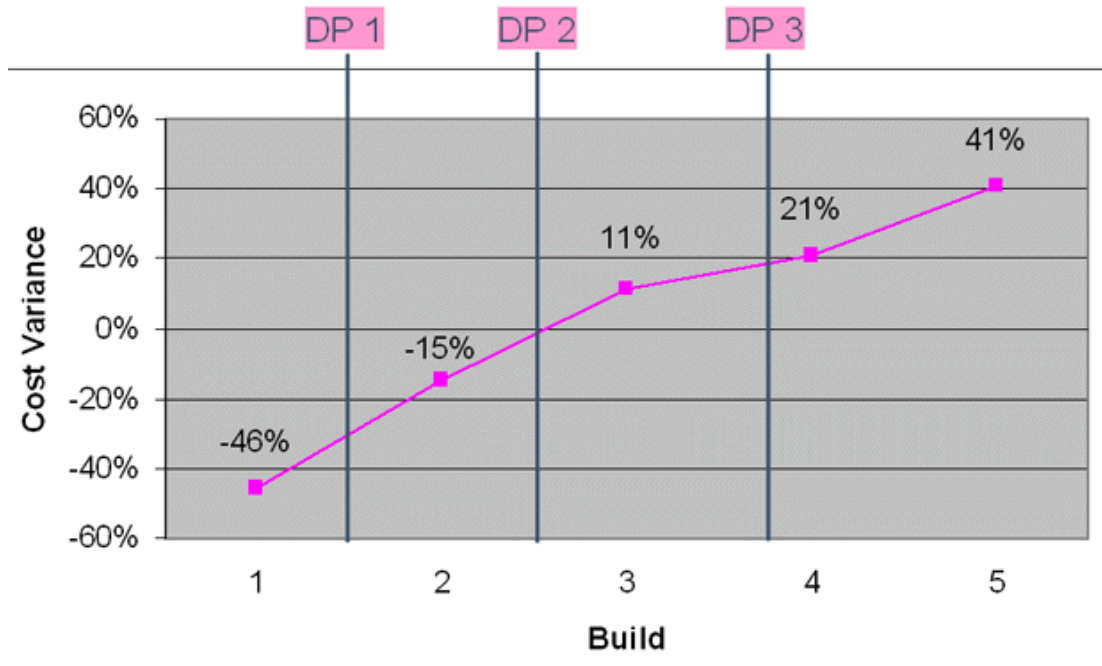


Figure 4: Cost Savings at Northrop Grumman IT

As seen later in this technical report, the Northrop Grumman IT project achieved similar results for schedule performance, product quality, and return on investment. Comparable results from other organizations are described in more detail in the case descriptions in Section 4. Many other examples of cost, schedule, and productivity improvements in concert with improved product quality, customer satisfaction, and return on investment can be found throughout this report and on the CMMI Performance Results Web site.

3.3.2 Schedule

This category covers improvements in schedule predictability and reductions in the time required to do the work. Figure 5 provides a better sense of the full range of differences in schedule performance than can be seen in Table 2. As seen in Figure 5, there are six data points from lower maturity level organizations that reported improvements over time in schedule performance. In fact, four of the largest percent improvements in schedule performance come from lower maturity organizations. Once again, there are many possible reasons why the lower maturity level organizations have achieved relatively high percentage improvements. Individual percentage differences should not be over-interpreted.

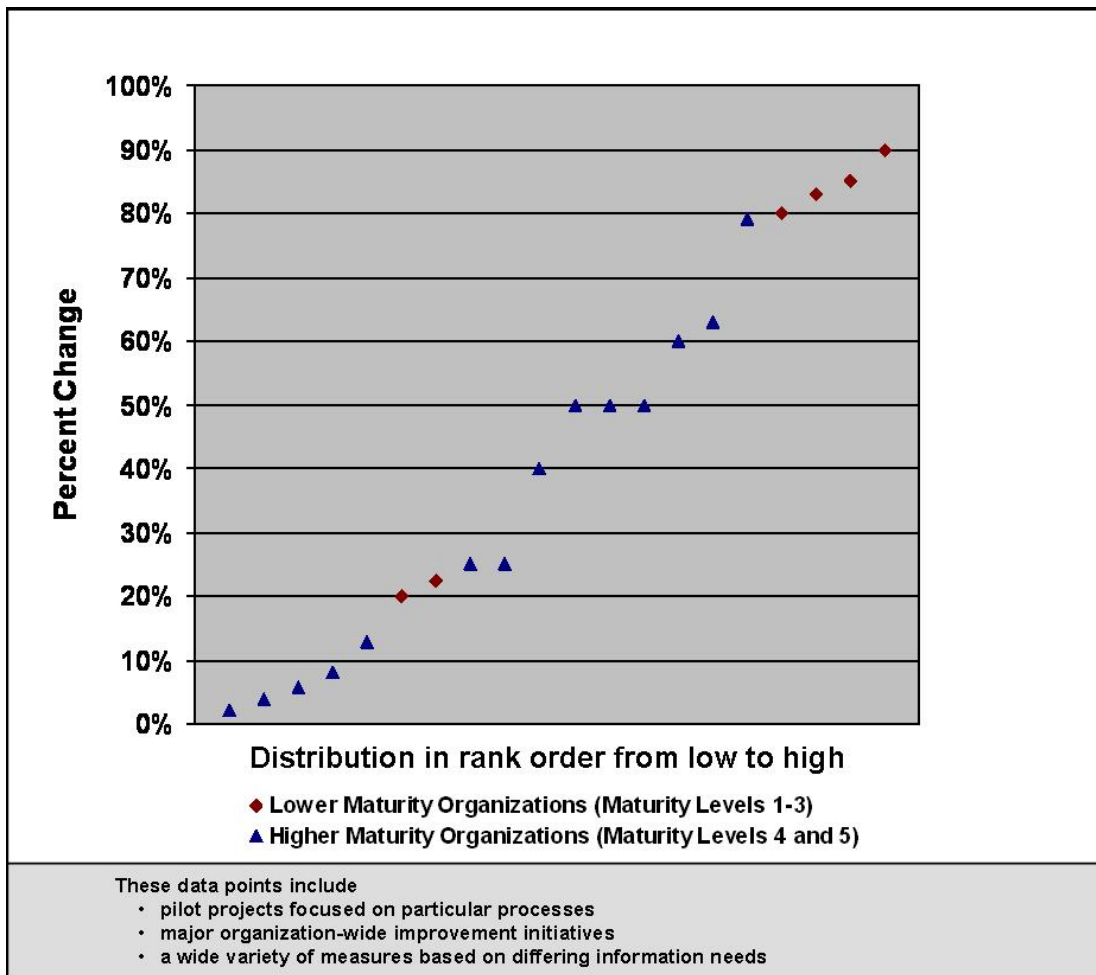


Figure 5: Changes Over Time in Schedule

Table 8 includes a few selected assertion statements that describe the kinds of schedule predictability and performance gains that have been achieved through CMMI-based process improvement.

Table 8: Summary Benefits and Impact—Schedule

#	Result	Organization
1	On-time delivery remained well over 90 percent, moving from 97% to 99%, with a slight improvement as the organization moved from SW-CMM maturity level 3 to CMMI maturity level 5	IBM Australia Application Management Services
2	70 to 80 percent reduction in average slippage of project delivery dates as the organization achieved CMMI maturity level 2	JP Morgan Chase
3	Average days variance from development plan reduced from approximately 130 days to less than 20 days one year after reaching CMMI maturity level 2	NCR
4	Met every schedule milestone (25 in a row) on time, with high quality and customer satisfaction in a CMMI maturity level 5 organization	Northrop Grumman IT, Defense Enterprise Solutions
5	Substantially improved schedule variance over three causal analysis and resolution cycles in a CMMI maturity level 5 organization with PSP-trained engineers	Northrop Grumman IT, Defense Enterprise Solutions

#	Result	Organization
6	Schedule variance improved from approximately 25 percent to 15 percent as the organization moved from SW-CMM maturity level 3 to CMMI maturity level 5	Reuters
7	On-time deliveries improved from 79 percent to 89 percent as the organization moved from SW-CMM maturity level 3 toward CMMI maturity level 4	Systematic Software Engineering
8	Schedule variation decline by 63 percent as the organization moved from SW-CMM maturity level 4 to CMMI maturity level 5	The Boeing Company

Note for example, the third statement in the table. It is from NCR Self Service in Scotland, which had been appraised at CMMI maturity level 2. As seen in Figure 6, this organization had a noticeable reversal immediately after it began its move to CMMI. As it worked toward CMMI maturity level 3, this organization progressed from a little over 60 days average variance from plan at SW-CMM maturity level 3 to a little less than 20 days.

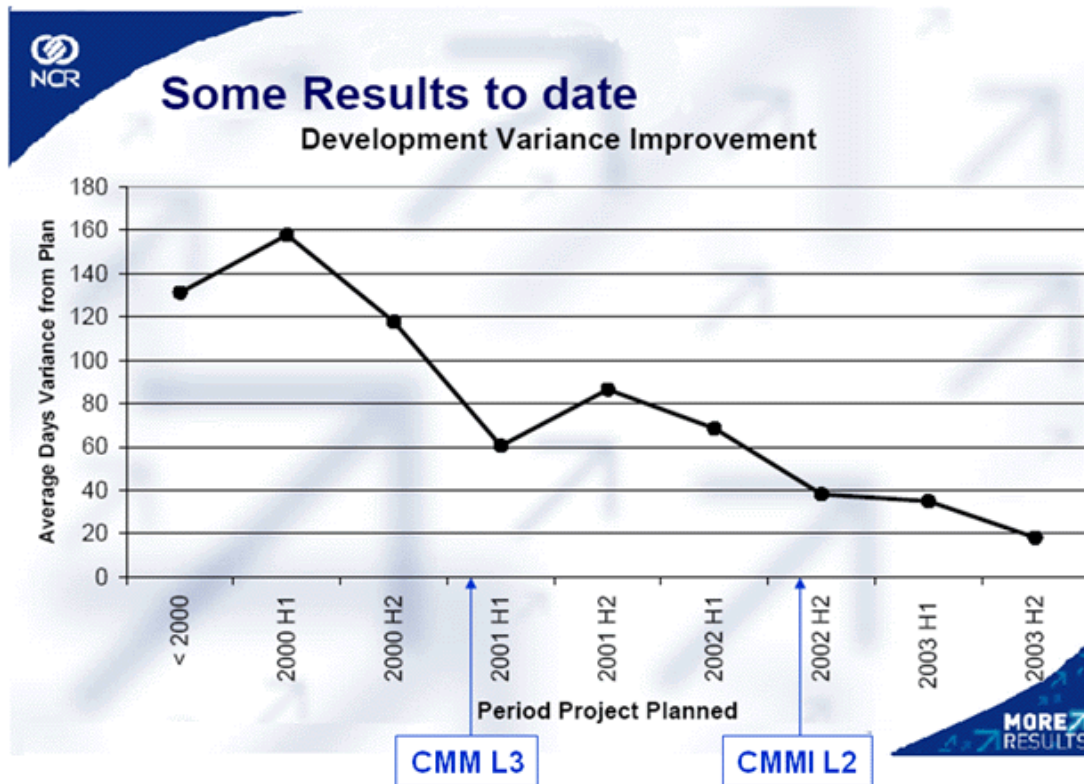


Figure 6: Schedule Improvement at NCR Self Service, Scotland

Figure 7 shows the marked improvement in schedule performance that mirrors the cost performance improvements at Northrop Grumman IT shown in Section 3.3.1. The organization completed its first build one percent ahead of schedule and the second build one percent behind schedule. It completed the fifth build in a little less than half the time originally planned. As seen in Table 8, the same organization met every scheduled milestone on time with high quality and customer satisfaction.

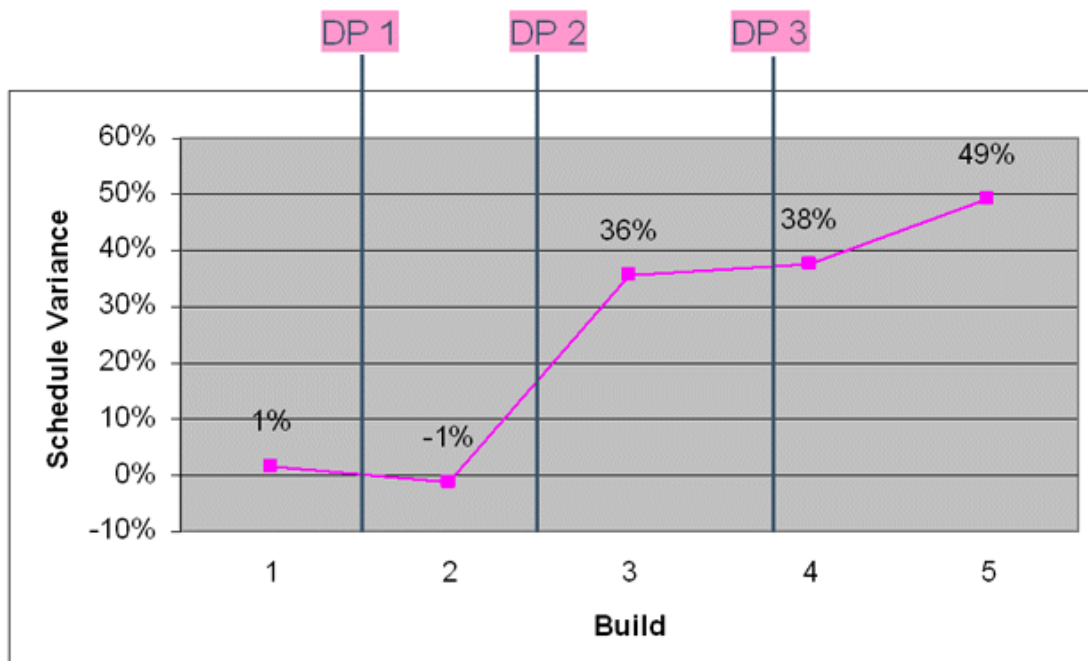


Figure 7: Schedule Improvement at Northrop Grumman IT

3.3.3 Productivity

This category includes various measures based on the amount of work accomplished in a given period of time. Figure 8 shows the full range of differences in productivity, six of which come from lower maturity level organizations. Most of the productivity gains fall in the range between 10 and 100 percent improvement (i.e., the best among them have doubled their initial productivity as a result of their CMMI-based process improvement efforts). The most extreme outlier is from improved defect detection practices in an organization that already was progressing toward CMMI maturity level 4. The next highest data point is from a single project in a higher maturity level organization. The third highest data point is from a higher maturity level organization that included value added by new business in its measure of productivity gain. These three measures were useful in their own organizations' business contexts; however, these results do highlight the shortcomings of using dissimilar measures when comparing organizations.

Table 9 includes selected assertion statements that describe the kinds of productivity gains that have been achieved through CMMI-based process improvement. Notice in particular the first table entry. It shows a marked productivity increase in the same anonymous organization that also had lowered its cost of quality during its first year of CMM-based improvement by using the Measurement and Analysis process area to structure its improvement effort (see the discussion in Section 3.3.1). As with cost and schedule performance, most of the reported productivity gains are reported by higher maturity organizations.

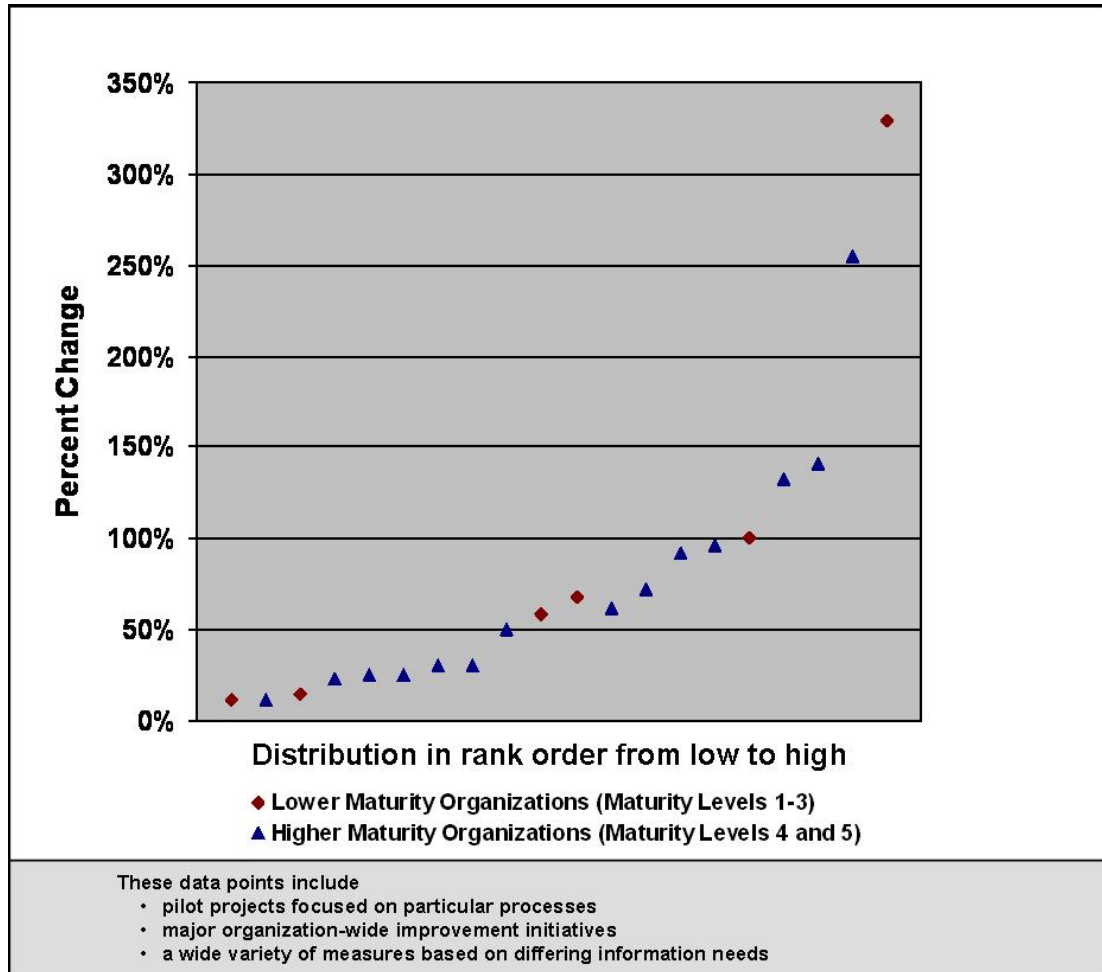


Figure 8: Changes Over Time in Productivity

Table 9: Summary Benefits and Impact—Productivity

#	Result	Organization
1	Used Measurement and Analysis process area to realize an 11 percent increase in productivity, corresponding to \$4.4M in additional value	Anonymous 2
2	\$103 million dollars saved in maintenance costs and \$99 million dollars saved in development costs due to increased productivity as the organization moved from SW-CMM maturity level 3 toward CMMI maturity level 5	IBM Australia Application Management Services

#	Result	Organization
3	Over 20 percent improvement in account productivity as the organization moved from SW-CMM maturity level 3 toward CMMI maturity level 5	IBM Australia Application Management Services
4	Doubled the number of releases from three to six per year as the organization implemented CMMI maturity level 3	JP Morgan Chase
5	Productivity, measured in source statements per month, increased by 11 percent between SW-CMM maturity level 5 and CMMI maturity level 5. This improvement is also a 72 percent increase from SW-CMM maturity level 3	Lockheed Martin Maritime Systems & Sensors – Undersea Systems
6	Doubled labor productivity as the organization progressed toward CMMI maturity level 5 from SW-CMM maturity level 3	SAIC System and Network Solutions Group (SNSG)
7	25 percent productivity improvement using CMMI over a three year period as the organization moved from SW-CMM maturity level 5 toward CMMI maturity level 5	Siemens Information Systems Ltd.

Expanding on the statement in the third row of Table 9, Figure 9 shows the 20 percent increase in account productivity at IBM Australia Application Management Services in more detail expressed as function points per full-time equivalent staff member (FP/FTE).

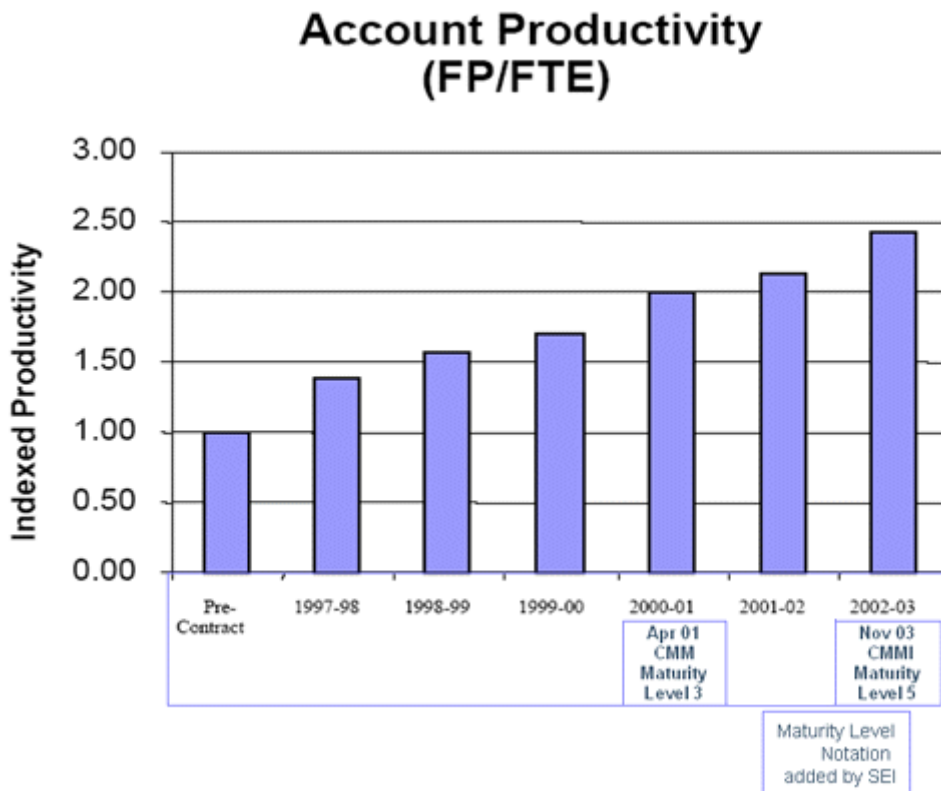


Figure 9: Productivity Improvement at IBM Australia

Expanding on the statement in the sixth row of Table 9, Figure 10 shows the pattern over time leading up to a major improvement in labor productivity as the SAIC System and

Network Solutions Group progressed toward CMMI maturity level 5 from SW-CMM maturity level 3.

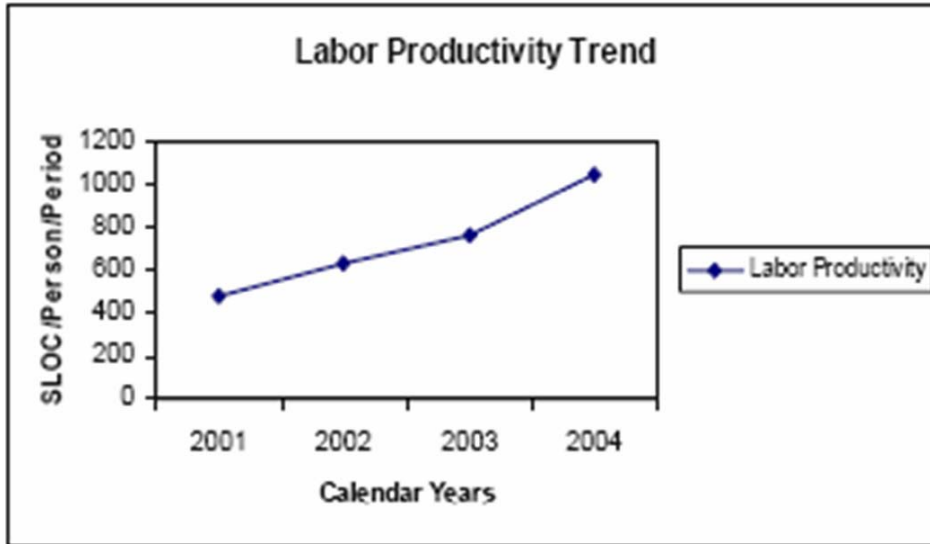


Figure 10: Productivity Improvement at SAIC

3.3.4 Quality

Improvement in product quality is most frequently measured by reductions in numbers of defects. Once again, the specific measures vary depending on the business objectives and other information needs of the reporting organizations. Such measures include counts by phase of injection or discovery and total density.

As seen in Figure 11, twelve data points come from lower maturity organizations that have reported improvements over time in product quality. As is true with the other measures of improved performance, there can be many reasons for the differences between these lower maturity organizations and the greater number of higher maturity organizations that have released their quality improvement results.

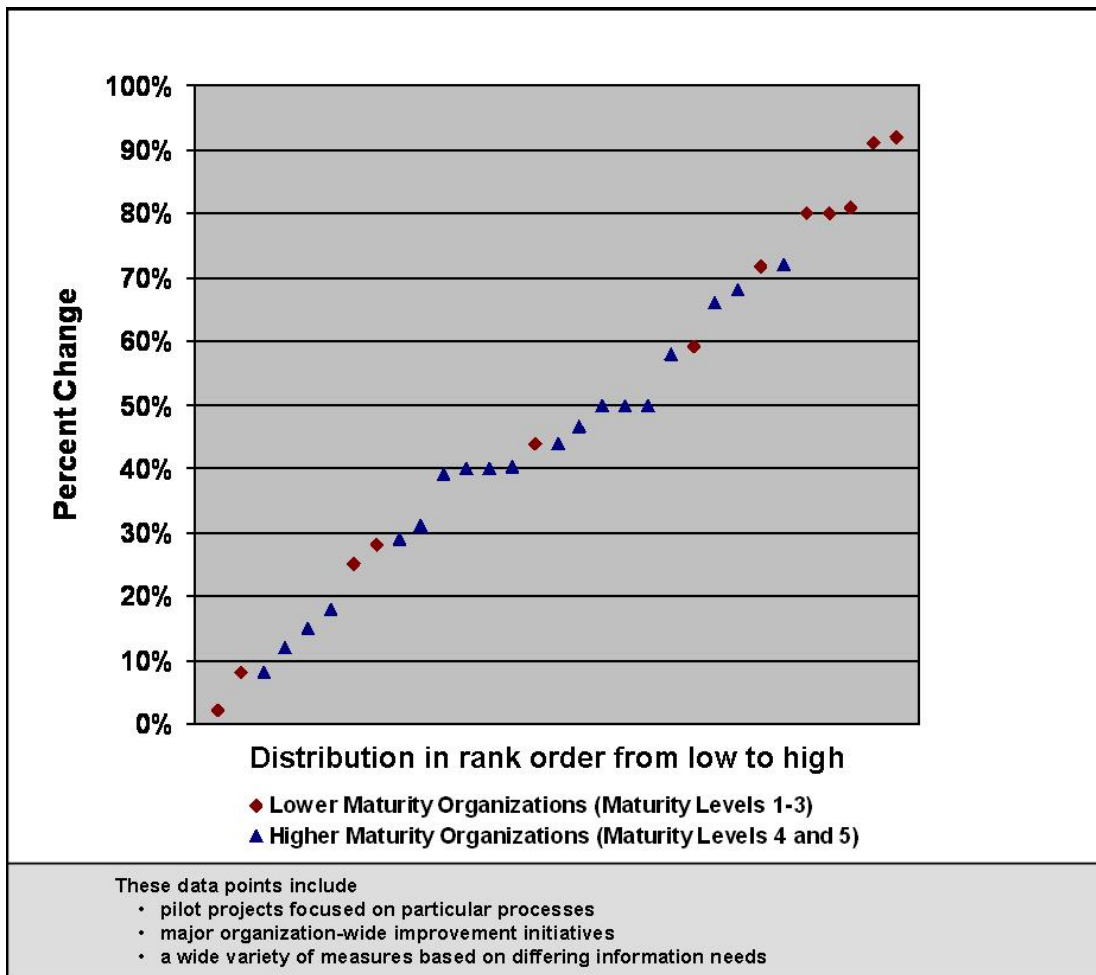


Figure 11: Changes Over Time in Quality

Table 10 includes a few assertion statements that describe the kinds of improvements in product quality that have been achieved through CMMI-based process improvement. The first table entry is from the same anonymous, medium-sized company that reported cost savings due to improved hardware engineering practices (see the earlier discussion about the first row of Table 7 in Section 3.3.1). Although this company was only aiming for a CMMI maturity level 3 determination, it consciously used causal analysis and resolution practices to achieve its 44 percent reduction in defects.

Table 10: Summary Benefits and Impact—Quality

#	Result	Organization
1	44 percent defect reduction following causal analysis cycle at an organization moving toward CMMI maturity level 3	Anonymous 1
2	40 percent reduction in all production problems and over 80 percent reduction in Severity 1 problems, as the organization moved from SW-CMM maturity level 3 toward CMMI maturity level 5	IBM Australia Application Management Services

#	Result	Organization
3	Reduced defect rate at CMMI maturity level 5 approximately two thirds compared to performance at SW-CMM maturity level 5	Lockheed Martin Maritime Systems and Sensors – Undersea Systems
4	Reduced software-defects-per-million-delivered-SLOC from a 1992 baseline by over 50 percent at SW-CMM maturity level 5 and then to 80 percent at CMMI maturity level 5	Lockheed Martin Systems Integration, Owego, NY
5	Reduced identified defects from 6.6 to 2.1 per KLOC over three causal analysis and resolution cycles in a CMMI maturity level 5 organization with PSP trained engineers	Northrop Grumman IT, Defense Enterprise Solutions
6	Over 110 percent improvement in effectiveness of phase containment as the organization moved from SW-CMM maturity level 3 to CMMI maturity level 5	Reuters
7	Improved defect removal before test from 50 percent to 70 percent, leaving 0.35 post release defects per KLOC as the organization moved from SW-CMM maturity level 5 toward CMMI maturity level 5	Siemens Information Systems Ltd.
8	Reduced defect density an average of 71 percent in three technical areas. On average, 46 percent of that reduction occurred as the organization moved from SW-CMM maturity level 5 toward CMMI maturity level 5	Siemens Information Systems Ltd.

As seen in Figure 12, IBM Australia Application Management Services achieved a 40 percent reduction in all production problems, along with a reduction of over 80 percent in Severity 1 problems as the organization progressed toward CMMI maturity level 5. These improvements in product quality complement the 20 percent increase in account productivity shown in Figure 9.

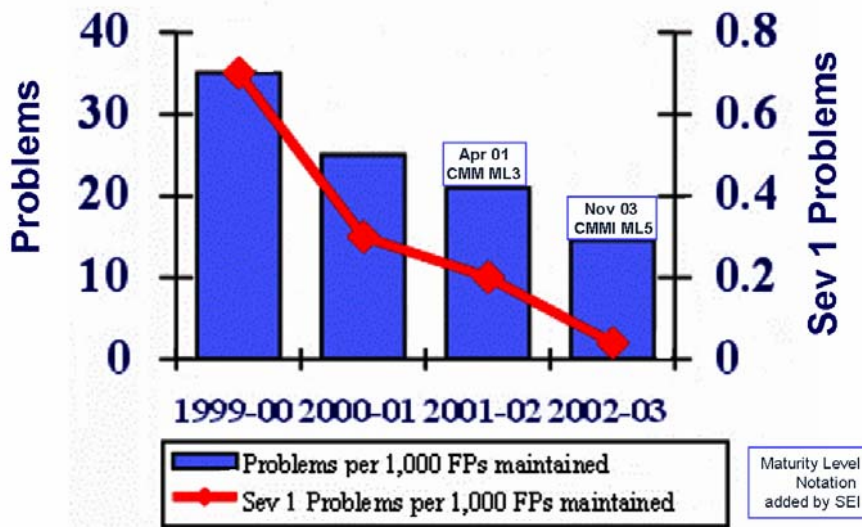


Figure 12: Quality Improvement at IBM Australia

Figure 13 shows average reductions of 46 percent in defect density at Siemens Information Systems Ltd. as it moved from SW-CMM maturity level 5 toward CMMI maturity level 5. Comparable improvements in cost of quality and estimation accuracy are noted for the same organization in Table 7. Productivity improvements during the same time period are found in Table 9.

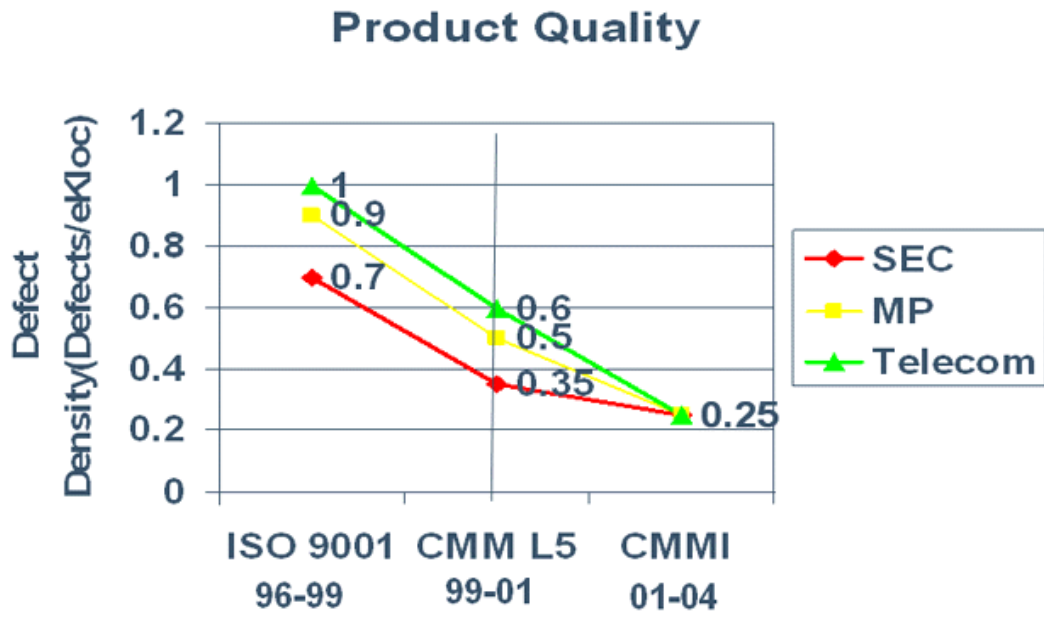


Figure 13: Quality Improvement at Siemens

Finally, Figure 14 shows the marked reductions in defects achieved at Northrop Grumman IT. They come from the same three-and-a-half-year, firm-fixed price inventory tracking project that achieved comparable gains in cost and schedule performance (see Figure 4 and Figure 7). Although the defect density rose slightly immediately after the third causal analysis cycle, it fell substantially after the fifth build.

Defect prevention using PSP and CAR at CMMI ML5

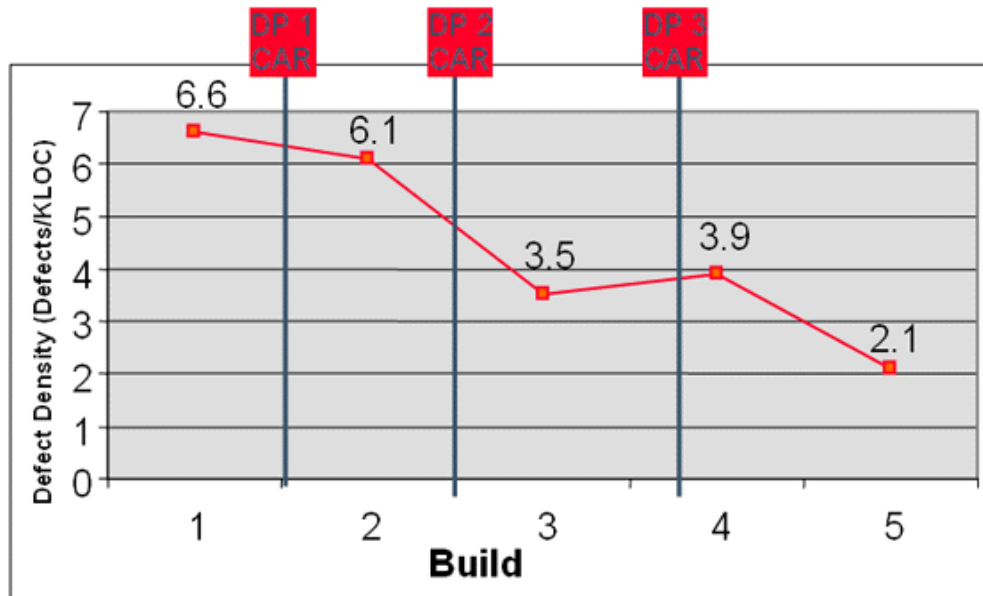


Figure 14: Quality Improvement at Northrop Grumman IT

3.3.5 Customer Satisfaction

This category generally includes changes based on customer surveys. Award fees also are sometimes used as surrogate measures. As seen in some of the more detailed case descriptions that follow in Section 4, some organizations do regularly collect, analyze, and use quantitative measures of customer satisfaction. Few results that can be expressed as change over time are available yet. Only one of them comes from a maturity level 3 organization that already was on its way to CMMI maturity level 5. This is why no data points from lower maturity organizations are included in Figure 15.

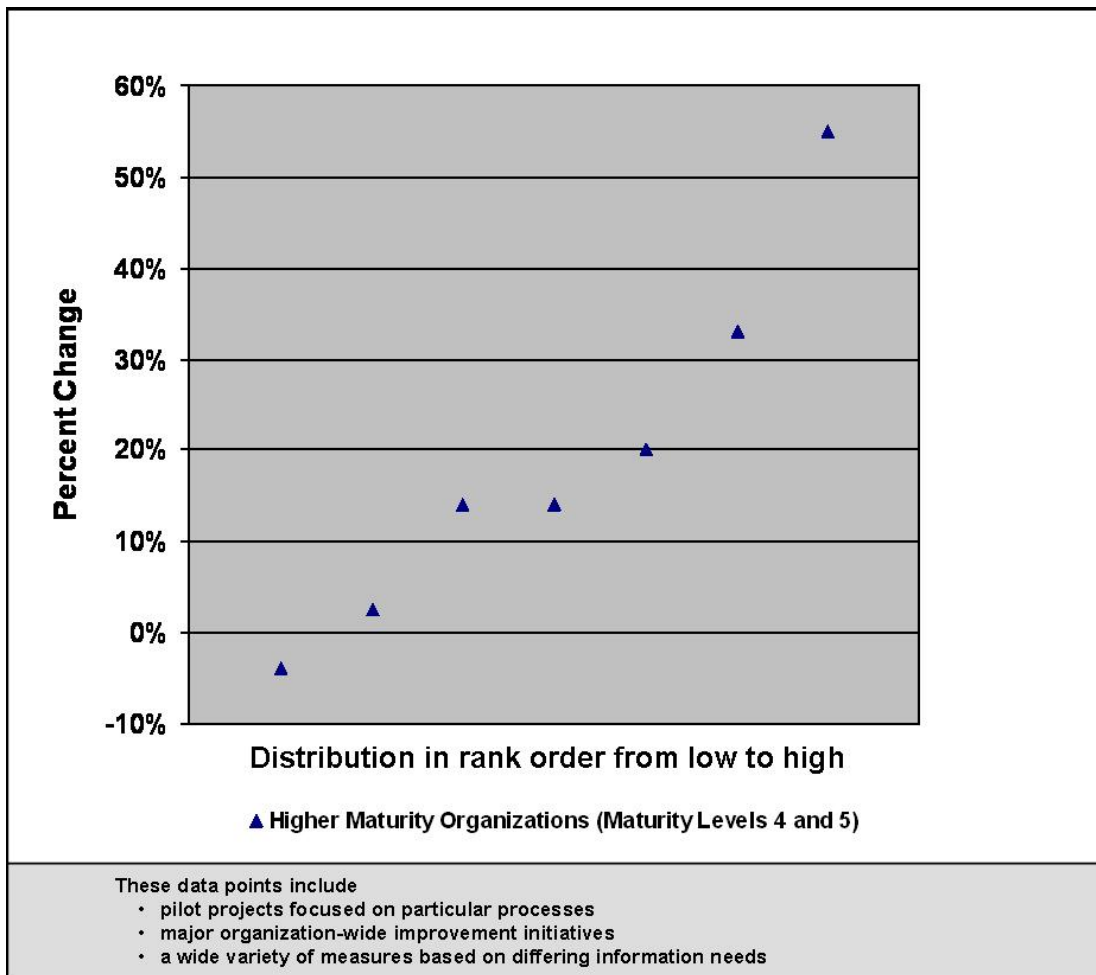


Figure 15: Changes Over Time in Customer Satisfaction

With the exception of those that are described in more detail in the case descriptions in Section 4, Table 11 includes all of the examples that can be expressed as change over time. The table also includes a few examples that cannot be expressed as change over time.

Table 11: Summary Benefits and Impact—Customer Satisfaction

#	Result	Organization
1	Slight decline in customer satisfaction as the organization moved from SW-CMM maturity level 4 to CMMI maturity level 5. The results remain essentially stable for a series of customer surveys, with average survey responses around 4 on a five point scale over the entire time period.	The Boeing Company
2	Increased award fees by 55 percent compared to an earlier SW-CMM baseline at maturity level 2	Lockheed Martin Management and Data Systems
3	Earned an exceptional rating in every applicable category on a contractor performance evaluation survey in a CMMI maturity level 5 organization	Northrop Grumman IT, Defense Enterprise Solutions
4	Received more than 98 percent of possible customer award fees in a CMMI maturity level 5 organization	Northrop Grumman IT, Defense Enterprise Solutions

#	Result	Organization
5	Steady increase in customer satisfaction as the organization progressed toward CMMI maturity level 5 from SW-CMM maturity level 3	SAIC System and Network Solutions Group
6	Customer satisfaction index increased an average of 42 percent in three technical areas from 1996 through 2004. An average of 48 percent of that improvement occurred as the organization moved from SW-CMM maturity level 5 toward CMMI maturity level 5	Siemens Information Systems Ltd.

As seen in the fifth row of the table, there was a steady increase in customer satisfaction at SAIC; further detail can be seen in Figure 16. Note in the sixth row of the table that there were improvements in three technical areas at Siemens. The MP and Telecom results are virtually the same, so they are indistinguishable in Figure 17.



Figure 16: Customer Satisfaction at SAIC

Customer Satisfaction

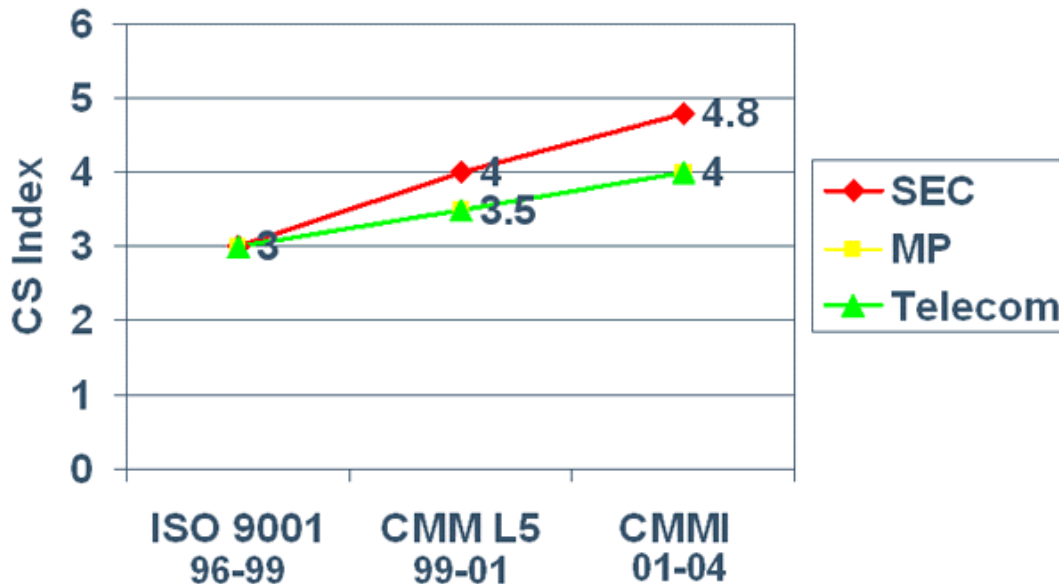


Figure 17: Customer Satisfaction at Siemens

3.3.6 Return on Investment

Return on investment (ROI) can be expressed in many ways [Denne 04, El Emam 05]. In addition to benefit-to-cost ratios, these include companion measures of net present value, internal rate of return, payback periods, and break even points. More comprehensive benchmarking comparisons will need to consider all of these.

The results reported here include only those that can be expressed as ratios of benefits to costs over time. As is true for all of the other performance categories in this technical report, the costs and benefits included here vary according to the business objectives and other information needs of the reporting organizations.

Many higher maturity organizations apparently calculate return on investment or do related cost-benefit studies,¹ and very few of the ROI results reported here come from lower maturity organizations (see Figure 18). Similarly, the scope of the efforts for which these organizations report ROI results tends to focus on specific process improvements in individual business units. Reports of return on total improvement investment are much less common for larger organizational unit or enterprise-wide maturity level improvement

¹ In a recent survey, 64 percent of the respondents reported that they calculate ROI or do related cost-benefit studies. The majority, but not all, of the 59 respondents were from higher maturity organizations. These results are from an unpublished report by D. Goldenson, G. Draper, and D. Gibson titled *Benchmarking CMMI Cost and Impact: Interim Report*. This report was completed in December 2004, but the distribution of the full document is limited to the benchmark contributors.

initiatives. That is why there is so much variation in the ROI ratios in Figure 18 and Table 12 and why some of them may appear to be so high.

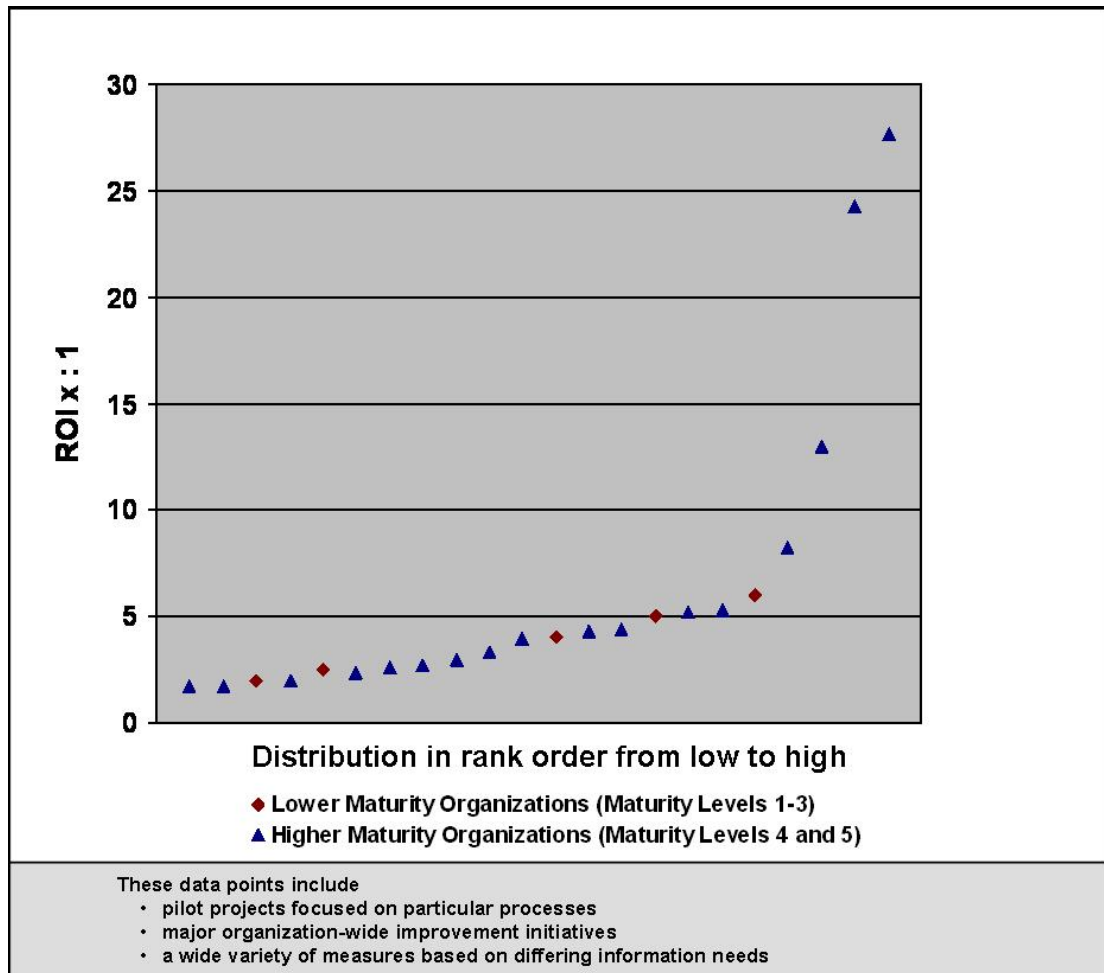


Figure 18: Changes Over Time in ROI

Higher maturity organizations in particular appear to be much more interested in reducing costs of quality and poor quality, and in improving product quality and customer satisfaction, than they are in overall ROI. Instead, some organizations use estimates of ROI to decide how to allocate their available process improvement resources.

Table 12 includes a few selected assertion statements that describe the kinds of ROI improvements that have been achieved through CMMI-based process improvement. Again, further information can be found in the more detailed case descriptions in Section 4.

The first three entries in Table 12 have reported overall return on their investments aimed at maturity level improvements. The fourth entry, from Tata Consultancy Services, describes the

overall return on their process improvement initiatives for an entire year.² The rest of the table entries describe the ROI of more focused process improvement efforts.

The fifth table entry is from the same anonymous organization that used the CMMI Measurement and Analysis process area to structure its initial CMM-based process improvement effort. Not only did this organization reduce its cost of quality and improve its productivity markedly in the space of one year, it also realized a notable return on its improvement investment, even when amortized over less than six months.

Finally, there was a very high return on investment achieved at Northrop Grumman Information Technology, Defense Enterprise Solutions. Once again, this result is from the same inventory tracking project discussed earlier that went through three causal analysis and resolution cycles to improve its peer review processes (see Figure 4, Figure 7, and Figure 14). As can be seen in more detail on the CMMI Performance Results Web site, investments for calculating the 13:1 ROI included the effort to conduct the causal analysis cycles, refine the process assets, and develop and deliver additional team training. Benefits were calculated by estimating the effort and cost that would have been incurred had the defect density remained at the build 1 baseline.

Table 12: Summary Benefits and Impact—Return on Investment

#	Result	Organization
1	6:1 ROI in a CMMI maturity level 3 organization	Raytheon Corporation, Anonymous site
2	3:1 ROI in a CMMI maturity level 5 organization	Raytheon Network Centric Systems, North Texas
3	2:1 ROI over 3 years as the organization moved from SW-CMM maturity level 5 toward CMMI maturity level 5	Siemens Information Systems Ltd.
4	ROI of 2.65:1 from Organizational Innovation and Deployment (and People CMM) improvements across all Development Centers in a CMMI maturity level 5 organization	Tata Consultancy Services
5	Used Measurement and Analysis process area to realize a 2.5:1 ROI over 1st year prior to being assessed at SW-CMM maturity level 2, with benefits amortized over less than 6 months	Anonymous 2
6	13:1 ROI, calculated as defects avoided per hour spent in training and defect prevention, over three causal analysis and resolution cycles in a CMMI maturity level 5 organization with PSP trained engineers	Northrop Grumman IT, Defense Enterprise Solutions
7	Over 2.5 ROI from process automation estimated at maturity level 5	Reuters
8	Over 3:1 ROI due to post release defect reduction as the organization moved from SW-CMM maturity level 3 to CMMI maturity level 5	Reuters
9	ROI of 4.28:1 realized by reduced rework effort through early detection of memory leaks in a CMMI maturity level 5 organization	Tata Consultancy Services
10	ROI of 5.21:1 in productivity enhancement, defect reduction, and shorter delivery cycle time by implementing and utilizing a Center of Excellence Web site in a CMMI maturity level 5 organization	Tata Consultancy Services

² Tata also estimates ROI as part of its regular process management activities, which closely follow the guidance in the CMMI Organizational Innovation and Deployment process area.

#	Result	Organization
11	ROI of 5.33:1 realized through the development and utilization of use case estimation guidelines and a template in a CMMI maturity level 5 organization	Tata Consultancy Services
12	ROI of 27.7:1 in productivity enhancement, defect reduction, and shorter delivery cycle time realized by implementing and utilizing an Asset Repository at Centers of Excellence in the Development Centres in a CMMI maturity level 5 organization	Tata Consultancy Services

4 Case Descriptions

The following case descriptions provide additional detail about the performance results achieved by 10 organizations that have used CMMI models to guide their process improvement efforts. The results include examples for all six performance categories described earlier in this technical report. Each description provides background information about the participating organization and its products and prior experience with process improvement. The background information is followed by additional detail about the organization's implementation of practices advocated by CMMI models. The performance results are presented along with additional detail about business objectives, measurement criteria, and actions that were taken based on the analyses.

Some of the results have been normalized to protect proprietary information. SEI staff members reviewed the data and results to better understand them and judge their accuracy. In several instances, SEI staff also provided assistance with study design and analysis. Individuals from participating organizations were asked to provide their evidence and contextual information using a standard format to facilitate summarization and quality assurance. They were asked to discuss their measurement criteria, including evidence that the results can properly be attributed to CMMI-based processes as opposed to other factors or unintended measurement effects.

4.1 3H Technology

written with Ruth Buys

Background

Organization Background

3H Technology (3HT) is an information technology company offering a wide range of products and technical services. These include performing custom software development, systems integration, and product implementation. 3HT develops custom-tailored applications for the automotive, medical, pharmaceutical, real estate, property management, banking and finance, and retail industries. Product implementation services include analysis of user environments, followed by custom tailoring of its products. Other services include providing quality assurance, network support and training, writing technical and user documentation, and offering process improvement consulting. 3HT distributes two of their own products:

- eSnap—a knowledge management program

- ElectroLease—a document imaging software package that was built to meet the special interests of real estate professionals.

3HT has about 185 full-time staff and 20 to 25 consultants. Approximately 60 full-time staff work in Network Solutions; the remaining staff work in Software Development or Program Management. The Network Solutions staff supports over 2,100 users in over 67 sites around the Washington, D.C. Metropolitan area.

Process Improvement History

3HT had no real experience with process improvement prior to starting its ISO and quality assurance initiatives in 2004. The quality assurance initiative began in the Software Development Division, and the ISO 9001:2000 certification effort began in the Network Solutions Division. A few months later, but before ISO certification was achieved, the Software Development and Program Management Divisions began work with CMMI. During the period from March 2004 through December 2004, quality assurance, ISO, and CMMI initiatives were proceeding concurrently. In January 2005, the ISO effort went into maintenance mode.

CMMI-Based Process Improvement

3HT began its CMMI implementation essentially from scratch. During the first four weeks of the CMMI effort, a process improvement infrastructure, comprised of an Engineering Process Group (EPG) and a Management Steering Group (MSG), was established. 3HT had strong management support from its senior management, as evidenced by the willing attendance of the CEO, COO, and CIO at a two-day training session on CMMI. It took some time to establish the management steering committee and to understand what was needed. The senior managers agreed to participate on the management steering committee, attended all of the meetings, and responded to requests. While there was some reluctance among individuals in middle management, 3HT was finally able to garner their support as well.

The process improvement strategy undertaken at 3HT was not unusual. 3HT began with the initiation of several Process Action Teams (PATs) who worked to establish guidance on how to document processes and other documentation conventions. The effort initially focused solely on reducing defects in delivered software. Then, work started in the Project Management area with the review of existing assets and a gap analysis against the relevant CMMI process areas. These included Project Planning (PP), Project Monitoring and Control (PMC), and Risk Management (RSKM). For the most part, 3HT was able to build on existing processes. However, there were several significant process elements that 3HT had to create from the beginning. These included two example plans, a general project plan and a quality assurance plan, and a process for formal risk identification and tracking. Additionally, the software group had to adopt a standard form for preparing its project plans and the associated work breakdown structures. The initial SCAMPISM Class C appraisal was completed while the Project Management PAT was completing its work. The information from the appraisal was used to validate the revised project management process descriptions.

Other process action teams were chartered in succession until all CMMI maturity level 2 and 3 process areas were addressed. Improvements were made to processes which mapped to Requirements Management (REQM), Configuration Management (CM), Project and Product Quality Assurance (PPQA), and Measurement and Analysis (MA). New processes begun as part of the process improvement initiative included Validation (VAL), Verification (VER), and Project and Product Quality Assurance (PPQA) for all software development projects. Improvements included tracking size data, adding a requirements traceability matrix, and launching configuration audits. New organization-level processes included the establishment and monitoring of a process asset library and the collection and reporting of process improvement measures. 3HT documented and integrated existing processes where possible and defined new processes where it was not. Since many of the existing processes at the organizational level as well as the project level had not existed on paper before this time, and were not used consistently, all of the defined processes seemed new.

All of the previously described process documentation took place while the EPG was working intensely with two pilot projects. In August 2005, 3HT sponsored an externally led SCAMPI Class A appraisal and achieved CMMI maturity level 3.

After the SCAMPI appraisal, 3HT continued deploying the newly documented and defined processes on all software development projects and validated the use of these processes. 3HT continues to perform regular gap analyses, comparing the processes used in the projects to the documented processes. Every project that lasts for at least six months will experience at least one full and one follow-up audit. The Quality Assurance and Process Improvement groups plan these activities for each quarter. Since August 2005, all improvement processes are monitored and tracked by the EPG to ensure continued adherence to relevant standards, implementation by all projects, and continuous improvement.

Performance Results

Performance measurement related activities in 3HT include the collection and reporting of process improvement measures such as the level of effort, the size of the process asset repository, the number of non-conformances identified in process audits, and the progress on deliverables. This data is reported regularly to senior management.

Quantitative results provide interesting insights into the process improvement effort at 3HT. Some of the results still raise questions on the sources, validity, and usefulness of the data 3HT is collecting. While there is sufficient data to conduct analyses relative to several process areas, the data is not consistent in all cases. Some of the data is subject to interpretation, and the different timeframes in which the data was captured sometimes make it difficult to perform comparisons. These difficulties are common and can be expected in many organizations initiating a measurement program.

Measuring Software Defects

One of the reasons 3HT started process improvement was to address problems related to defects in the software. 3HT needed to understand the level of quality in software delivered to the customer. The quality assurance process at 3HT transfers software from the developers, who are using tools to track defects, to the quality control group, where Rational's ClearQuest is employed. After management authorization, the software is delivered to the customer. The customer then sends the software to an independent, third-party contractor who does verification and validation (IV&V). Data is gathered to show the number of defects collected during quality control tests using ClearQuest compared to the average number of defects identified per release from IV&V reports. If errors are found in IV&V testing, 3HT does the rework.

Prior to process intervention, the releases were on average 75 percent defect free. 3HT took a look at the effectiveness of its quality control procedures by comparing the average number of defects found before and after implementing these procedures. The organization found that after the process intervention the releases are on average 98 percent defect free.

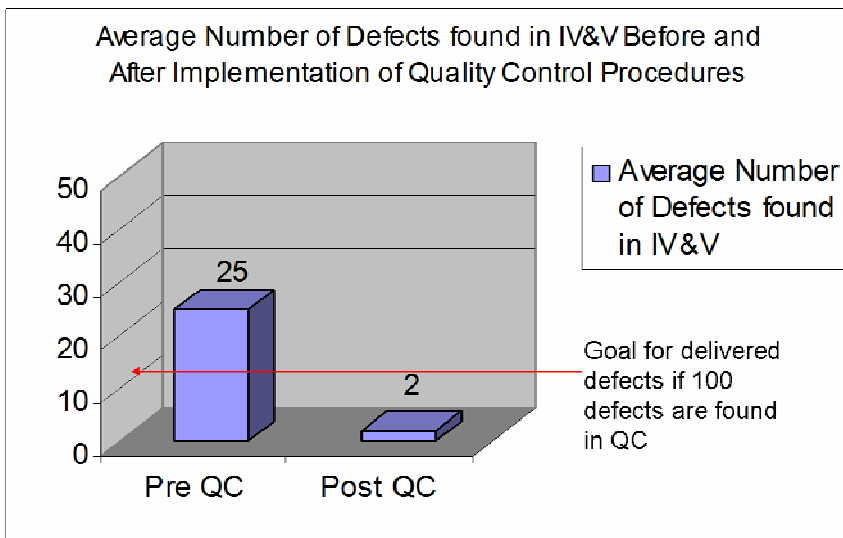


Figure 19: Number of Defects

The results seen in Figure 19 can be attributed to CMMI because while 3HT had a method to identify and record defects from IV&V reports before the CMMI-based quality assurance, validation, and verification processes were implemented, the analysis of that data, which could have helped 3HT decide what to improve, was not directly supported.

Measuring Process Improvement

3HT captured data about the costs of doing CMMI-based process improvement inside the organization. Originally, the organization estimated it would take a total of 13,000 hours to perform the process improvement work. It took less time than that for several reasons.

First, the efforts associated with process improvement tasks were not tracked during the first four months of the pilot phase because it took that long to establish and deploy a viable effort measurement process and get the appropriate accounts established in the Finance department. The need to establish new accounts in Finance brought to light the lack of defined procedures for completing and approving time cards. When the EPG noted this, the Finance and Human Resources departments requested assistance from the EPG in defining its processes. The assistance was supplied in the areas that were immediately needed by the EPG, and the problems were reported to senior management, so additional actions could be taken, if they were deemed necessary. It also took less time than expected to do process improvement because the EPG followed a disciplined improvement method and they recognized the benefit of defining and improving existing processes wherever possible rather than building new processes.

Accurate effort reporting allowed 3HT to track time spent on various work components, to compare estimates to actuals, and to calculate other performance measures such as cost/benefit analysis and earned value. Other measures that were established included the size of the process asset repository, number of non-conformances identified in process audits, and progress on deliverables. These measures were used for many processes, but measurement began with the process improvement effort.

3HT tracked the estimated versus the actual hours spent on process improvement tasks. Estimates were logged into a spreadsheet, and the actual hours spent were transferred from time sheets to this spreadsheet so that they could be compared. Because of the initial improvement efforts initiated with the Finance Department, 3HT was able to use the data from Finance Department reports. The original level of effort estimated was 13,000 hours. The actual level of effort for the 12-month period, covering the last 8 months of the pilot projects and the first 4 months of the rollout, was approximately 8,000 hours. This includes the time spent training approximately 100 staff members.

Measuring Process Enactment and Compliance

As with all organizations improving processes, it became important to track the changes being made, and because CMMI was being followed it was desirable to map these changes to the model. The following measures were taken to track the organization's progress toward CMMI maturity levels (Table 13). First, the number of practices that could be categorized as largely, partially, or not implemented were captured. Then, a percentage of compliance to CMMI process area practices was calculated and displayed using a stoplight chart. Prior to the process improvement effort, the implementation of the practices were as follows:

Table 13: Implementation of Processes Prior to Improvement Effort

Level 2 practices	Largely implemented	Green	25%
	Partially implemented	Yellow	50%
	Not implemented	Red	25%
Level 3 practices	Largely implemented	Green	27%
	Partially implemented	Yellow	43%
	Not implemented	Red	30%

Figure 20 shows the same results in graphic form.

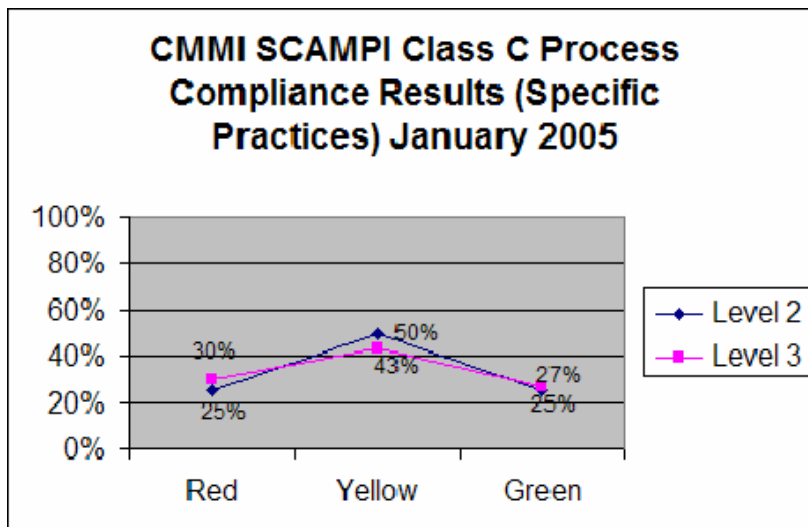


Figure 20: SCAMPI Class C Results

After the process improvement effort and the SCAMPI Class A appraisal in 2005, all of the practices for which 3HT was appraised were categorized 100 percent Green. This included all of the practices in the process areas at maturity level 2 and maturity level 3 except Supplier Agreement Management, which was excluded from the scope of the improvement effort and SCAMPI appraisals.

In order to evaluate the level of compliance with internal organizational standard processes, processes are evaluated through internal process audits. The numbers of major and minor process non-conformances are collected and compared to the expected values for each process area. In the first half of 2005, 66 instances of non-conformance were identified; after process intervention, in the second half of 2005, 52 instances of non-conformance were identified. EPG members believe that the number of non-conformances should have gone

down more, but they are still improving the effectiveness of the audit process. Where instances of non-conformance were found, members of the EPG worked with project managers to develop corrective actions.

The EPG also examined its processes by keeping track of the number of process change requests (PCRs) it received. In the first pass, after implementing new processes, the organization received 58 PCRs. 3HT used these to identify and track input on process performance, to determine process volatility, and to support continuous improvement. PCRs are entered into a Process Change Request Log that is then reviewed by subject matter experts for an assessment of the impact and generation of recommendations.

3HT intends to maintain what it has gained from process improvement and plans to implement continuous improvements. The organization is considering achieving higher maturity levels as time and resources permit.

4.2 ABB

written with Aldo Dagnino

Background

Organization Background

ABB is a leader in power and automation technologies. It enables utility and industry customers to improve performance while lowering environmental impact. ABB's products help operate utilities, process industries, manufacturing plants, and other industries. ABB has representation in over 120 countries and employs 110,000 people. A vast majority of ABB's products have software and hardware components.

The ABB unit presented in this case description develops modular substation automation systems to monitor the condition of electrical equipment at electrical utility companies. This equipment includes circuit breakers, power transformers, and other transmission and distribution systems. ABB substation automation systems provide remote control and monitoring capabilities of all kinds, from power distribution-level to extra-high voltage substations. The substation automation systems developed by this ABB unit are quite complex and include hardware and software components. The products make use of intelligent electronic devices (IEDs) for protection and control, and they lay the foundation for all the higher level functions such as advanced power system management and the monitoring of the condition of the equipment while it is in use. The software that is embedded in the hardware of substation automation products makes the systems easy to use and adaptable to customer-specific requirements. The scalable modular systems developed by this unit reflect the typical utility customer needs for the following range of applications:

- transmission, sub-transmission and distribution substations

- new installations and refurbishment of existing substations
- utilities and industries
- gas and air isolated switchgear

A sample product that shows the complexity of substation automation systems developed by this unit is the substation automation system for sub-transmission and distribution of power (SAS510). The SAS510 contains a station computer with human machine interface (HMI) for local control, monitoring, and system configuration. The station computer also is equipped with local area network (LON) interfaces for the integration of bay control IEDs and with LON and/or IEC60870-5-103 interfaces for the integration of protection IEDs.

Process Improvement History

ABB starting using the SW-CMM for process improvement in some of its units in 1999. A pilot of processes based on CMMI was completed in the Fall of 2001 for one of these units. The unit described in this case never used SW-CMM and started using CMMI in January of 2003.

The ABB software and systems process initiative process improvement (ASPI) group addresses processes for the full product life cycle (systems and software process initiatives). Since the organization is spread across the globe, there is a unit at each location that is responsible for supporting local process improvement.

ABB has used the IDEALSM model since 1999. All process improvement initiatives at ABB use an interpretation of IDEAL's continuous process improvement engine. This is true not only for CMMI but also for all ABB efforts based on principles of lean manufacturing, business process reengineering, and the theory of constraints. This group uses the initiation phase of IDEAL to explain CMMI, ask a business unit about its business objectives, and do a quick assessment to see if the unit is ready for process improvement. A full IDEAL cycle lasts about a year and a half.

CMMI-Based Process Improvement

The following CMMI-based process improvement efforts apply to one ABB unit over a two-year period from January 2003 to the end of 2004. The unit did not have prior experience using CMMI, but there were notable improvements by the second year. This unit had at the time of the study approximately 35 hardware and software developers.

In January of 2003, the ABB Corporate Engineering Process Group (CEPG) performed an internal ABB CMMI Class B appraisal on this unit based on CMMI maturity level 2 process areas and the Requirement Development and Verification process areas. This appraisal resulted in the identification of strengths and weaknesses. Before the appraisal, a meeting with this unit's senior management established that a major business objective was to reduce the cost of poor quality (COPQ) by 25 percent in 2003 as compared to its results in 2002. At

that time, COPQ was defined as the cost associated with fixing defects in the software modules after system level testing was performed and before the product is shipped to the customers. In order to maintain an acceptable level of consistency, it was important that there were no major differences on how the COPQ was determined between 2002 and 2003.

Using the results of the appraisal and other discoveries, this unit created an action plan to address all weaknesses identified in its implementation of each of the process areas. The business goal of reduction in COPQ was used to prioritize the unit's process improvement activities. It became clear that in order to meet this goal, the unit needed to focus on the CMMI Requirements Development and Requirements Management process areas. These two process areas were clustered into one process at this ABB unit: the requirements engineering (RE) process. A project to improve the RE process was established and in two months the new process was developed for the whole organization based on the pertinent CMMI practices. This process was piloted and used at a later stage in 2003 in a major product development project. The Measurement and Analysis process area was employed to monitor and determine the COPQ for the remainder of 2003. After the pilot, the new RE process was institutionalized for the whole product development organization so that all new product development projects would follow the same process.

The appraisal had established that the largest source of defects in the process were due to the development and maintenance of software requirements. Hence, defects were tracked when the system-level testing was performed and then the effort and cost associated with reworking those defects were recorded. A comparison with the same effort and cost of defects recorded at the system-level testing in 2002 was performed.

The following points describe the improvement in processes for each CMMI process area that was related to the organization's RE process:

- **Requirements Development**—The ABB unit used market requirement specifications (MRS) in the past, but the MRS were not formally defined and not enough time was given to generate them. Requirements Development helped this unit create a template for the elicitation and collection of requirements and a process to consistently analyze, prioritize, and validate customer requirements.
- **Requirements Management**—This process area helped this unit create a process to ensure the proper understanding of requirements and set up a process to adequately and consistently manage changes to requirements. With these processes team members can come to a common consensus about changes; formerly, they had a loosely defined baseline that could be changed without a formal change request process, and this would cause inconsistencies and incompatibilities.
- **Measurement and Analysis**—This ABB unit already had its business objectives mapped to high level measurement objectives. While this was atypical elsewhere in ABB, they needed more guidance about how to choose the right measures and analytic techniques when allocating the measurement objectives to specific product development activities. The Measurement and Analysis process area helped them do this.

Performance Results

As noted in the previous section, this ABB unit aimed to reduce its cost of poor quality (COPQ) by 25 percent after implementing its new CMMI-based requirements engineering process. The unit calculated COPQ by measuring defects found at the integration and system level testing stages (for software and hardware) and tracking time for defect corrections and retesting. At this stage, defects are more costly to fix. If defects are found, the appropriate components must be corrected, and they must then be sent back to hardware or software testing and the time to fix and re-run tests must be tracked.

Figure 21 shows a comparison of the cost of poor quality in 2002 and 2003 on a cumulative basis as well as month-by-month. The absolute values have been sanitized in the figure; however, the cumulative cost of poor quality was 30 percent lower in 2003 in the unit's second year of CMMI-based improvement.

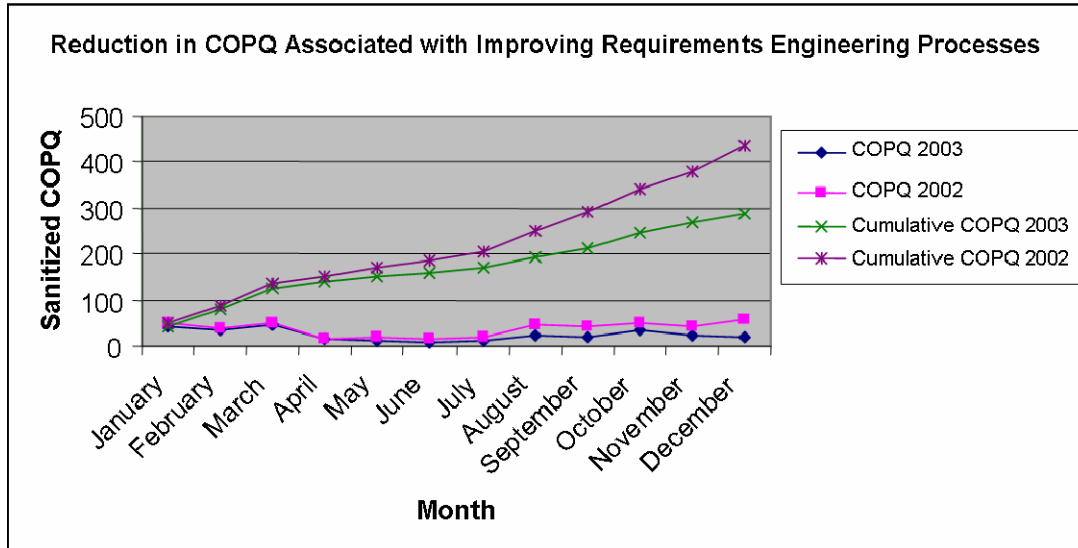


Figure 21: Reduction in COPQ Associated with Improving Requirements Engineering Processes

ABB started calculating ROI corporate wide in 2003, and the typical ROI for major process changes is 3:1 to 5:1 (benefit to cost of process improvement activities). This ABB unit had a net economic benefit of 50 percent. Costs associated with improving the RE processes included the work involved in changing processes, training people on the new processes, doing the internal ABB CMMI Class B Appraisal, and involving the corporate process improvement group. The only benefit included in the ROI calculation is the savings that resulted from the 30 percent reduction in COPQ. Amortizing the benefits over only one year, the unit achieved a 2:1 return on investment (ROI).

Including the reduced costs of developing and maintaining the product and amortizing over a longer period of time would yield a less conservative ROI.

4.3 Hitachi Software Engineering

written with Mutsumi Komuro

Background

Organization Background

Founded in 1971, Hitachi Software Engineering is a global supplier of IT services and employs over 5,000 people worldwide. With sales of over \$2.1 billion in FY 2003, Hitachi Software provides products, professional services, consulting, and support.

Hitachi Software Engineering is one of the largest software companies in Japan and has four major groups for different business domains:

- Industrial Systems Group (ISG)
- Financial Systems Group
- Public and Social Systems Group
- Software Development Group

The improvement activities and performance results described in this case description are mainly from ISG. The customers of ISG make industrial products and include automobile makers, electronic device makers, and filmmakers. Typical development products and services of ISG include customer relationship management systems, enterprise resource planning (ERP)-based systems, and software for embedded systems and information appliances.

The ERP-based systems are supported by SAP R3, a software package created by SAP Labs in Germany. SAP R3 integrates and automates many of the business practices associated with operations, production, and distribution involved in manufacturing products or services. Hitachi Software Engineering also provides consulting and customizing services for other users of SAP R3.

The size of products produced at ISG varies from small to medium, when compared to the other major groups in Hitachi Software Engineering, but the complexity and criticality are relatively higher because some products are used as the infrastructure for developing embedded products and information appliances.

Process Improvement History

Hitachi Software Engineering had little prior experience with model-based process improvement initiatives or standards. Only the Software Development Group has experience with ISO 9000, and none of the four groups has had experience with Six Sigma approaches. The company never used the SW-CMM to guide its process improvement activities.

Instead of using common process improvement standards, Hitachi Software has been conducting two kinds of periodic internal “movements”: quality improvement movements and productivity enhancement movements. Each movement has a duration of two to three years, and they have been conducted since the establishment of Hitachi Software Engineering. Currently, the 10th quality improvement movement and the 11th productivity enhancement movement are being conducted company wide. ISG also conducted a separate code inspection movement that was sponsored by the ISG general manager to enhance the quality of ISG products.

A company-wide process improvement initiative based on CMMI was launched in 2001. The initiative started because of competition Hitachi Software faced in its industry. The organization wanted to stay ahead of the pack, and at that time the Japanese government was considering requiring a Japanese version of CMMI for all suppliers.

All four of the major business groups at Hitachi Software Engineering achieved CMMI maturity level 3 in 2002. The Public and Social Systems Group achieved level 3 in January, followed by the Financial Systems Group in June and the Software Development Group in July. The Industrial Systems Group achieved maturity level 3 in October. In addition to providing a thorough understanding of the strengths and weaknesses of the groups’ then-current practices, preparing for the maturity level 3 appraisals and their associated team training provided an important focus on process issues to help kick off the CMMI-based improvement initiative [Komuro 03].

ISG has approximately 800 employees and is very eager to train them on its standard processes, which are based heavily on CMMI. The SEPGSM group at ISG typically consists of 4 to 5 full-time members and 20 to 30 part-time members who also serve on several supporting working groups.

CMMI-Based Process Improvement

SCAMPI appraisals conducted prior to the start of its process improvement initiative based on CMMI showed the need for improvement at Hitachi Software Engineering. In particular, the appraisals showed that the organization needed to be less product centric and focus on process as well as product. As stated before, ISG achieved CMMI maturity level 3 in October 2002. A focus on improving the organization’s peer review processes helped ISG achieve maturity level 4 in February 2004 and maturity level 5 in October 2004.

ISG began by evaluating its existing practices in order to incorporate the best ones into its new and revised peer review processes. Relationships of improvement activities to business goals were clearly stated, and project members were involved in the improvement of their own processes.

A fair amount of performance data were available from the ISG code inspection movement by the time that the organization achieved CMMI maturity level 3. The performance data were analyzed statistically as ISG moved toward CMMI maturity levels 4 and 5. There

initially were some flaws in the measurement process (e.g., some data seemed to be incorrectly recorded and some key measures were missing); however, the early results encouraged ISG to continue improving its code inspection practices. The following improvements were implemented:

- The measurement process and definitions of measures were made clearer.
- Peer review performance objectives were related explicitly to business goals.
- Existing best practices found during the analysis were recorded.
- A tool to plot control charts was developed using Excel macros.
- Training courses were conducted for the first four activities.
- An ISG service was provided to support the projects in the analysis of their peer review data.
- ISG provided a project support service to analyze source code, using Hitachi Software Engineering's Code Director tool to identify static semantic errors and failure to follow coding standards.

Prior to the CMMI initiative at ISG, quality assurance (QA) activities consisted of independent verification of various work products. The projects first verified their own work products, including various specification documents and source code. The same documents and programs then were verified by QA departments that report directly to the ISG board, independently from the projects, using their own checklists and test sets.

While QA representatives usually participated in progress meetings with the projects, they did not check the projects' ongoing process activities often. The main focus of the QA activities was to check the work products rather than the processes. The CMMI Process and Product Quality Assurance process area had a positive effect on product quality because it helped guide ISG to conduct quality assurance on process as well as product characteristics.

Other important process improvements advocated by CMMI included the following:

- An ISG measurement system with an emphasis on testing was in place long before the organization began using CMMI; however, a number of flaws were recognized based on guidance found in the Measurement and Analysis process area. In particular, the process area encouraged the organization to explicitly relate measurement to its high priority business goals.
- While ISG previously did have informal processes to aid in the making of major decisions, the organization used the Decision Analysis and Resolution process area to formalize those processes, especially for comparing alternatives.
- As noted above, the organization also relied heavily on activities advocated by CMMI for Quantitative Project Management, Causal Analysis and Resolution, and Organizational Innovation and Deployment to improve its peer review processes.

Testing had been emphasized previously, and it was not an improvement priority for CMMI-based improvement at ISG; however, reducing testing costs was a major emphasis for the organization's higher maturity effort.

Performance Results

The performance results presented here focus on those due to improvements in ISG processes for peer review and quality assurance. The results are drawn from pilot studies and other statistical analyses conducted prior to wider scale deployment throughout the organization. The peer review results are based largely on hypothesis testing using regression analysis methods as well as the statistical process control techniques used for quantitative project management at ISG. The quality assurance results are based on pilot testing.

The organization's measurement definitions and procedures have changed as its measurement capabilities matured; therefore, ISG has not calculated overall performance improvements resulting from adopting CMMI or achieving higher maturity levels.

Early in its CMMI improvement initiative, ISG observed a strong negative correlation ($r^2=.72$) between defect detection prior to unit testing and total defect density throughout the product life cycle. Projects that found defects earlier also had substantially fewer total defects. Moreover, the effort and cost to find and fix defects captured at unit test proved to be 2.28 times more costly than those found during peer review. This was true even though the early peer reviews were less efficient than those based on subsequent process improvement. Improvements to peer reviews at ISG have improved staff productivity and reduced costs while improving product quality.

Early in their implementation of quantitative project management activities, ISG engineers also noticed that Fagan-style inspections used in their exemplary projects seemed to work better than the less formal peer review walkthroughs that were usually conducted elsewhere in ISG. Relatively little data yet existed for the Fagan-style inspections, and the organization had not yet established separate baselines; however, regression and other statistical analyses were able to detect differences ranging from almost 4.5 to over 10 times more defects found with the inspections. More defects were found earlier with Fagan-style inspections when correcting them was substantially less expensive.

Possibly because there was a learning curve associated with the first few instantiations of the Fagan-style inspections, ISG was not able to confirm from its early results that its Fagan-style inspections were more efficient than its walkthroughs. While the inspections clearly found more defects than the walkthroughs, more effort was spent on preparing for the inspections. Still, the ISG measure of peer review efficiency was based on the number of defects identified in a peer review divided by the effort spent on the peer review only. The cost of correcting the defects is substantially more expensive when they are found later in the product life cycle.

Looking more closely at special causes of variation, ISG identified a series of peer review practices that it then incorporated in other pilot projects. These included clarifying in advance what aspect of the work product should be checked, limiting the duration of the reviews, and limiting the number of participants in the reviews.

Subsequent piloting also found that more defects escaped detection during peer review when ISG tried to cover too large a product in a single review; therefore, the organization established an upper limit for review size. As seen in Figure 22, though, use of the Hitachi Software Engineering Code Director static analysis tool increased the upper limit of manageable review size by 30 percent. Overall, the return on investment for the Fagan-type inspections was 3.9:1 as opposed to postponing verification until unit test. The comparable return for the less formal walkthroughs was 2.3:1.

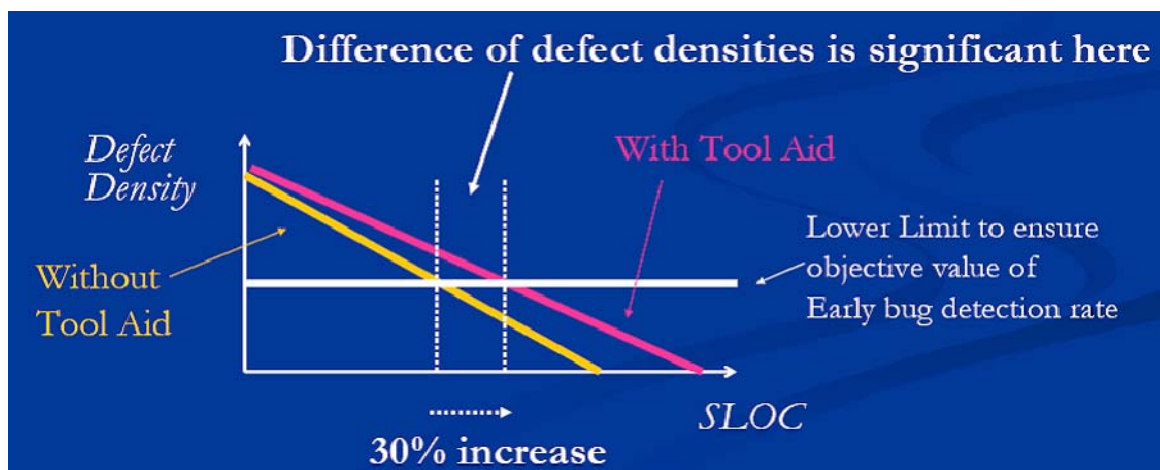


Figure 22: Peer Review With and Without Tool Aid

Prior to deployment throughout the organization, ISG conducted a series of pilot studies of the effects of including process along with product in its quality assurance activities. Data were gathered from 16 pilot projects, one or two of which were selected from each ISG department. Defect density in those projects was 15 percent lower than the ISG baseline. In addition to the improvement in product quality, the organization calculated a return on investment (ROI) of 1.7:1 due largely to reduction in the cost of subsequent verification and validation activities. Separate analyses conducted by the QA departments reported ROI ratios ranging from 6.3:1 to 9.8:1 when the costs of correcting field errors and other management and engineering problems were factored into the ROI ratios.

4.4 Motorola Global Software Group

The Motorola Global Software Group (GSG) develops and maintains custom software for many Motorola products and services. GSG provides technical leadership and expertise to deliver advanced solutions for software that must be used seamlessly throughout the corporation and by its customers worldwide. With a flexible pool of over 6000 engineers, a total of 14 GSG Software Design Centers are distributed throughout the world. This section contains brief case descriptions detailing the performance results achieved through CMMI-based process improvement by the Centers in China, India, and Russia.

4.4.1 Motorola GSG China Center

written with Angel (Liu Qi) Liu

Background

The Organization and Its Products

Like all Motorola Global Software Group Software Design Centers, the primary business of the GSG China Center is to provide software development services and solutions to other Motorola business units. GSG China's products include various embedded systems in cellular, network system, and other telecommunication devices. GSG China was established in 1993. There are three sites in China, in Beijing, Chengdu, and Nanjing, and GSG China currently employs a staff of more than 1200 individuals.

Work throughout the Global Software Group is organized into several business divisions that align with Motorola's major corporate business units. The China Center does most of its business for three GSG divisions:

- The Embedded Products and Systems Division provides innovative and rapid software solutions for Motorola's consumer products.
- The Infrastructure Solutions Division provides software products and systems solutions for the Motorola network telecommunication business and its customers worldwide.
- The Integrated Communication Solution Division provides software and systems solutions for the professional two-way radio businesses.

GSG China provides end-to-end solutions in many areas, including mobile terminal software development; wireless; embedded system software; professional two-way radio software development and testing; network management; and automotive telecommunication and system software development. GSG China has led many regional and global projects, and its software products and services are widely applied in Motorola products across a variety of platforms. The Center's products vary in size from 18,000 non-comment source statements (KNCSS) to 381 KNCSS. The China Center's projects include designing, developing, testing, porting, reverse engineering, and performing other services.

In addition to its heritage in providing end-to-end solutions in the various fields just mentioned, GSG China now is working with Motorola Software Technology Groups, particularly in the areas of software engineering tools, intelligent user interfaces, open source technology and embedded systems, and seamless mobility enablers.

Process Improvement History

GSG China was the first software organization in China to use the SW-CMM as a basis for their process improvement program. In 2000, this organization was the first in China to be appraised at maturity level 5. Process engineers in the China Center began focusing their attention on CMMI in 2002. By the end of 2003, the China Center had begun its formal transition to CMMI, and it was appraised at maturity level 5 in September of 2005.

Like all Motorola GSG Centers, the one in China uses Digital Six Sigma in concert with its CMMI-based improvement efforts. Digital Six Sigma is a Motorola deployment that stresses e-learning and automation to ensure the institutionalization of process improvements.

Some GSG China operations also use TL9000 audits in concert with CMMI. Created to meet the quality requirements of the worldwide telecommunications industry, the TL 9000 Quality Management System provides additional insight into telecommunications processes for resource management, disaster recovery, device control, and preservation of product [QuEST 06].

CMMI-Based Process Improvement

For GSG China, the transition to CMMI was part of a natural progression of continuous CMM-based improvement. A CMMI taskforce was established in November of 2001. The Center's process engineers began training and performed a gap analysis in April of 2002.

By early 2003, senior management authorized the process engineers to begin piloting and start training on what it considered to be critical new practices based on the CMMI Project Management and Engineering process areas. Particular attention was paid to the CMMI upgrades to Project Planning, Project Monitoring and Control, Requirements Management, and Verification. Full scale planning and modification of the Center's Organizational Standard Process began in December of 2003. Changes to the software production process then were piloted and deployed throughout the Center's operations.

Major process improvements achieved through GSG China's transition to CMMI include the following:

- The GSG Process Hierarchy Structure was adapted for use by the China Center to accommodate process changes due to CMMI. It is organized by process to assist the projects on process model selection, and it provides guidance and flexibility for projects to select and tailor their processes at a detailed subprocess level. The process asset library

can be accessed by several criteria, including CMMI process areas, phase, process templates, checklists, and other types of documents.

- The Center's engineering processes, particularly for requirements development, unit test, and validation now provide more practical guidelines, templates, techniques, and tools.
- The increased emphasis on CMMI in organizational processes led GSG China to deploy a COTS enterprise project management system as a common project management platform. Customized by Motorola corporate, it supports GSG China's multi-site team to work in an integrated manner on resource management, time tracking, project planning, milestone tracking, risk management, and related activities. All project status and performance can be planned, tracked, and measured in a quantitative manner, and it provides a global view for project and infrastructure management at all levels.
- The Center's quantitative project management processes were modified to focus more on critical processes aligned with business objectives, particularly in the areas of requirements management and verification.
- Causal Analysis and Resolution (CAR) and Organizational Innovation and Deployment (OID)-based processes were used to improve verification process effectiveness without compromising quality in specific classes of cases. The formal process rules the Center previously used were less effective for smaller documents and project teams. Mini-reviews and mini-inspections were introduced; effort and cost were reduced without affecting defect density. The results were used to establish new baselines for planning and quantitative project management.
- The Center's requirements development and management process was improved based on guidance in CMMI that did not exist in the SW-CMM. Late additions and changes to requirements are measured. The project level results then are rolled up to the organizational level for senior management insight and to set control limits for future use in quantitative process management of requirements volatility. The measured and estimated impact of the requirements changes also led to new project processes for replanning, estimation, and a factual basis for negotiation with customers.
- New GSG China practices based on the CMMI Decision Analysis and Resolution (DAR) process area were used to improve the Center's managerial and engineering processes, particularly those that map to the Technical Solution, Configuration Management, and OID process areas. These DAR-based practices have been applied to improve decision making effectiveness at both the organization and project level.

As noted earlier, the GSG China CMMI transition project began in December of 2003. It continued for 22 months through September of 2005. The total effort spent was approximately 17.6 staff years, which is about 1.1 percent of the Center's total engineering effort. Most of the effort, 60 percent, was spent on training for deployment. About 20 percent was used on process redesign, and 14 percent was devoted to appraisal activities. More than 92 percent of the employees received classroom training on the new GSG China software production process.

During the transition, the areas in need of improvement were identified by analyzing the gap between CMMI and the Center's then current processes. Priorities were set based on the impact and urgency of the improvements. For major improvements, the Center followed an OID-based process including evaluation, pilot, and deployment. During the piloting phase, 31 process assets were selected to be piloted in 14 projects that covered all of the Center's major areas of business. Since this transition, GSG China has continued to renew its process architecture and assets. At the time of this writing, 182 new and revised process assets have been deployed.

Performance Results

Cost of quality, estimation accuracy, and product quality all have improved markedly as the Motorola Global Software Group China Center upgraded to CMMI. The Center's customer satisfaction ratings, which already were very high, continued to improve. The customers continued to report that the Center exceeded their expectations.

All of the measurement definitions and quantitative results reported here are maintained in a Motorola GSG central data warehouse. The results are based on 170 projects of the China Center from 2000 through 2005. In addition to the results presented here, GSG China regularly manages earned value quantitatively.

As a result of improved verification processes, particularly product peer review and software test processes, GSG China was able to reduce its overall cost of quality by over one third, 36.5 percent, from its pre-CMMI baseline (see Figure 23). The cost of poor quality remained under control at less than 5 percent during the same period.

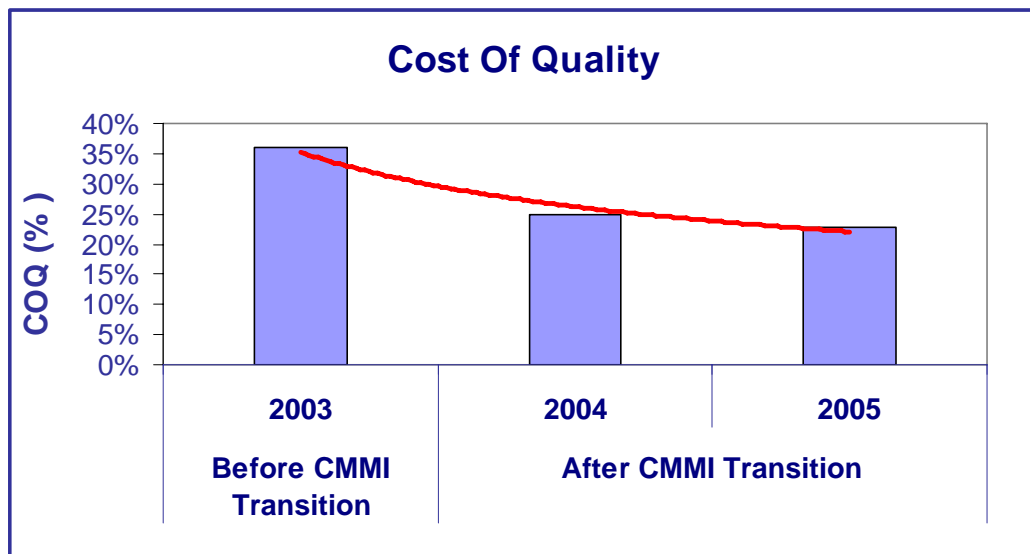


Figure 23: Cost of Quality

As seen in Figure 24, the China Center was able to improve its product quality at the same time that it reduced its cost of quality. Again, the improvement in performance was largely due to improved verification processes, which had been adapted through application of the Center's improved casual analysis and resolution procedures. Fewer defects were inserted, and the Center was able to reduce its software faults per thousand lines of code found prior to release by 40.2 percent from its pre-CMMI capability.

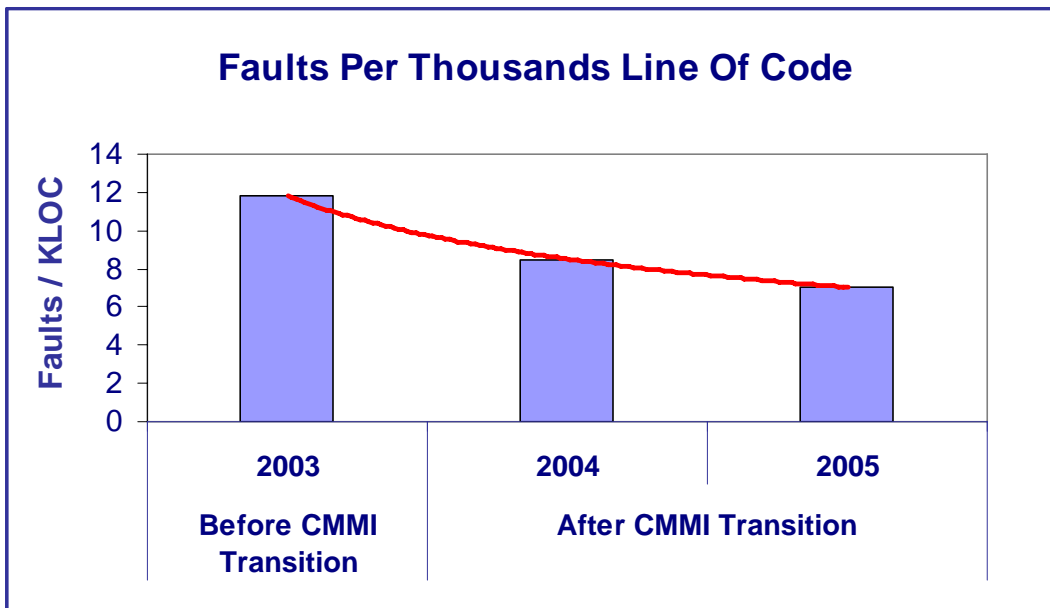


Figure 24: In Process Faults per Thousand Lines of Code

Particularly through their improved project planning, estimation, and tracking practices, GSG China was able to improve its initial effort estimation accuracy by almost a third, 31.4 percent, as the organization moved to CMMI maturity level 5 from its SW-CMM maturity level 5 baseline. During the same time period, the accuracy of estimated schedule duration improved by well over three quarters, 84.2 percent, over its performance at SW-CMM maturity level 5. The percentages shown in Figure 25 are based on the absolute values of the differences between the respective actual and estimated values divided by the original estimates for each time period.

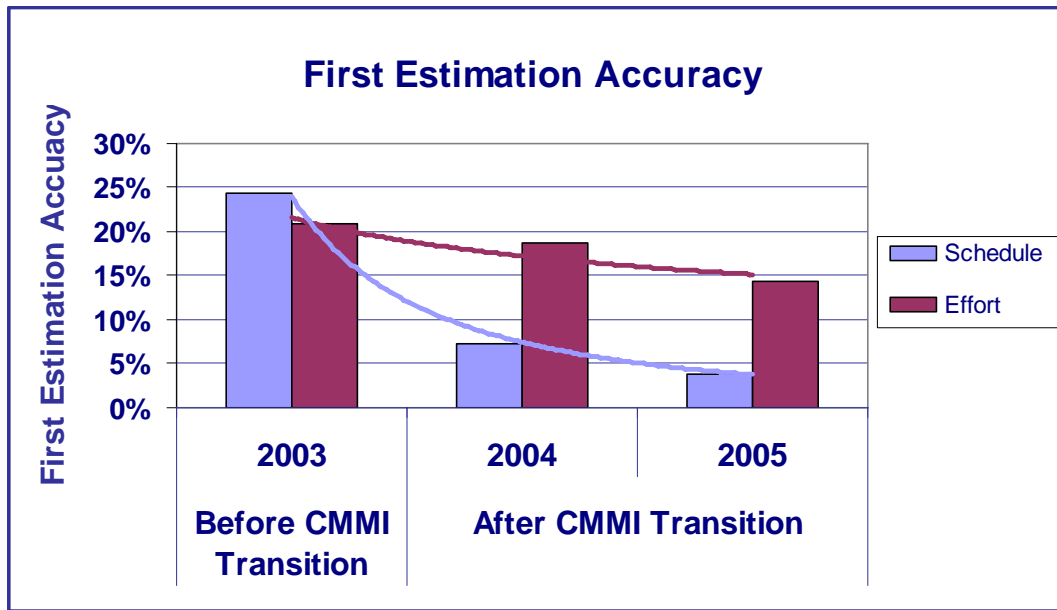


Figure 25: First Estimation Accuracy

With a sustained on-time delivery rate of 100 percent, the GSG China Center has consistently received high scores on its customer satisfaction surveys, which are conducted at the conclusion of every project (Figure 26). The surveys follow standard GSG practice, with scores of 8 out of 10 being considered “very good” and 9 representing “excellent” performance. Performance goals are updated every year. The China Center’s goal for 2005 was 8.86; it achieved an average score over all of its surveys of 9.03. Since the transition to CMMI, the surveys show that GSG China has continued to exceed its customers’ expectations. It has continued to achieve high customer satisfaction levels, as measured by the customers’ answers to explicit questions about the Center’s ability to deliver cost effective, high quality products on time by providing excellent technical solutions and project execution.



Figure 26: Overall Customer Satisfaction

The Motorola GSG China Center has grown in both staff size and business volume since beginning its journey to CMMI maturity level 5. By the end of 2005, the China center's staff was almost double what it had been in 2003. Its business volume and revenue increased substantially by 55 percent during the same time period. The Center believes that its continuous improvement of an already highly mature process has been an important competitive advantage.

4.4.2 Motorola GSG India Center

written with Balaji.R

Background

The Organization and Its Products

Motorola India Electronics Ltd (MIEL) was founded in 1991 and had 60 employees in the first year. The organization had grown to 800 employees prior to its transition to CMMI in March of 2003. By February of 2006, the organization had tripled in size to 2400 employees. The organization attributes its ability to manage its process culture while accommodating such rapid growth to the additional guidance provided by CMMI best practices.

MIEL develops and maintains telecom software for Motorola cell phone products, wireless networks, broad band cable modems, and automotive and home solutions. Motorola Global Software Group's work is represented and organized by several business-centric divisions. The Embedded Products and Systems Division (EPSD) is the largest division in GSG India. It provides innovative and rapid software solutions for Motorola's consumer products. The MIEL Infrastructure Solutions Division (ISD) provides customer software, software products,

and systems solutions to the Motorola Networks telecommunications business and its customers worldwide.

MIEL provides services from requirements to field test and shipment of the products to the market. The products continue to grow in size and increasingly require additional innovative and difficult features. Since 2002, typical product size has grown from 130 KLOC to 2218 KLOC, mostly in C and C++ code.

Process Improvement History

Prior to embarking on its move to CMMI, MIEL had been appraised at SW-CMM maturity level 5. The organization made the decision to upgrade to CMMI in March of 2003. Other than mapping and indexing its process assets to the new model, MIEL had relatively little to accomplish to meet the criteria for appraisal at CMMI maturity level 5 in May of 2003. In addition to its prior experience with the SW-CMM, MIEL is compliant with ISO 9000 and TL9000; the latter of which is specific to telecom standards [QuEST 06]. Like all Motorola GSG Centers, MIEL also has a prior and continuing improvement history based on Digital Six Sigma methods, applied in particular to telecom call performance.

CMMI-Based Process Improvement

Several new and changed processes were implemented as part of the transition to CMMI at Motorola India Electronics Ltd. While many maturity level 4 and 5 processes had been initiated during the SW-CMM period, substantial changes in MIEL processes were deployed throughout the organization due to continuing improvements based on CMMI. The changes from which the performance results presented here originated took place from 2003 through 2005.

Modeling and simulation methods based on the Motorola Digital Six Sigma effort were used to predict tangible performance improvements in cost of quality and poor quality. These were followed by piloting, prior to full deployment, using standard processes that had been initiated during the SW-CMM period. MIEL used the continuous representation of CMMI to guide their improvement efforts. All of the following changes to MIEL processes were based explicitly on guidance that was not present in the SW-CMM. Moreover, the increased formal discipline of many of these new processes facilitated MIEL's integration with automated tool support and related process technologies.

- An enhanced inspection process was introduced and institutionalized using causal analysis and resolution procedures to improve the previous inspection process. Self reviews now are conducted prior to formal inspections. Inspection moderators, who are subject matter experts, prescreen the self inspection results before calling the formal inspection meetings. The moderators now can send the self inspections back for rework, saving a great deal of staff time and effort that otherwise would be spent on preparation and conduct of the formal reviews.

- Inspection guidelines are modified as necessary to keep preparation rates and inspection time within baseline limits. Additional root cause analysis is done regularly to investigate classes of errors found later in the product life cycle after the formal inspections. Causes of injection for such defects that are not found until later have been identified, and rules have been established to capture them earlier. As a result of following CMMI, MIEL also now inspects all design documents, planning documents, and other major work products in addition to 100 percent of its code.
- Automation of control chart applications used on inspection data has improved the effectiveness of both design and code phase containment. The regular use of a commercial off-the-shelf (COTS) verification product has been institutionalized to reduce code defects creeping into the next phase; Klocwork is a static code analyzer that detects memory leakage, array indices that are out of bounds, and related errors [Klocwork 06].
- Formal Decision Analysis and Resolution (DAR) practices have been instituted in the engineering phases to improve various product quality attributes. In particular, a rigorous DAR process now is followed during the design phase, which rates alternatives with specified criteria.
- Major changes in audit methodology have been instituted for both process and product quality assurance. Different types of audits, both focused and continuous, now use in-house tools that explicitly identify non-conformances in real time with the direct involvement of project managers. All corrective actions are established in real time, and they are monitored and formally tracked to closure. MIEL's audit process previously used checklists that were covered subjectively as time permitted; now, all checkpoint questions are covered regularly.
- A COTS tool for enterprise project management is now being used to improve MIEL scheduling and tracking of process compliance [Primavera 06a].
- Improvements in MIEL validation processes have brought them more business in system integration and testing. The use of test automation tools such as their in-house-developed Simulated Field Environment has helped MIEL reduce the number of defects found in the field. For similar reasons, MIEL uses a COTS product, Smoke Suite, to automatically run test cases. MOTO_OATS, an in-house Web-based tool, is used for analyzing orthogonal pairs of test cases to handle pair-wise combinations of requirements. This has improved the writing of test cases to handle such combinations. As seen in the Performance Results section of this case description, these improvements have resulted in more effective defect capturing during testing and less staff effort devoted to test design and execution.
- The emphasis in CMMI on bi-directional traceability led MIEL to upgrade its requirements management process, supported by tools such as DOORS [Telelogic 06] and the Rational EmbeddedPlus DoorKeeper [IBM 06].

Performance Results

Overall, the implementation of CMMI at Motorola India Electronics Ltd has improved management commitment for continuous, disciplined process improvement. The performance results reported here have contributed to that commitment and to the organization's ability to triple its size in the three years since its movement to CMMI. In particular, management saw additional value in the emphasis in CMMI on continuous capability improvement and organizational level monitoring.

The Measures

MIEL regularly collects and analyzes data for several performance measures. All of the data are collected and managed using Web-based tools that were developed in-house and are well integrated with the organization's standard processes. The following measures that MIEL uses are categorized by their mappings to CMMI process areas.

- **Requirements Management:** Requirements phase containment effectiveness (PCE) and requirements volatility
- **Technical Solution:** Design phase containment effectiveness, code phase containment effectiveness, and defect density
- **Verification:** Review fault density, inspection rate and inspection preparation rate (both counted in lines of code or pages per hour), review cost of quality, and review cost of poor quality
- **Validation:** Test cost of quality, test cost of poor quality, in-process faults (major errors and defects divided by product size), post release defects, and phase screening effectiveness (similar to phase containment effectiveness but applied to test phases)
- **Project Planning and Project Monitoring and Control:** On time delivery, effort, size and schedule estimation accuracies, productivity (lines of code divided by staff days), and earned value analysis

All phase containment effectiveness (PCE) measures are expressed as percentages of defects identified in the phase where they were injected. Defect density, review fault density and test fault density measures are numbers of faults divided by product size. Post-release defects are simple counts. Cost of quality is measured as percentage of staff effort spent on ensuring product quality. Cost of poor quality is measured as percentage of staff effort devoted to rework. In addition, MIEL collects process compliance measures such as number of non-compliances per audit and number of audits per month.

Project-level analyses are performed monthly using these measures. The results of those analyses are used as needed for process improvements and other corrective actions. Organization level quarterly analyses are done to update organizational process enactment and performance baselines.

The following points deserve emphasis in interpreting the results that follow:

- Other things being equal, the baseline year for comparison of the effects due to CMMI-based improvement would be 2002, at which time the organization still was following SW-CMM appraised maturity level 5 processes.
- Comparisons between 2002 and the years that followed are difficult though, since MIEL measurement procedures changed considerably after 2002. Procedures have been instituted to improve measurement validity. Moreover, the defect and related measurement definitions have changed. Prior to 2003 MIEL did not include previously existing defects that were injected prior to the time MIEL took over the work on pre-existing software products. By now, most of those defects have been found, so including the 2002 results in the figures below would understate the improvement in the CMMI period that followed.
- The development efforts undertaken since 2002 remain essentially similar in application domain; however, the degree of difficulty of the work has increased.
- MIEL was appraised at CMMI Maturity level 5 in 2003. Particularly notable additional work using Digital Six Sigma tools and techniques was initiated in concert with CMMI-based improvement during the same year.
- Additional implementation of MIEL processes that map to the Project Planning, Project Monitoring and Control, Verification, and Validation process areas were instituted in 2004 via their enhanced inspection process, EPMS, and Teamplay [Primavera 06b].
- Major audit process improvements took place in 2005.
- The results are based on 40 projects each year.

The Results

Automation of its audit process helped MIEL improve its ability to detect non-compliances in its process and product quality assurance efforts. By 2005, the organization was able to detect 412 non-compliances in 50 audits conducted over a three-month period. Earlier in the same year, it found 109 non-compliances in 82 audits that were conducted in the same time frame. This improvement is largely due to the major changes in audit methodology that MIEL undertook based on guidance from the CMMI Process and Product Quality Assurance process area.

Figure 27 shows that the organization's requirements phase containment effectiveness (PCE) was sustained at 90 percent in spite of the enormous organizational growth and the inclusion of more projects that focused on later stage life-cycle products. Similarly, the design and code PCE improved by 8 percent and 12 percent respectively, even when expressed conservatively as fractions of 100 percent of total phase containment effectiveness.³ In the end, the

³ There is only limited room left for improvement over the 2003 baseline of defects that had previously escaped detection. The same differences would appear greater if they were expressed as percentages of the possible room left for improvement.

organization was able to contain more faults well within its development phases, thereby reducing rework as well as the defects that otherwise may have been delivered to customers. Much of this improvement resulted from process improvements based on the CMMI Verification and Organizational Training process areas.

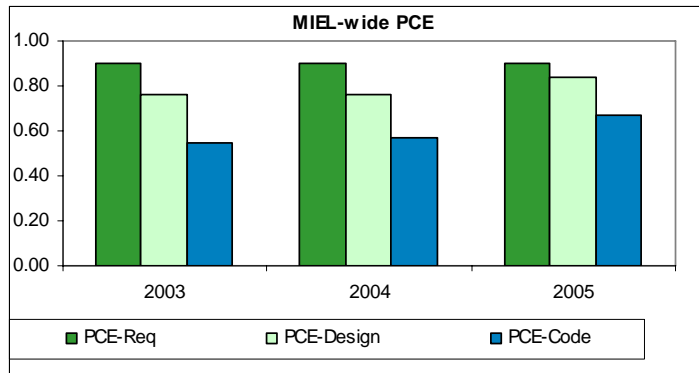


Figure 27: Phase Containment Effectiveness

Major in-process faults⁴ (IPF) also have fallen since 2003, from 5.21 to 3.22 faults per KLOC (Figure 28). Hence, the faults delivered to customers with respect to the product size have been reduced substantially. Much of the decrease took place as a result of the institutionalization of improved processes based on the CMMI Causal Analysis and Resolution, Organizational Innovation and Deployment, Technical Solution, and Decision Analysis and Resolution process areas.

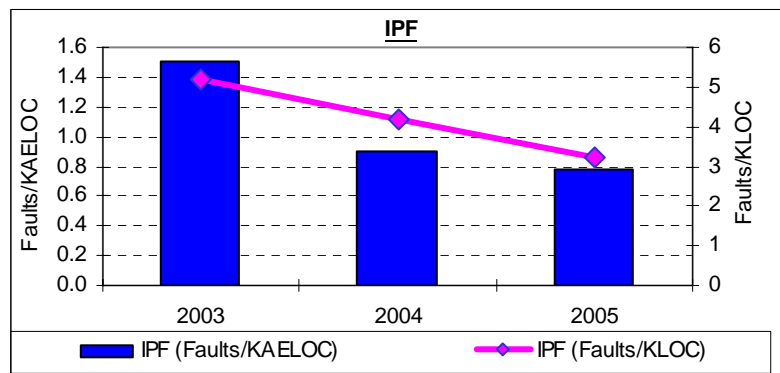


Figure 28: In-Process Faults

⁴ Not all projects at MIEL cover the full scope of the organization's standard software process. For example, code and unit test may be the final phase. Comparable to measures elsewhere of defect density prior to release, in-process faults (IPF) at MIEL include all of the faults identified by the final phase of each project.

The decline in in-process faults also is shown in Figure 28 expressed as faults per thousand assembly-equivalent lines of code (KAELOC), with a drop from 1.5 to 0.8. The count in KAELOC is used to normalize any differences in the development languages used. As seen in the figure, the trends in KLOC and KAELOC are quite similar.

Cost of quality (COQ) at MIEL has declined by 15 percent since 2003 even when expressed as fractions of 100 percent (Figure 29). There was a 30 percent decline in cost of quality when expressed as a decrease from the baseline of 50 percent in 2003 to just under 35 percent in 2005. Much of the decrease is due to automation, which took place as part of the institutionalization of improved processes based on the Verification, Validation, and Organizational Innovation and Deployment process areas. The slight COQ increase in 2005 is due the inclusion of integration and interoperability testing as MIEL took on later stage life-cycle products and services.

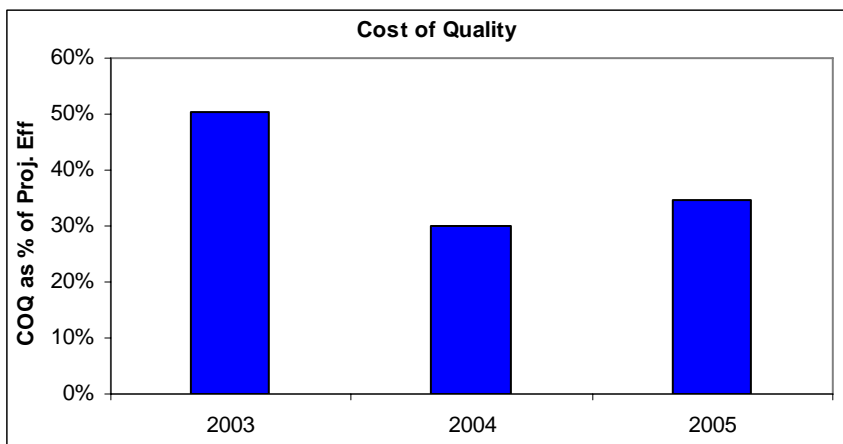


Figure 29: Cost of Quality

Motorola Global Software Group Centers regularly conduct customer satisfaction surveys at project completion for every project the organization undertakes. MIEL ratings have increased from an average of 8 (very good), at the end of the SW-CMM period, to 9 (excellent) out of 10, since its move to CMMI. The survey questions query explicitly about categories such as absence of defects, communication, domain knowledge of engineers, functionality, product quality, usability, and performance. The improvement in customer satisfaction is due particularly to the organization's increased focus on quality and innovation.

4.4.3 Motorola GSG Russia Center

written with Alexander Babkin

Background

The Organization and Its Products

Founded in 1997, Motorola's St. Petersburg-based software development center is part of the Motorola Global Software Group that develops software for Motorola products. The GSG Russia Center is one of the major software development facilities in the Europe, the Middle East, and Africa (EMEA) region, and it serves Motorola customers worldwide. Its four major domain areas include wireless platform solutions, automotive and telematics, cellular networks infrastructure, and access solutions. Currently, the Center has more than 500 employees.

One of the Center's competences is developing software for integrated cellular and trunking network infrastructures. This work includes software for base stations, controllers, latest-generation mobile switches, and other components.

The Access Solutions department specializes in remote access solutions, and it is a leading software, service, and hardware provider for networking, embedded systems, and custom communications applications.

The Center also works on real-time embedded systems. These systems are used to implement operating systems for various applications, optimize algorithms using special functionality of Motorola processors, and analyze real-time system behavior.

An important field for the Center is the development of software for automotive electronics and telematics systems. The Center also develops software functionality for Java-based handsets, including audio and video reception, processing, and transmission.

As seen in Figure 30, almost two thirds of the development work done in 2004 and 2005 by the GSG Russia Center involved prototyping prior to the full implementation of new products and system functionality. Work classified as "prototyping" at GSG Russia also includes new product development once the requirements have been stabilized. Several rounds of prototyping typically are conducted to elicit customer requirements and get early feedback on basic system functionality, after which the projects proceed with further development of the new systems and functionality for the delivered products.

About half of the Center's work is new development (see Figure 31), and almost 40 percent is devoted to maintenance and enhancement of existing software. The "hybrid" category includes concurrent repairs and adding major new functionality to the existing software. "Porting/Localization" efforts involve the migration of existing software to new platforms or user interface languages.

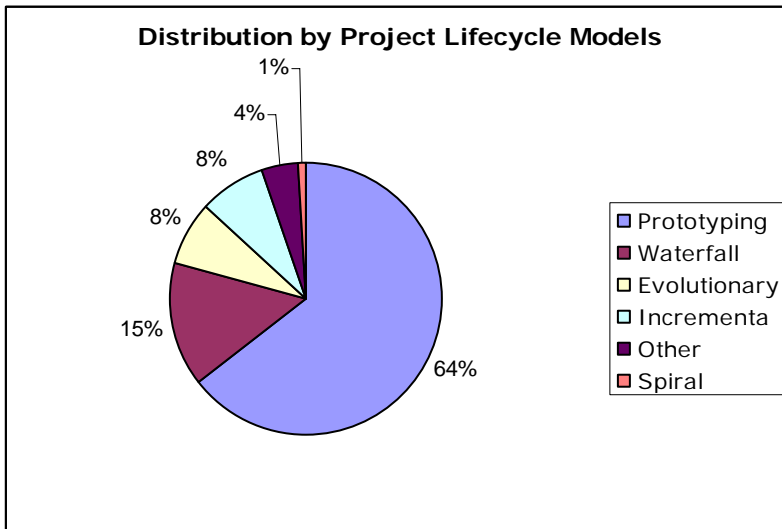


Figure 30: Distribution by Project Lifecycle Models

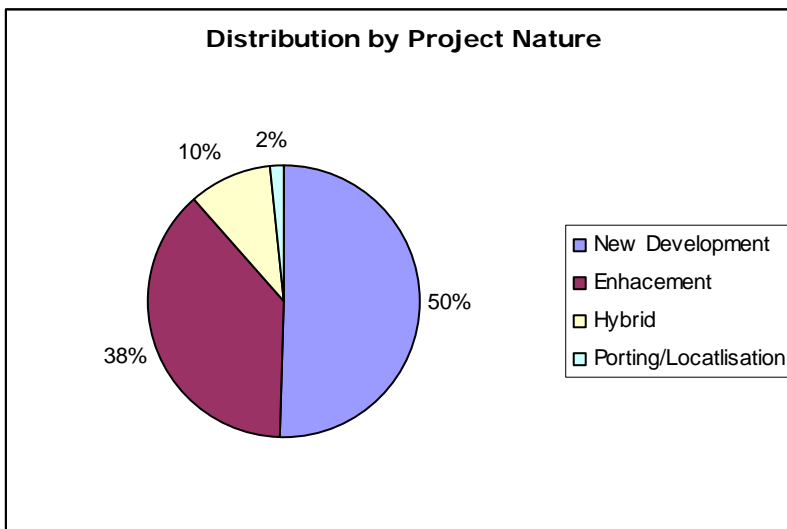


Figure 31: Distribution by Project Nature

Motorola GSG Russia measures project size by the amount of what they call delta code. As seen in Figure 32, the amount of such code that was added, deleted, or modified varied considerably in 2004 and 2005; the projects also differed considerably in terms of the amount of staff time they require (see Figure 33).

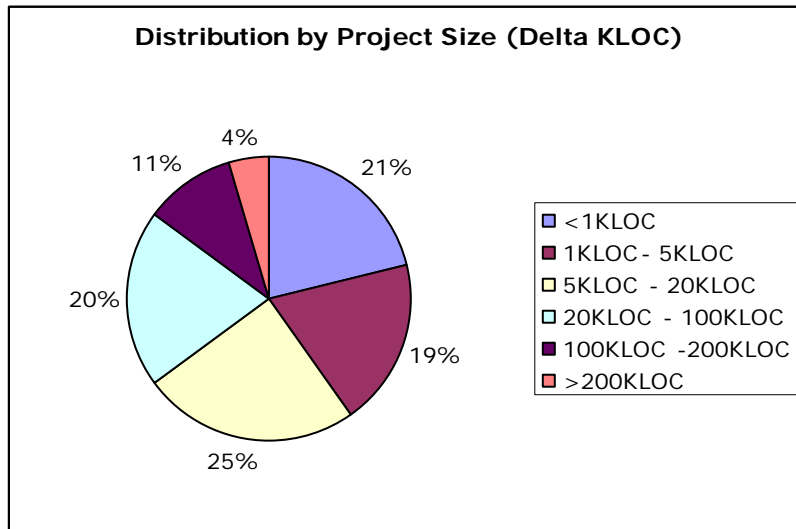


Figure 32: Distribution by Project Size

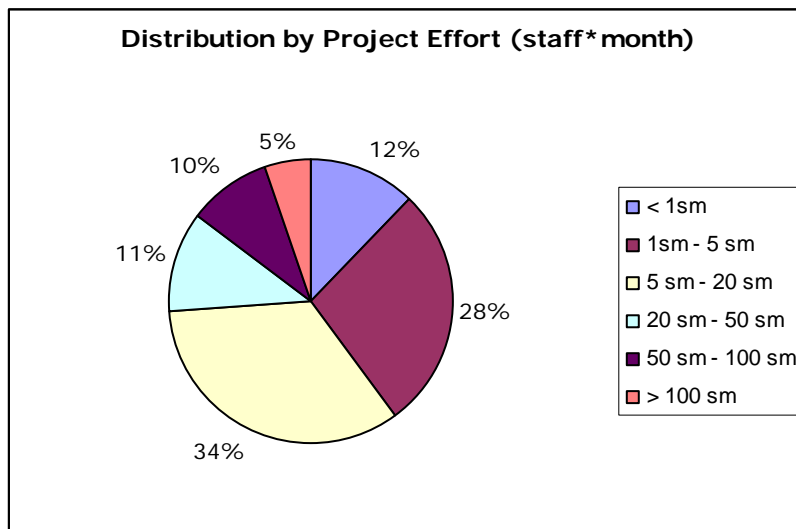


Figure 33: Distribution by Project Effort

The projects can differ in difficulty regardless of product size and effort required. For example, some projects with less than 5KLOC involve simple enhancement of existing functionality; others deal with difficult optimization. The Russia Center uses a series of “integral” characteristics to help project managers tailor their processes as appropriate. The characteristics are obtained after weighting the projects against parameters such as size, novelty of technologies, complexity of interaction within a team, and intended use of the application. Similar procedures are used for calculation of cycle time reduction metrics.

Process Improvement History

Process improvement at the GSG Russia Center has been guided largely by Capability Maturity Models, initially the SW-CMM and then CMMI. Major events in the Center's history include the following.

- June 1997 – start of deployment of software production processes
- July 1999 – assessed at SW-CMM maturity level 3 using the CMM Appraisal Framework (CAF) compliant Motorola Software Assessment method and by doing so, became the first company in Russia with an appraised CMM maturity level
- September 2001 – assessed at SW-CMM maturity level 5 using the CAF-compliant Motorola Software Assessment method and by doing so, became the first company in Russia assessed at the highest maturity level
- November 2002 – start of CMMI Transition project
- October 2003-April 2004 – participation in piloting of SCAMPI Class C and B Appraisal Methods
- November, 2004 – appraised at CMMI maturity level 5 using the SCAMPI Class A method and by doing so became the first center of Motorola world-wide that went through a full succession of SCAMPI Class C, B and A appraisals
- 2005-2006 – beginning CMMI V1.2 piloting

Like other Motorola GSG Centers, the GSG Russia Center also has used Digital Six Sigma. Beginning in 2003, the organization used aspects of that methodology to implement processes based on the CMMI Organizational Innovation and Deployment process area. GSG Russia also had a long history using Goal-Question-Metric (GQM) methods to guide its measurement efforts. With those exceptions, GSG Russia has implemented no other major improvement initiatives.

CMMI-Based Process Improvement

The Motorola GSG Russia Center already had a well-defined and proven software production process, having been appraised at maturity level 5 under the SW-CMM for over a year prior to initiating its transition to CMMI. The following points were critical in GSG Russia's choice to upgrade its organizational processes.

- increased emphasis in CMMI on organization-level business goals
- incorporation of additional industry best practices in the Project Management process areas
- integration of additional engineering discipline addressing both system and software production processes
- flexibility to focus on selected process capability profiles using the CMMI continuous representation

- increased clarity provided by more detailed descriptions and guidelines than were found in the CMMI source models
- increased consistency since many model practices were significantly reworked to remove duplications, ambiguities, and cyclic references
- upcoming sunseting of the SW-CMM

GSG Russia introduced several major changes to its software production process during its transition from the SW-CMM to CMMI. GSG Russia redefined all of the practices described below based on the additional explicit guidance it found in CMMI.

- The focus on business objectives in CMMI led GSG Russia to change its practices for selecting subprocesses for quantitative and statistical control. Moreover, the emphasis in the Measurement and Analysis process area on aligning measurement objectives and activities with business information needs and objectives helped GSG Russia redevelop its approach to managing quantitatively based on its business priorities.
- GSG Russia has developed and deployed process performance models to forecast and control cost of quality (COQ) and cost of poor quality (COPQ) indicators. It started development on more formal models due to its reading of CMMI, particularly the Organizational Process Performance (OPP) process area. This Center now leverages the use of historical database and process performance baselines to predict anticipated values of COQ and COPQ based on classifications by type and complexity of projects.
- The unification in CMMI of technology and process change management approaches to identify, evaluate, select, and deploy significant innovations was very helpful for the GSG Russia Center. The Center found it valuable to realign what previously were two separate GSG Russia processes into a single more focused one because processes and technologies typically are implemented together in a unified manner.
- GSG Russia shifted its focus on causal analysis processes from the relatively narrow defect prevention perspective in the SW-CMM to the broader problem prevention focus in CMMI, and now addresses issues related to process performance, customer satisfaction, and process compliance. GSG Russia continues its proactive focus on causal analysis for prevention as well as resolution of existing problems, which it attributes to a “high maturity” risk management perspective in its reading of the SW-CMM.
- Based on the Decision Analysis and Resolution process area (DAR), the Russia Center has implemented formal decision making techniques. Alternatives for selecting architectures are limited for its products that are embedded into larger systems; however, the Center has used DAR techniques to evaluate alternative technical solutions. In addition, this Center uses life-cycle modeling to update organizational processes to accommodate advanced technologies that provide alternative solutions that otherwise would be difficult to apply to certain categories of projects. Using outside suppliers is new to GSG Russia, so it also formally evaluates alternatives for supplier selection. Other applications of DAR include decisions about alternative process and technology choices (e.g., scenarios for introducing new metrics into projects).

- GSG Russia has developed more advanced product integration procedures as a result of its interpretation of CMMI. In particular, the Center has redesigned its tailorable process integration sequences, and alternative sequences, to get projects thinking about product integration procedures from the very beginning so that elaborations later are more manageable.
- This Center also has extended its use of operational scenarios to include requirements development and validation. This work was suggested by the initial CMMI gap analysis. Previously, operational scenarios were not formalized, and they were considered separately from requirements. Integrating the two has been especially helpful for products that are parts of larger systems.
- Finally, the GSG Russia Center has revised its supplier management processes to accommodate CMMI practices related to the selection of suppliers, COTS and in-house vendor reviews, supplier product acceptance, and adoption.

The Motorola GSG Russia Center conducted its transition to CMMI like any other project in Organizational Innovation and Deployment (OID) fashion. All in all, more than 30 percent of the organization's process assets were revised during the transition project, and more than another 10 percent of the organization's process assets were newly created based on CMMI. Approximately 20 staff months were devoted to the initial gap analysis, process changes, and process training. It took 14 additional staff months for organizing and conducting subsequent SCAMPI Class C, Class B, and Class A appraisals. It took nine months to progress from the initial gap analysis to the start of the first pilots of the new processes. The overall duration of transition project, from the initial gap analysis through the SCAMPI Class A appraisal, was two years.

Performance Results

At the time of this writing, Motorola GSG Russia Center has been working in accordance with revised processes based on CMMI for well over one year. During that time, it has run a series of improvement projects in accordance with the OID process area. The projects addressed the following aspects of the software production process:

- Automation of the previously existing peer review process, using a tool for planning, capturing, and reporting review results: The tool works remotely with a focus on identifying high priority items for corrective action.
- Automation of a stakeholder commitment process, which facilitates getting explicit signoffs, resource allocations, and related assurances of involvement
- Optimization of project documentation and work product flow, with the following revised procedures and related process assets to reduce redundancies:
 - Collaborative procedures for identifying which assets (critical, optional, or informative) must be shown to customers, management, product teams, or other relevant stakeholders to ensure that the right documents go to the right people

- A series of project templates (e.g., for testing, design, and project planning) with a focus on priorities where templates are most necessary
- Redeveloped audit processes to catch non-compliances as early as possible, and, thereby, reducing the total number of audits and checks without compromising quality

The Russia Center has significantly improved its business value in many ways based on its application of CMMI. Key performance indicators demonstrate that the Center has both sustained and improved the performance gains it made based on the SW-CMM. The Center has significantly reduced its cost of quality and markedly shortened its product cycle time while maintaining compliance with the organization’s Six Sigma-based product quality criteria. The following results were obtained from more than 30 projects.

The effort counted as cost of quality by GSG Russia includes verification activities, and particularly peer review and testing; cost of quality also includes quality auditing and problem prevention. Costs of poor quality include rework throughout the life cycle. Both cost of quality and cost of poor quality are expressed as percentages of overall effort spent for software product development. As seen in Figure 34, cost of quality is approximately half of what it was at the beginning of the series during the SW-CMM period. It has dropped another third from its value when the Center began its transition to CMMI. Peer review effort alone is half what it was at the transition. Cost of poor quality remained under 5 percent throughout the entire period.

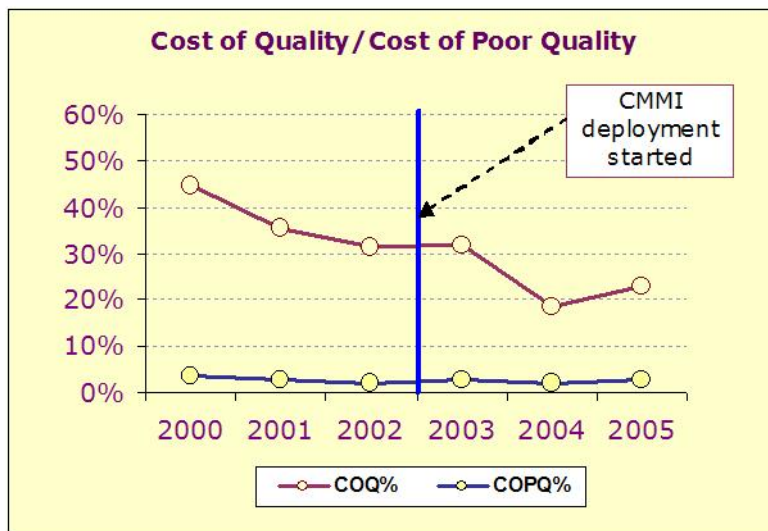


Figure 34: Cost of Quality and Cost of Poor Quality

By the end of 2005, product cycle time had been reduced by almost 40 percent from its baseline during the Center’s use of the SW-CMM. Well over half of that improvement took place after the implementation based on CMMI (see Figure 35). Cycle time for obtaining sign-off commitments was cut by more than half since 2002.

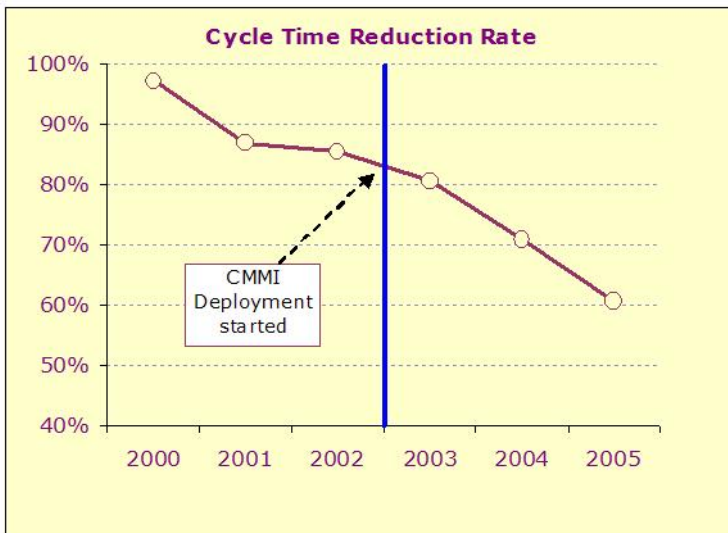


Figure 35: Product Cycle Time Reduction Rate

The post-release defect rate reported by GSG Russia customers was notably low from the beginning of the Center’s adoption of the SW-CMM, and it was even lower by the time it moved to CMMI. Since the upgrade to CMMI, this defect rate has dropped by another 15 percent from the 2002 baseline. As already noted, the Center has sustained this low post-release defect rate while significantly improving cost of quality and decreasing cycle time.

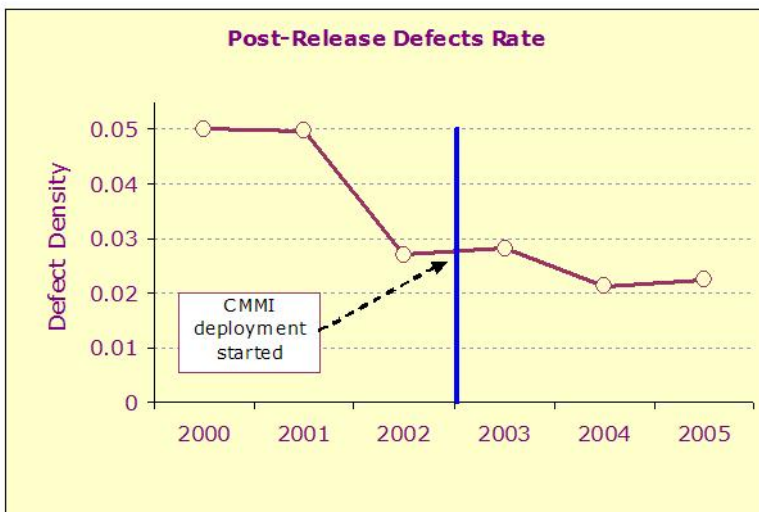


Figure 36: Post-Release Defect Rate (per KLOC)

The return on investment (ROI) from GSG Russia’s optimization of documentation flow was 1.7:1 within the first quarter after deployment. Less labor effort was spent on projects that produce more in less time. Investments counted in the calculation included all effort spent on developing and deploying the improvements, which included new training. Measures of return included reductions in cost of quality and cycle time based on labor effort only. All

comparisons were normalized using baseline parameters for the type of product produced. This conservative estimate of ROI does not account for additional business value made possible by the Center's improved efficiency. For example, reductions in cost of poor quality (COPQ) were not counted in the ROI calculations because COPQ is well under control in this organization.

The Russia Center also conducts regular surveys of its process practitioners' satisfaction. The results improved significantly after deploying the revised CMMI-based processes (from 8.8 to 9.2 out of a possible 10 points).

4.5 Raytheon Network Centric Systems, North Texas

written with Jill Brooks

Background

The Organization and Its Products

Raytheon is an industry leader in defense and government electronics, space, information technology, technical services, and business aviation and special mission aircraft. This case description focuses on one of the organizations that form a part of the larger Raytheon Company.

Raytheon Network Centric Systems (NCS), which is headquartered in McKinney, Texas, develops and produces mission solutions for networking and command and control. The organization's programs include civilian applications, command and control systems, battle space awareness, integrated communications and air traffic management systems and netted sensor systems. NCS serves all branches of the U.S. military, the National Guard, the Department of Homeland Security, the Federal Aviation Administration, other U.S. national security agencies, and international customers. There are five major sites and numerous smaller satellites which make up Raytheon Network Centric Systems. These sites have a total of 11,500 employees and contributed to Raytheon's \$21.9 billion in sales in 2005. NCS work breaks down into four major areas: hardware engineering accounts for 39 percent of the work done, systems engineering accounts for 27 percent, 24 percent is allocated to software engineering, and 10 percent to management and support.

Process Improvement History

Raytheon's NCS North Texas Software Engineering organization began its process improvement journey in 1989, when it was part of Texas Instruments. In the 12 years between 1989 and 2001, the organization worked on developing, deploying, and improving the software development processes. In 1992 as part of Texas Instruments, the organization was presented with the Malcolm Baldrige award and achieved SW-CMM maturity level 2.

In 1994, the organization, which was still a part of Texas Instruments, achieved SW-CMM maturity level 3. Beginning in 1997, Raytheon merged with portions of Texas Instruments, Hughes Electronics, and E-Systems. At this time, the new organization took on the task of bringing together processes and practices from the three separate companies, workforces, and cultures. To help the organization meet this challenge, Raytheon began the adoption and development of Raytheon Six Sigma™. In June 2001, Raytheon applied its Six Sigma practices to the adoption of SW-CMM and achieved maturity level 4.

CMMI-Based Process Improvement

Raytheon NCS North Texas, in conjunction with Raytheon SAS (Space and Airborne Systems) North Texas, was the first Raytheon organization and the 5th company in the world to achieve CMMI maturity level 5. In September 2003, it achieved CMMI maturity level 5 in its software organization and maturity level 3 in its systems organization. Raytheon NCS attributes a large part of its continued success to the application of its Six Sigma program to CMMI implementation. Another important success factor at NCS relates to its focus on change management. After the identification of a performance gap, a cross-functional, multi-site team develops a “behavior management package” that includes process documentation that is deployed to all engineering personnel. Multiple techniques are used to facilitate the desired behaviors which are followed up with management and independent reviews.

Raytheon NCS introduced a number of new practices as it moved from the SW-CMM to CMMI maturity level 5 in the software organization:

- The organization instituted practices based on the Requirements Development process area, made modifications to practices based on the Requirements Management process area, and began to use these practices to balance requirements on different projects. The enhanced requirements practices are used to assure that everyone has a shared understanding of what is the most important work, to identify what can drop off, if necessary. These priorities are also coordinated with customer priorities and constraints.
- As part of quantitative project management, Raytheon increased its use of statistical process control (SPC) techniques to manage its peer review processes. Tooling was developed to facilitate near real-time analysis by peer review participants. Corrective actions were undertaken in instances where defects were above or below established control limits.
- NCS applied Causal Analysis and Resolution practices at the organizational level to resolve issues and contribute to the Organizational Innovation and Deployment process.
- NCS practices based on the CMMI Decision Analysis and Resolution process area were applied to help the projects in the organization choose among alternative process and technical solutions. The use of a tool called Expert Choice [Expert Choice 06], which allows users to identify and weight criteria and assess various proposed solutions against

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these criteria, facilitated the implementation of DAR. The combination of this tool with the Decision Analysis and Resolution process area was cited as a strength in the NCS CMMI appraisal.

- The processes employed for cost estimation, verification, and testing were refined.
- During this time frame, NCS performed many Six Sigma projects for elements of behavior associated with most of the organization's process development.

Combining CMMI and Raytheon Six Sigma, NCS uses the following steps to apply CMMI maturity level 4 and 5 process areas in the software part of the organization:

- a process capability baseline (Organizational Process Performance) is established
- goals related to performance excellence are established and regularly monitored for the programs
- measurement is used to stabilize processes
- if this baseline does not satisfy the goals, the root causes (Causal Analysis and Resolution) are determined
- opportunities for improvement are then identified, selected, prioritized and piloted (Organizational Innovation and Deployment)
- if these changes generate improvements, the new process is measured, the goals are adjusted, and a new capability baseline is established

Following these successes, NCS faced another tough cultural and organizational issue. Historically, the organization had treated its systems engineering group and its software group as different organizational entities. Software engineering tends toward more traditional development, while systems engineering focuses more on creating early prototypes and on early development work. The fact that these two organizations had been managed separately, had their own management sponsorship and had developed their own set of processes was the reason for the separate appraisals.

At present, these groups, including hardware, are being treated as one organization with a common process architecture. The change toward integration facilitates the shift of work packages around the five NCS sites, which is another important goal. The creation of common definitions of performance measures across disciplines has been a major challenge. In addition to refining and extending the original measures, NCS has also developed a tool to help gather and manage the data collected according to the new definitions.

As soon as NCS has completed this effort, it intends to have a joint appraisal to evaluate the entire organization (systems, software and hardware) against all five levels of the CMMI.

Performance Results

Raytheon NCS uses its measurement results to characterize performance in terms of organizational goals and to identify opportunities for improvement. The organization is focused on the following four requirements:

- meeting budget and schedule commitments
- providing quality products that satisfy the customer
- ensuring that its pricing remains competitive
- providing a capable, stable, and diverse workforce

The organization's Cost Performance Index (CPI) and Schedule Performance Index (SPI) address its business objectives of meeting budget and schedule commitments. These measures are equally applicable to software, systems, and hardware engineering.

The organization addresses its goal of delivering quality by measuring defect density. As a part of the effort to develop and use appropriate defect measures for different disciplines, NCS divided the development effort, in general, and the stages identified for peer reviews, in particular, into 14 stages. Previously, all five sites used different phase definitions of varying granularity. Figure 37 shows the names of the 14 stages and the measures used in eight different areas. Only two of the measures listed below the areas are identical.

Peer Review Stage	Hardware Eng							
	Program Eng	Systems Eng	Software Eng	Analog /RF Electronics	Digital Modules	FPGA	Mech Eng	Test Eng
Plans & Processes	Pages	Pages	Pages	Pages	Pages	Pages	Pages	Pages
System Requm Definition		Requm						
System Design & Architecture		Requm						
Product Requm Definition		Requm	Requm					
Product Design & Architecture		Requm						
Component Requm Definition				Requm	Requm	Requm	Requm	Requm
Preliminary Design = 40 % Of combined design phase			LOC	Terms	Terms	LOC	Sq Ft of Drawings	Test Requm
Detailed Design = 60% of combined design phase			LOC	Terms	Terms	LOC	Sq Ft of Drawings	Test Requm
Implementation			LOC	Terms	Terms	LOC	Sq Ft of Drawings	Test Requm
Integration			LOC	Terms	Terms	LOC	Sq Ft of Drawings	Test Requm
Product Verification & Validation			Requm	Requm	Requm	Requm	Requm	Requm
System Integration		Requm						
System Acceptance Test		Requm						
System Field Test		Requm						

Requm = Requirements

Terms = Terminations

Figure 37: Defect Stages, Categories, and Measures

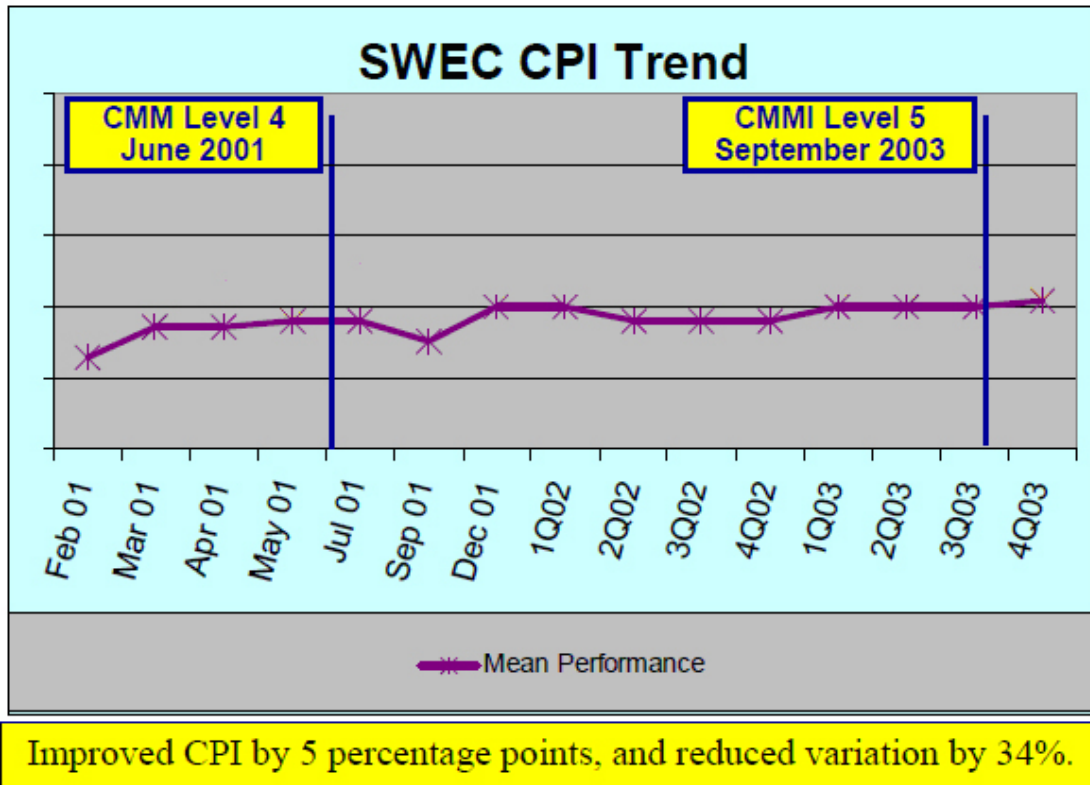
Raytheon NCS also measures the frequency of change requests (open versus closed) and requirements volatility. The latter is important because volatility can lead to higher costs than planned and to related risks to cost and schedule.

Measurement results that are shared in this report date back to the 2003 CMMI maturity level 5 appraisal. Due to the organizational changes since that time, NCS has updated its measurements so that they are consistent across the organization and applicable to all of its disciplines. Performance results based on the new measures are not yet available and analyses based on the older data have not been updated.

Cost and Schedule Performance Indices (CPI and SPI)

The Cost Performance Index answers the question, “How much work has been completed by this point in time compared to what we have actually spent to reach this point?” Schedule Performance answers the question, “How much work has been completed by this point in time compared to what was scheduled or planned to be completed?”

A major contributor to improvements and predictability in cost and schedule performance is the extent to which projects follow standard processes. CPI and SPI are shown using very similar charts. As seen in Figure 38, NCS was able to improve CPI by 5 percent between the SW-CMM maturity level 4 appraisal in June 2001 and the CMMI maturity level 5 appraisal in 2003.



SWEC = Software Engineering Center

Figure 38: Cost Performance Index

Over the same period of time, variation in CPI was reduced by 34 percent, and variation on the low end was virtually eliminated (Figure 39).

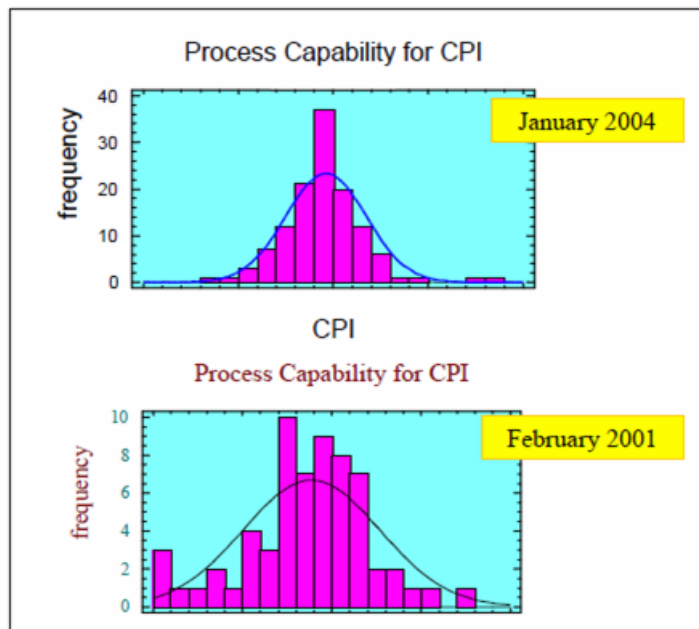


Figure 39: Cost Variation

Improvements in schedule lead to an 8 percent improvement in the organization's schedule performance index and a 50 percent reduction in variation between June 2001, when the last SW-CMM appraisal was conducted and September 2003, when the organization was awarded CMMI maturity level 5.

Defect Density and Defect Containment

Defect density is used in conjunction with other measures to monitor a program's progress toward continuous improvement at Raytheon NCS. In 2003 and before, defect containment was primarily calculated post release. The quality of a product was evaluated by the number of defects per delivered unit from the customer's point of view. Defect density, compared to a desired level and defect containment, evaluated by the stage of injection and stage of detection, are now both measured using the newly defined project phases. Raytheon NCS also continues to measure defect variation between programs and total defect density and defect containment numbers in qualification testing when the customer is present.

It is more difficult to attain consistency in measures of defects across disciplines. The organization is working on definitions of unit measures to employ in different disciplines and contexts. NCS continues to use source lines of code (SLOC) as the primary unit for software defects. The organization found it necessary to define different defect measures for software, systems and hardware, which include the following:

- number of interfaces for architecture and systems integration
- numbers of specific types of requirements for systems
- number of terminations on boards for hardware

- lines of code for FPGA (field programmable gate arrays)
- number of test requirements for test engineering

Figure 37 shows all of the measures used for software, systems and hardware.

NCS has employed Statistical Process Control as a method of measuring time spent on peer reviews. A defect density measure is captured and used to determine if the organization needs to conduct additional peer reviews. The cost of fixing each defect is not used for this purpose because NCS prefers to focus its attention on correction and prevention rather than on expenditures. As seen in Figure 37, NCS's defect density in software was reduced by 44 percentage points, and the variation was reduced by 31 percent.

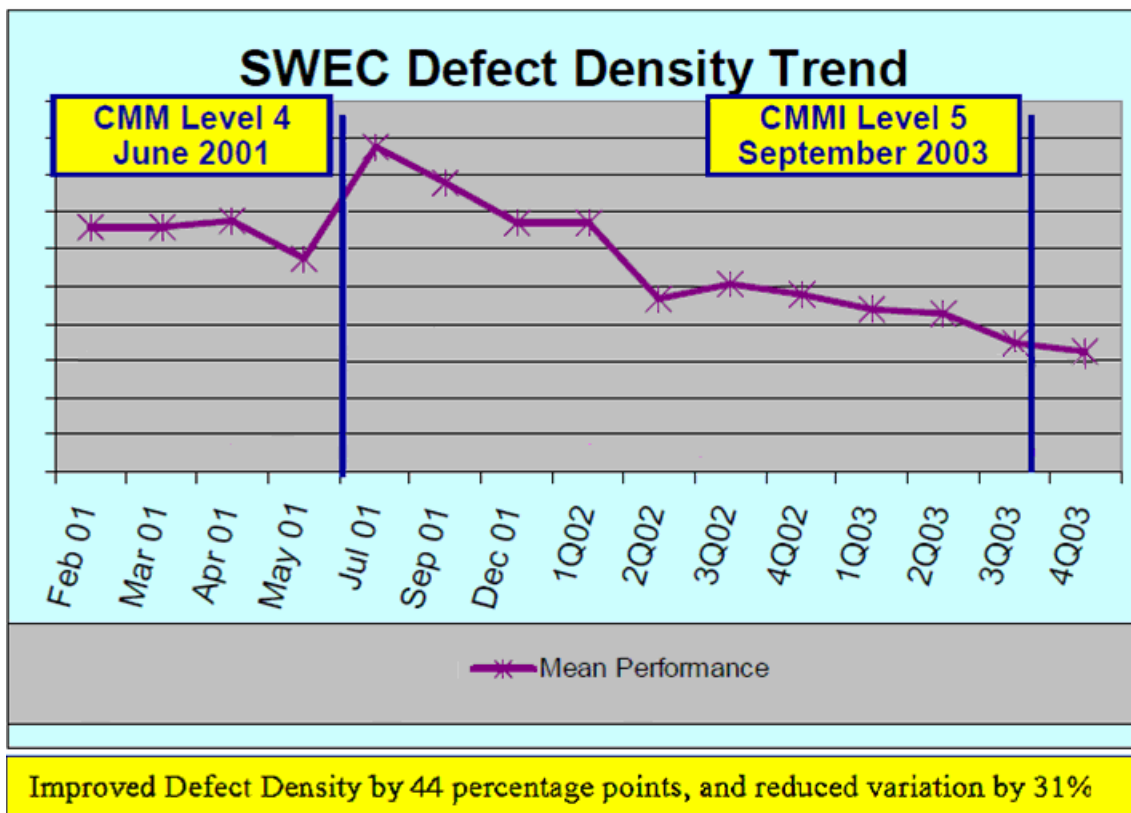


Figure 40: Defect Density

Raytheon NCS achieved an overall ROI of 3:1 through significant cost avoidance which resulted from its organizational improvements. The organization's overall quality program and its improvements in business performance were recognized as organizational strengths in its CMMI maturity level 5 appraisal.

4.6 TrialStat Corporation⁵

written with Khaled El Emam

Background

The Organization and Its Products

TrialStat Corporation is a small software company in Canada that develops software for use in the clinical trials phase of the drug development process. Its customers are the pharmaceutical industry and contract research organizations that run clinical trials for them. Its products are also used in observational studies such as patient registries, cohort studies, and disease surveillance. The company was founded at the end of 2001. It currently has over 30 employees.

TrialStat's main product is called ClinicalAnalytics (CA) [TrialStat 06]. It is released iteratively with additional functionality added for various customers. The software runs on multiple platforms, including various mobile devices, and operates in connected mode (in a Web browser) and disconnected mode when there is no Internet connectivity. The development team consists of nine developers, one requirements analyst, and five quality assurance staff. The remainder of the company consists of the data center operations team, sales, marketing, professional services, support, documentation, and executive management.

The company operates in a regulated environment. The most relevant FDA regulations are documented in the Code of Federal Regulations (21 CFR Part 11) and the various guidelines related to that published by the FDA and the pharmaceutical industry. These regulations apply to the software product itself and to the processes used to develop and maintain that software. In addition, because the software application is used to collect and store sensitive personal health information on thousands of individuals from around the world, practices to ensure the security of the application are critical and are usually included in the scope of a regulatory audit.

Process Improvement History

TrialStat has been involved in a software process improvement effort since 2002. The effort began soon after startup and was guided initially by the CMM for Software and then by CMMI. A formal CMMI-based appraisal has not been performed, but the CMM models have been used as the basis for a continuous internal process improvement effort.

Because of competitive pressures, the release cycle for the CA application had to be short. Therefore, a decision was made early to adopt an agile methodology that promised rapid releases. Proponents of agile methods recommend a three-week (or shorter) release cycle and

⁵ This section is an abridgement and extension of work that will appear in the forthcoming book titled *CMMI: Guidelines for Process Integration and Product Improvement, Second edition* by Mary Beth Chrissis, Mike Konrad, and Sandy Shrum.

suggest that this is doable in practice. At the outset, a three-week release cycle was attempted; however, this created many problems.

A three-week release cycle resulted in rapid burnout of the development team as the pace became increasingly exhausting. The company was at risk of losing key developers, who were unwilling to put in the overtime and weekends to maintain the three-week release cycle. It was also evident that the only way to have such short iterations was to curtail most requirements analysis activities and to have absolutely minimal quality assurance on the product, both of which were unacceptable.

The development team then experimented with increasing the release interval. After a number of attempts it was decided that a three-month interval was sufficient. This was short enough to address the rapidly changing business needs, but long enough not to exhaust the development team. It allowed enough time for sufficient requirements analysis work up front and for effective quality assurance.

All process improvements were (and still are) implemented within this three-month iterative framework as described in the next section. One important advantage is the provision of rapid feedback, making it possible to pilot new practices and tools and evaluate their value quickly.

CMMI-Based Process Improvement

CMMI-based practices were introduced iteratively at TrialStat in conjunction with the releases of the ClinicalAnalytics products. The most important process areas for TrialStat were Organizational Process Focus, Organizational Process Definition, Process and Product Quality Assurance, Organizational Training, and Measurement and Analysis. The initial order of implementation focused mostly on maturity level 2 practices to meet the new company's recognition of the importance of good project management. At the same time, because of the regulated nature of the company's business, some of the process-oriented practices in maturity level 3 were also important from the beginning.

Resources were dedicated to defining and improving processes early on in the company's history. For an engineering team of this size, a part-time allocation of a senior engineer plus as-needed administrative support was sufficient to make considerable progress.

A strong focus on process definition was necessary from the start. Standard operating procedures documenting all of the engineering and business processes had to be developed at the same time as the project management practices were being implemented. The process definition strategy involved experimenting with new processes until they were working. Each process then was standardized and documented in a standard operating procedure. The small organizational size meant that there was no difference between organizational and project procedures; they were all the same.

Process documentation proved helpful for this small organization, making it easier to integrate new staff and ensure that the staff contributed sooner. Without that documentation, corporate growth would have been more painful. The people typically attracted to a small organization are not necessarily process oriented. Process documentation contributed to establishing clear ground rules for new staff and enforcing a process-oriented corporate culture.

Regular internal audits ensure process compliance. Audits are performed by third parties. While the audits are against the FDA regulations, on the process side there is considerable overlap with CMMI model practices. Training capabilities were not developed in-house, but were all outsourced. However, training plans and records have to be maintained for all staff as part of the company's regulatory requirements.

The iterative development process allowed for the continuous introduction of new project level practices based on the project management, engineering, and support process areas. It also enabled rapid feedback on the effectiveness of these practices. Each of the iterations represented an opportunity to introduce new processes, a new technology, or expertise in the form of an individual with specialized skills. After three months it was possible to determine whether the intervention succeeded or had the desired impact. If it did, then it was kept for subsequent iterations. Those that cause problems were either adjusted, taking into account what was learned, or eliminated in subsequent releases.

This mode of introducing changes does impose some constraints. The interventions cannot be large because the development team has to be able to learn them, master them, and apply them well enough in the iteration to provide feedback to management at the end of the iteration. Therefore new practices had to be introduced gradually. For example, when peer reviews were introduced, they focused only on the requirements. Then code peer reviews were first done only on the database operations that were likely to have significant performance impacts on system. Then they were extended to include error handling code as the iterative cycle continued.

Performance Results

The Measures

The collection and use of measurement for decision making started from the very beginning of the project and was subsequently expanded in a series of iterations. First, data on post-release defects were collected. These data were necessary to manage and prioritize defect correction activities and resources. Once that system was in place, measures related to the ability to meet schedule targets were collected.

Scope management was the next issue. Because the delivery date for each of the iterations was fixed, flexibility was necessary to control the scope of work that could be completed within that time period. Features scheduled for the iteration were sized for a three-month cycle. In some cases, features were split and implemented over multiple releases. The

challenge was coming up with an appropriate approach to measuring the size of the requirements early. Currently, using the number of use cases to measure the size of requirements has worked well in the TrialStat environment.

The measurement of size and complexity became the subsequent focus of measurement. As the system grew, it became critical to manage its size and complexity. One approach used was to re-factor specific parts of the system to reduce complexity.

The resources available for each release were fixed. The same number of people was available each time, and each release cycle had a fixed duration. Therefore, the estimation challenge was to define a scope that was small enough to be completed within the available fixed resources and time. The following were the primary determinants of whether the scope was manageable:

- The size of the features that were being planned for a release.
- The complexity of the features that were being implemented for a release. This was determined subjectively by the number of new screens, the number of new database tables, and the coupling between each new feature and existing features.
- The newness of the technology that was being used. New technology may mean, for example, a new third party component or external library, a new data exchange standard, or sub-discipline such as genetics that needs to be supported by the ClinicalAnalytics product.
- The availability of developers who are most suitable for a feature. For example, if a key database developer was going to take vacation during a release then that was going to have an influence on the scope that is scheduled for that release.

The Results

Because of the continuous process improvement throughout most of the history of the company, TrialStat's goal was to achieve stable or incrementally improving performance results over time. The size and complexity of the ClinicalAnalytics product has increased with each of its iterations, so improvements in both process and product are needed just to maintain current performance status. The differences in size and complexity over time also make it impossible to directly compare the performance results before and after each process intervention; however, the performance results can be compared to norms and benchmarks to interpret the relative value added by the CMMI-based process improvements.

The ability to meet schedule commitments is crucial in TrialStat's business. Figure 41 shows the company's ability to meet the deadlines for five recent major releases of the CA software product. The y-axis shows the delay in delivering each release in days. Three of the five were delivered on time. The longest delay was one week in release 6, which represents an approximately 8 percent deviation from plan. The other was three days late.

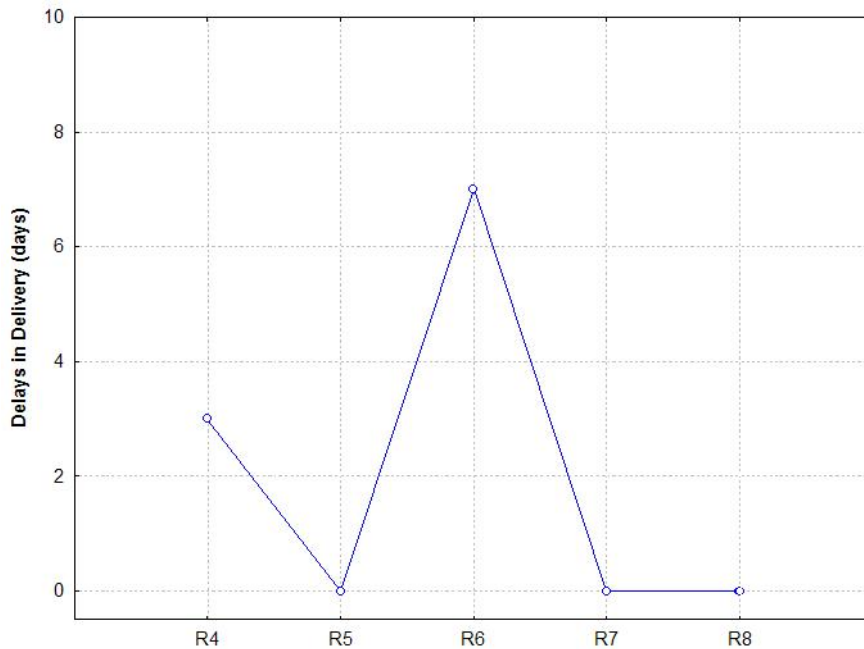


Figure 41: Ability to Meet Schedule Targets

The results in Figure 42 show the post-release defect density for a series of recent major and minor releases of CA product distributed across the x-axis. Defects are expressed per function point on the y-axis. These defects are known to have existed in the product post-release, and were discovered through customer usage or internal testing after the product was deployed. Size was converted to function points using Jones' backfiring table [Jones 00].

The line at the top of the graph is a benchmark for projects in the manufacturing domain. From the most recently published data set of the International Software Benchmarking Standards Group⁶ (ISBSG), manufacturing had the highest median quality benchmark across all of the domains reported in *The ROI from Software Quality* [El Emam 05]. As can be seen in Figure 42, while there is variation in quality across the releases, the defect density per release tends to be considerably lower than the benchmark. The peaks in the graph coincide with the largest releases, and the troughs with the smallest releases.

Organizations that contribute data to the ISBSG benchmarks tend to submit results from their better projects, so this benchmark overstates average performance. It also understates the difference with the TrialStat defect density results.

⁶ ICBSG is an international organization based in Australia that collects data from software projects around the world and produces various software project benchmarks on an ongoing basis (<http://www.isbsg.org/>).

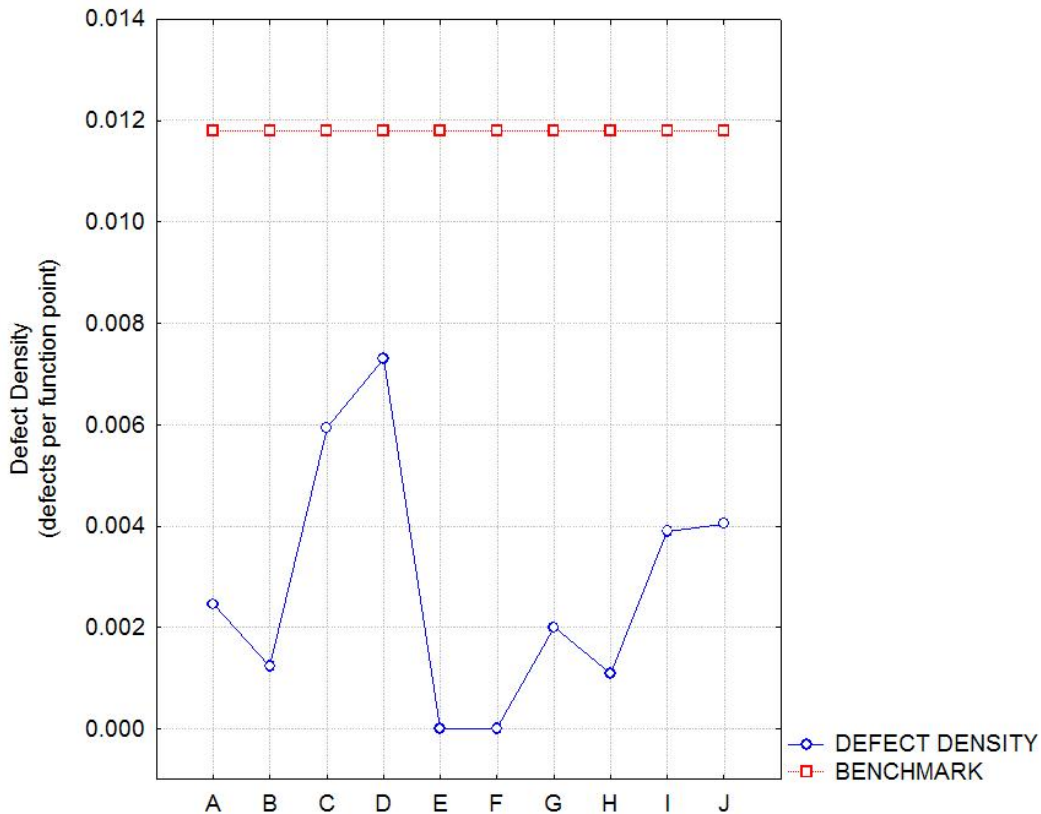


Figure 42: Post-Release Defect Density

The results in Figure 43 translate the quality advantage compared to the benchmark into dollar figures for end users of the CA software. The estimated cost savings shown in the figure accrue due to a lower incidence of production and shipment delays, less system down time, increased customer confidence, customer satisfaction with respect to timing, and fewer lost clients by using a higher quality product; the results assume a 100-person company at an average cost due to product defects of \$1,466 per employee when using benchmark quality products other than ClinicalAnalytics [Tassey 03]. A simple model to estimate these savings is presented in more detail in *The ROI from Software Quality* [El Emam 05].

The figure shows the estimated cost savings of each using each of the ten ClinicalAnalytics releases compared to using another product that had the same quality level as the ISBSG benchmark. For example, a 100-employee contract research organization that uses release E likely would experience a saving of more than \$100,000. Such dollar savings provide a compelling reason for TrialStat’s customers to continue using the company’s software.

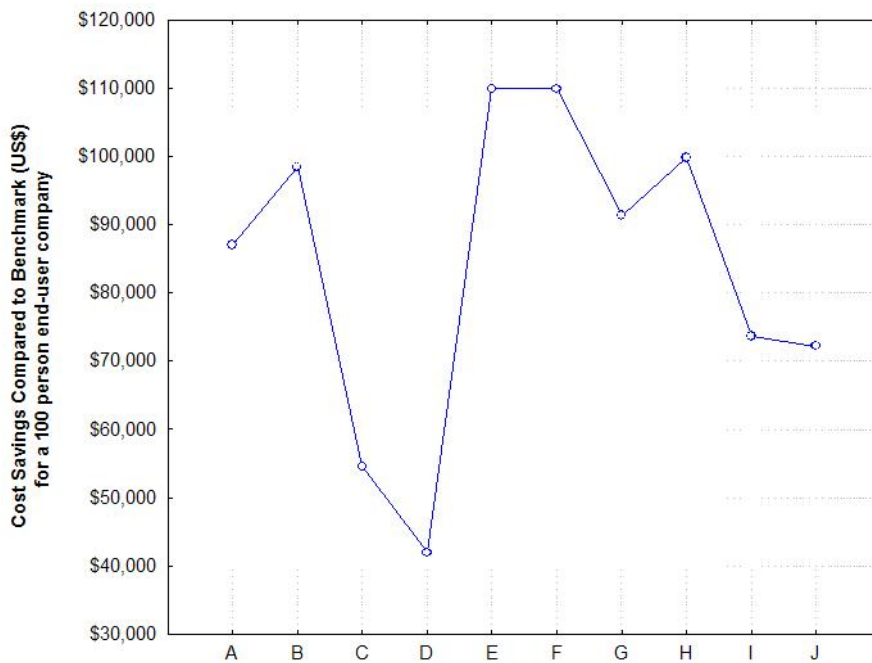


Figure 43: Cost Savings to the End User

4.7 Tufts Health Plan

written with Alan Bruno and Rob Houle

Background

The Organization

The Tufts Health Plan was founded in 1979 as a not-for-profit health maintenance organization (HMO). It has since expanded to a solution-based health plan that offers a variety of health care coverage options, including a Preferred Provider Organization (PPO), Point of Service (POS), Exclusive provider plan (EPO), five consumer-driven health plans and Medicare Advantage plans. There are 1800 employees in the health plan, excluding doctors and allied health professionals who provide care, and the provider network serves about 620,000 members. In a national ranking of more than 500 health plans, Tufts Health Plan was named third in the nation for both HMO and POS products and second in New England for clinical performance and member satisfaction. They are among 10 percent of all health plans which have earned the Excellent accreditation status from the National Committee for Quality Assurance (NCQA) NCQA is a nationally recognized, independent, not-for-profit organization dedicated to improving the quality of health care. Tufts Health Plan Medicare Preferred, a Medicare Advantage program for Medicare beneficiaries, was ranked as one of the highest rated health plans in the nation. Tufts Health Plan is also the first health plan in Boston to earn a J.D. Power and Associates award for outstanding member satisfaction or service excellence for 10 consecutive years.

There are 300 full time equivalent employees and contractors in the Information Technology (IT) department. These include personnel in development, operations, help desk, telecom, support and business process re-engineering. This department supports the multitude of business functions required to manage the delivery of health care to the organization's members (e.g., claims processing, referrals, information access, medical care management, plan benefits inquiries, and transaction processing).

Process Improvement History

In addition to many quality achievements in its primary health related services, Tufts Health Plan IT already had a considerable quality management framework in place before it embarked on SW-CMM and CMMI. Its Systems Engineering Process Architecture (SEPA) was established in 2000 to develop and integrate a variety of systems into the technology infrastructure. This process architecture covers all phases of system development and is organized around well-defined project delivery life cycles including waterfall and rapid development. The term system explicitly includes considerations of infrastructure and hardware. Systems are either fully developed in-house or in partnership with subcontractors. They include Tufts Health Plan proprietary software development, the integration of commercial-off-the-shelf (COTS) components, and hybrids of the two.

Several other models and frameworks were employed in developing the SEPA. The management of the operational infrastructure has been based on the standards of the Information Technology Infrastructure Library (ITIL). Business needs assessments, project planning, and project management practices are well defined within the organization following the Program Management Book of Knowledge (PMBOK) methodology.

Having accomplished many fundamental improvements already, the adoption of the SW-CMM was an evolutionary step. Tufts Health Plan had in place quality programs designed to maintain the stability of its processes, infrastructure, and operations. The organization had mature quality processes in the areas of configuration management, project management, software quality assurance, and change management. Tufts Health Plan had employed Architecture Review Teams and Change Control Boards for oversight of system changes for several years prior to the exploration of SW-CMM. IT at Tufts Health Plan already understood the benefits of process management, measurement and analysis, and a greater integration between the development project and support project teams, particularly during the initiation and planning phases of the life cycles.

It was not until they completed a formal process needs assessment, however, that the process team came to see how much their improvement needs coincided with the content of the SW-CMM. The SW-CMM effort began in 2001 when the IT organization formalized its process management area and reviewed the results of a needs assessment to quantify the lessons learned from its most recent development projects, and to examine root cause data from its formal configuration management and project management groups. The output was a "punch list" of areas needing improvement, prioritized by the number of occurrences and by their

criticality to the development process. The requirements of the Organizational Process Definition and Organizational Process Focus key process areas brought more structure to the maturing Process Management Team (PMT). The SW-CMM offered solid guidance on the characteristics of mature, stable processes and assisted in defining goals and objectives for the processes that the organization was trying to improve.

Tufts Health Plan adopted the SW-CMM in three years while still running day-to-day IT operations. The formal SW-CMM assessment took place in December 2004 and Tufts Health Plan achieved a maturity level 3 rating.

CMMI-Based Process Improvement

Although Tufts Health Plan IT was aware of the CMMI before 2004, it decided to fulfill the requirements of a SW-CMM assessment before initiating work on CMMI. Tufts Health Plan IT began work on the CMMI in January 2005. Their decision to move to CMMI was motivated by two business reasons: 1. the organization could no longer be appraised against SW-CMM since the model was sunset by the SEI, and 2. other companies were beginning to ask about CMMI compliance in Requests for Proposals. After all the improvements Tufts Health Plan had undertaken, the organization had to make only a few additions, and minor changes to implement the relevant CMMI-based process improvements.

The organization's primary CMMI focus was on the following process areas:

- **Requirements Development (RD):** Tufts Health Plan already had a fairly complete requirements development process. To enhance it, the people in the process group added sign-offs by developers, testers, and others who might be involved in peer reviews and with customers. This added surety about agreement on the part of all parties before proceeding into development. It also resulted in fewer requests for enhancements, which was one of the goals by which the organization was measuring itself.
- **Decision Analysis and Resolution (DAR):** Tufts Health Plan developed DAR guidelines and applied these wherever it used DAR. In particular, DAR was applied to the risk management and the software selection processes. The organization had a detailed software selection process, which began with receiving RFPs from vendors and proceeded through evaluation and selection of a system. DAR is used for the more difficult tool or software selections.
- **Organizational Process Focus (OPF), Organizational Process Definition (OPD) and Organizational Innovation and Deployment (OID):** Tufts Health Plan IT first implemented its Process Management Team (PMT) as it began to implement SW-CMM. The PMT has improved so much since that time, the appraisers said it looked like a maturity level 5 process. The Process Management Team (PMT), which consists of representatives from all IT departments, meets on a regular basis and reviews IT policies and procedures. The team performs impact analyses before approving any changes and communicates all approved changes via e-mail bulletins.

- Risk Management (RSKM): Tufts Health Plan IT made adjustments to its metrics plans and standard templates in order to include risk management; RSKM metrics are now collected and analyzed regularly.

Tufts Health Plan IT achieved maturity level 3 of CMMI SE/SW 1.1 at the end of February 2006. Its strengths included the following:

- Metrics reports that provide management with a clear picture
- Tools, especially its document management system and their PAL
- Organizational Process Focus and Organizational Process Definition (PMT)

Performance Results

Tufts Health Plan's IT organization established a metrics management system structured for three primary focus areas: IT value, business support, and IT operations. The organization has focused its effort on improving two specific categories within the IT Operations measurements area: project performance and process performance. Analyses center around tracking historical trends and comparing actual performance against estimates. They have further focused considerable attention on quality issues.

Project performance measures were developed by deriving measurement goals from the stated strategic goal of improving the performance of system development projects. The aim was to provide the project manager with timely information about the schedule, cost, and quality status of the product under development. Cost measurements include the costs for actual-to-planned labor as well as software, hardware, and other expenditures. The scheduling category includes comparisons of actual-to-planned work completed, and actual-to-planned effort expended. These measurements are calculated for both the given reporting period and the cumulative project timeline, and they must be generated with sufficient frequency to allow the project manager to take corrective action.

Process performance is measured at the organization level using the cumulative results of individual project metrics. Measurements about the organization's commitment to managing and improving processes are added. Specific measurements include process improvement volume, actual-to-planned effort expended, and actual-to-planned team activities completed.

The quality category includes measurements which provide broader insight into the operation of key processes. These are chosen because their execution directly influences the quality of the product under development. Measurements in this category focus on requirements, testing, peer reviews and quality reviews, and production issues.

Each project captures a minimum standard set of metrics which can then be rolled up to a higher level. Project schedules are tracked using dashboards that are reviewed by the Corporate Project Management Office. They use Service Level Agreements to measure and track customer satisfaction. Tufts Health Plan is in the process of developing a method for calculating their return on investment (ROI). It already tracks costs of fixes after test and next

steps are to calculate the baseline figures of costs to fix defects found, and to calculate ROI in dollars.

At Tufts Health Plan IT, most work is developed for internal customers, and that means that the most important measurements relate to deploying products into production. Testing is one place where pre-production defects are identified. Defects are identified during unit, functional, systems, and acceptance test cycles which are run in the test processing environment. As shown below, -total defects -dropped by 16 percent -between the last year when the organization’s processes were based on the SW-CMM and the implementation of CMMI processes (2004-2005). Over the 4 years portrayed below, defects dropped by 44 percent.


	2002	2003	2004	2005	 2004-2005
<i>Defects Identified in Testing</i>	2796	2469	1862	1565	-16%

Figure 44: Testing at Tufts Health Plan

Peer reviews comprise another important quality check at Tufts Health Plan. The figures below show that the number of peer reviews increased 68 percent between 2004 and 2005, and the number of issues identified increased 59 percent. These reviews are conducted prior to the moving the software or system into the production environment. Finding issues at this point means that they it costs less to fix problems and the defects are removed before they can be seen by customers.


	2003	2004	2005	 2004-2005
<i>Total Peer Reviews</i>	-	324	545	+68%
<i>Total Issues Found in Peer Reviews</i>	-	763	1211	+59%

Figure 45: Peer Reviews at Tufts Health Plan

Tufts Health Plan IT calculates productivity based on the number of change requests they field each year. When more time is spent on valued added change requests, the organization is more productive. All work comes into the IT department via change requests—from minor corrections to major new systems. Change requests at Tufts Health Plan act like work orders. An example of how a work order generates both small and large changes was a recent work order to change member identification numbers from Social Security numbers to random ID numbers. If something needs to be fixed, enhanced, replaced or built from scratch, it comes into the department through a change request. Corrective change requests identify problems which need to be fixed. The proportion of corrective change requests remained relatively

steady as a percentage of the total work to be done, hovering around 23 percent. There were 15 percent more total change requests between 2004 and 2005.


	2003	2004	2005	 2004-2005
<i>Total Change Requests (All Categories)</i>	1719	1607	1849	+15%
<i>% of Corrective Change Requests</i>	23%	24%	22%	- 2%

Figure 46: Change Requests at Tufts Health Plan

Metrics related to production issues, or the count of total global or systemic problems that occur in the production processing environment, comprise the final quality measure addressed in this report. These are issues that come to light after software or a system has been deployed into production. These issues are taken very seriously. The Production Issue Management Team, a cross functional group, holds daily meetings to review product defects identified from the previous day. In some cases, correcting the problem may be as simple as adding a new field to a checklist. In other cases, the issue is more complicated. In these cases, members of the team conduct a root cause analysis to identify the source and recommend process improvements to ensure elimination of future defects. The good news is that the number of Production Issues has also declined in the last two years.


	2002	2003	2004	2005	 2004-2005
<i>Total Production Issues</i>	1550	1306	1182	1086	- 8%

Figure 47: Production Issues at Tufts Health Plan

Tufts Health Plan achieved better quality products, delivered on time, and within budget, to more customers who were satisfied with the results. In addition, 100 percent of its major projects were completed on time in 2004 and 2005. Perhaps what is most notable is that the early improvement trends continued and accelerated during the deployment of the organization's CMMI-based improvements. The results are summarized below.

- 16 percent decline in defects identified in testing
- 68 percent increase in the number of peer reviews
- 59 percent increase in the total issues found in peer reviews
- 2 percent decrease in corrective change requests
- 15 percent increase in the total number of change requests fielded

- 8 percent decline in production issues (These are global or systemic problems in the production environment.)

4.8 Warner Robins Air Logistics Center

written with Millee Sapp, Robert Stoddard, and Thomas Christian

Background

In October 1997, Warner Robins Air Logistics Center (WR-ALC) at Robins Air Force Base, Georgia, consolidated its four previously separate software organizations into a single division called the Software Engineering Division. The consolidated organizations previously had some experience using the SW-CMM for process improvement, but these activities had been performed separately in each of the original four organizations.

A leadership decision to target a SW-CMM maturity level 3 rating for the new division required enterprise-wide process standardization to ensure a consistent management discipline across all of the organization's business domains. As a result, an initiative was established to consolidate the software processes of the original four organizations into a standard set of processes that the entire organization could use. The initiative defined three major domain processes:

- Test Program Set (TPS) Development
- TPS Maintenance and Modification
- Operational Flight Programs (OFP)

The Software Engineering Division immediately established an integrated Software Engineering Process Group (SEPG) and a Quality Metrics Group (QMG) to begin building upon the previous software process improvement experience and strengths brought together in the consolidation. With the assistance of the Software Engineering Institute (SEI), the SEPG and QMG established a process architecture to adopt the best practices identified in the existing best practices from the four original organizations and map those practices to the SW-CMM. This architecture became the design document for the corporate- and domain-level process documents that all projects in the organization would follow. The Software Engineering Division achieved SW-CMM maturity level 3 in an SEI-led, CMM-Based Appraisal for Internal Process Improvement in April of 2000.

During this same timeframe, WR-ALC became involved in the CMMI project. WR-ALC participated in a CMMI pilot appraisal that brought together projects involved in systems engineering, software engineering, and software acquisition.

In July 2001, the Software Engineering Division decided to transition from the SW-CMM to CMMI. For the next 12 months, the SEPG performed a gap analysis to determine which areas of the organization's process architecture would need to change. The priority was to correct

problems or make enhancements to organizational processes based on the CMMI process areas at maturity levels 2 and 3. The SEPG also began to identify the requirements for achieving maturity levels 4 and 5.

In October 2002, the division became part of the newly established Maintenance Directorate (WR-ALC/MAS) and benefited immensely from the director's strong support for software process improvement. In December 2002, the division rolled out a revised software engineering process to the organization. Implementation plans once again spelled out when projects within the organization would implement these new processes.

From September through December 2003, four Standard CMMI Appraisal Method for Process Improvement (SCAMPI) Class B appraisals were performed to assess the organization's readiness for a SCAMPI Class A appraisal. During the Class B appraisals, team members from WRALC, Ogden ALC, and the SEI reviewed more than 980 artifacts across seven projects and identified areas of risk in how the organization was implementing the practices identified in CMMI. These appraisals led to action plans for addressing the risk areas and verification meetings between each of the projects and the SEPG to determine whether the organization was adequately addressing the findings. An appraisal in October 2004 confirmed that the Software Engineering Division had achieved CMMI maturity level 5.

With the advent of the Air Force Materiel Command restructure, the Software Engineering Division has reorganized into the 402d Software Maintenance Group (402 SMXG). This reorganization consolidated the existing eight branches into five squadrons and one group staff organization. The 402 SMXG organization continues to mature its processes and provide exceptional products and support to its customers.

CMMI-Based Process Improvement

Achieving CMMI maturity level 5 would not have been possible without software processes standardized across the entire 715-person Software Engineering Division. In addition to the large number of software personnel, the division consisted of eight branches that had different focuses. Nearly 500 of the personnel have electronics engineering and computer science degrees. Each of these branches—an artifact of the 1997 consolidation of the software organizations supporting the directorates for avionics, electronic warfare, the F-15, and the Joint Surveillance Target Attack Radar System (JSTARS)—had different customers and its own individual cultures. Furthermore, two branches worked only in the test program set development, maintenance and modification domains, while five other branches worked only in the OFP domain. The eighth branch contained the SEPG, Quality Metrics Group (QMG), and administrative support such as computer network, financial, and personnel specialists.

The keys to standardizing processes across this diverse landscape were centralized direction and decentralized execution. The SEPG and QMG developed the organization's standard

software processes, following a standard format. These documents spelled out in detail a description of each process activity, the reason for it, the entry criteria, its inputs and tasks, the exit criteria, outputs, measures of the activity, and any required tailoring. The division's adamant commitment to excellence resulted in several detailed documents. These standardized documents provided organizational direction and policy; thus, they laid the foundation for the organization's further success.

The execution of division-wide organizational processes was decentralized by having functional experts from each branch document software processes at the domain or branch level. Following the same format—description, reason, entry criteria, inputs, tasks, exit criteria, outputs, measurement, and tailoring—these documents provide the standardization of software activities within a domain regardless of project size, complexity, customer, or priority.

Substantial improvements took place in the organization's practices that were heavily influenced by the Causal Analysis and Resolution (CAR), Organizational Innovation and Deployment (OID), Decision Analysis and Resolution (DAR), and the CMMI engineering process areas. Many newly detailed processes were documented for the division, and various plans, guides, and other process assets were prepared. The following items are among those most pertinent for the performance outcomes presented in this case description:

- documents describing the new software engineering process
- the peer review process
- practices for developing, implementing, and maintaining organizational processes
- the measurement program and the measurement plan.

Both TPS domains tailored their processes from the organizations standard processes. Owing to the unique focus of the branches in the Operational Flight Program domain, each branch prepared its own process guide. For example, in the JSTARS branch, the public-private partnership between the Northrop Grumman Corporation and WR-ALC ensured that processes were standardized so that the software produced at the two different locations (Robins Air Force Base and Melbourne, Florida) could be integrated readily. Elsewhere, the F-15 branch standardized its processes among its three customers—the Israeli Air Force, Royal Saudi Air Force, and U.S. Air Force—to benefit all three. All five OFP branches (avionics/airlift, electronic warfare, F-15, JSTARS, and Special Operations Forces/Combat Search and Rescue) standardized process guides in accordance with the division's organizational documents, which mandated adherence to these processes by all of the OFP branches, regardless of weapon system.

Of course, other important process improvements have taken place since the organization achieved CMMI maturity level 5. Two that are particularly important for the performance results presented in this case description are improvements to the organization's Web-based defect tracking system and its earned value tracking system. The defect tracking system provides support for identifying and tracking defects through corrective action. Its underlying

database provides information for CAR-related activities, which has led to shorter learning and improvement cycles both within and across projects. The basics of earned value tracking were in place earlier; however, the process has matured substantially since the organization reached CMMI maturity level 5. The resultant organizational baselines have been quite valuable for the organization's OPP- and QPM-related activities.

Performance Results

This process standardization effort within the Software Engineering Division eliminated late deliveries of software releases from August 2004 to January 2005. This marked improvement prompted the division to embrace a goal of 100 percent on-time delivery for fiscal year 2005. Similar dramatic results were also achieved in delivered defect reduction after implementing the CMMI maturity level 5 process improvement practices with no defects reported in fielded software during the same six month period.

A recent study confirmed the dramatic improvements in both cost and schedule variances. The study compared two samples of completed projects that included both hardware and software releases. The samples were selected randomly, stratified, and balanced to include similar projects and project managers. The first sample included projects completed prior to the CMMI improvement initiative, and the second sample consisted of projects completed during the past six months when the CMMI processes were institutionalized.

Figure 48 summarizes the differences in cost variance. The y-axis shows the number of projects, while the range of cost variance is shown across the x-axis. As can be seen in the figure, there was substantially more variation among the projects cost performance, and more of the projects came in over budget prior to the organization's move to CMMI maturity level 5. After the Software Engineering Division achieved CMMI maturity level 5, there was much less variation among the projects. There was very little variance between estimated and actual cost, and proportionally, more of the projects were completed under their cost estimates.

Due to the number of extreme values, the median (middle) values of cost variance were used for the statistical comparison. The 95 percent confidence interval of the median cost variance among the projects that were completed prior to the organization's achievement of CMMI maturity level 5 ranged from -6.4 percent to +7.78 percent. The same confidence interval after achievement of maturity level 5 was -1.0 percent to +7.4 percent. Negative cost variances are undesirable when representing cost over-runs. The median cost variance improved from 1.4 percent to 4.4 percent, and negative occurrences were almost completely eliminated. This improvement is significant at the 84 percent confidence level using the Mann-Whitney U test [Sheskin 03].

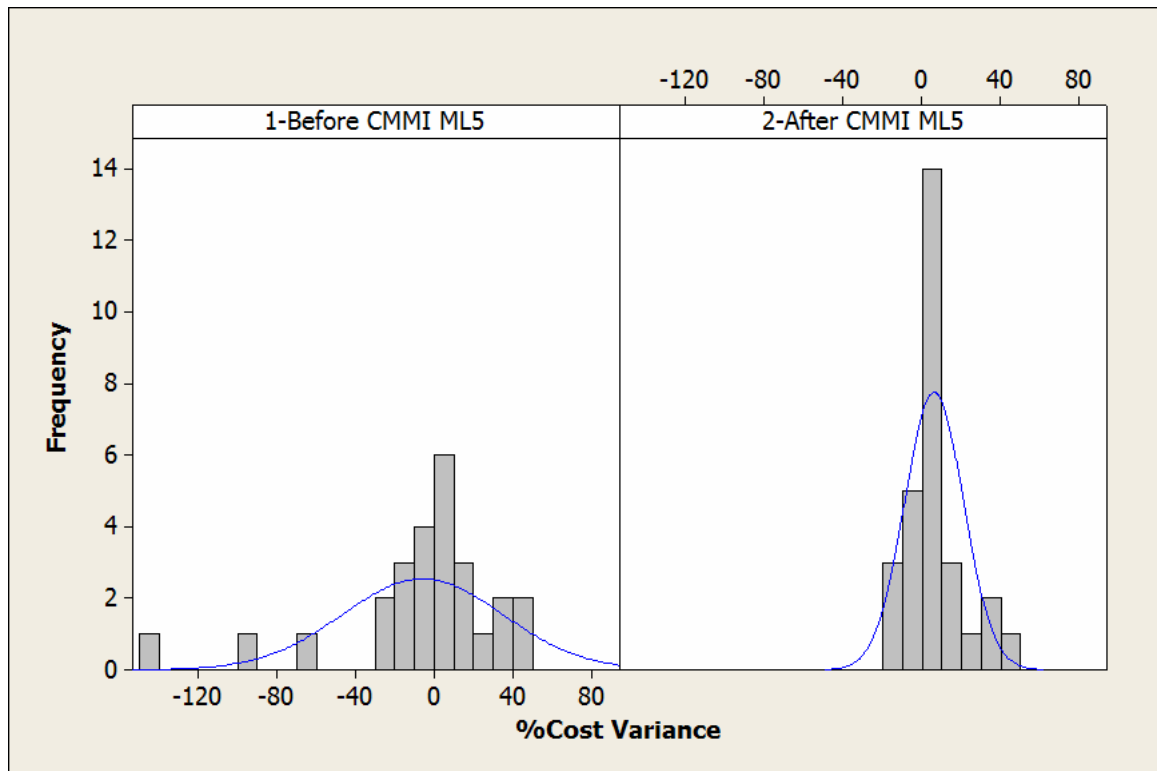


Figure 48: Change in Percent Cost Variance

As seen in Figure 49, the performance effects are even more striking with respect to schedule variance.⁷ Several products were delivered late, with considerable schedule variance, prior to the achievement of CMMI maturity level 5. After achieving maturity level 5, variation in schedule adherence was significantly reduced and negative occurrences were almost completely eliminated.

Again, due to the number of extreme values, the median values of schedule variance were used for comparison. The 95 percent confidence interval of the median schedule variance was -57 percent to +2 percent among the projects that were completed before the organization achieved CMMI maturity level 5. The same confidence interval after level 5 was achieved ranged from -2.5 percent to +0.2 percent. Similar to cost variances, these negative variances are undesirable schedule overruns. The median schedule variance improved from -15.8 percent to almost zero. The confidence level is 91 percent using Mann-Whitney U test criteria.

⁷ In order to keep the x-axes comparable visually, one extreme outlier in the Before CMMI ML5 section has been removed from the graphic; however, all 26 cases are included in the statistical analysis.

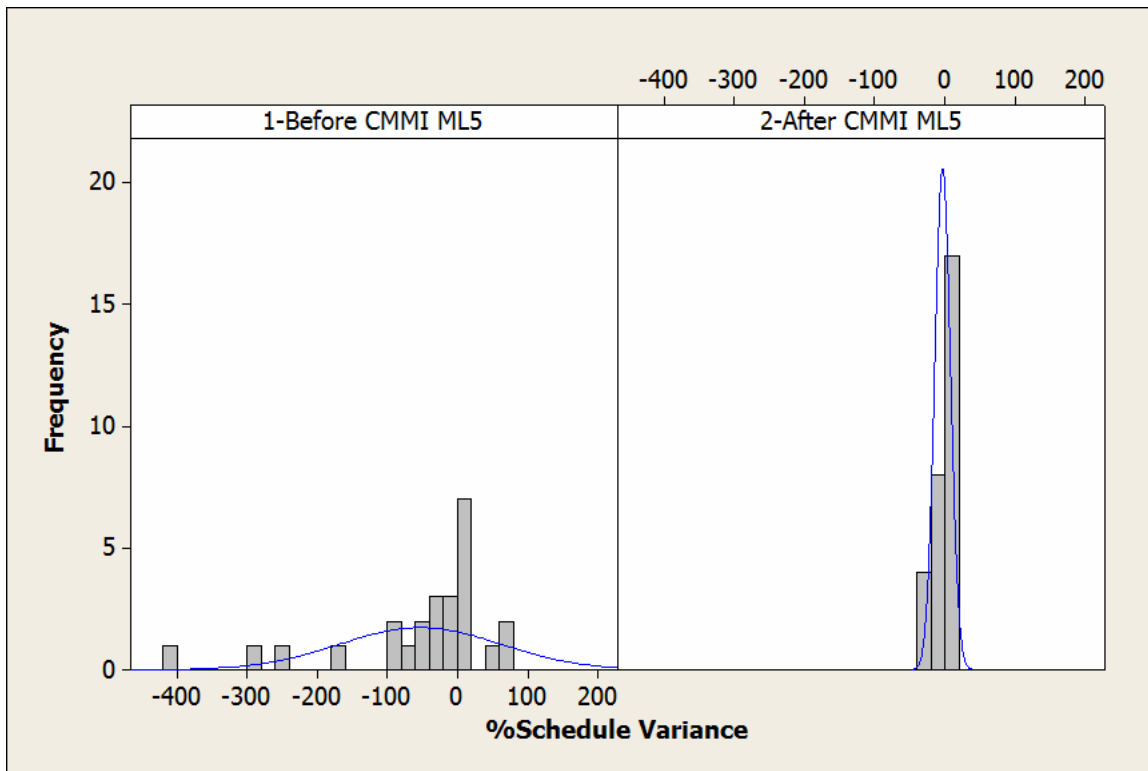


Figure 49: Change in Percent Schedule Variance

Comparable work about defect reduction was ongoing at the time that this SEI technical report was published. Similar results were expected; however, as previously noted, delivered defects already were very rare given the nature of the organization’s life critical products. Current work in the 402d Software Maintenance Group is exploring the performance effects that can be expected from further attention to reducing pre-release defects.

5 Summary and Conclusions

Much has been learned since the SEI report over two years ago on the impact and benefits of CMMI-based process improvement [Goldenson 03]. At that time, numerous studies already described the value of process improvement based on the SW-CMM for the development and maintenance of software and software-intensive systems [Benno 95, Butler 95, Dion 92, Dion 93, Herbsleb 94, Humphrey 91, Lebsanft 96, Lipke 92, McGarry 98, Wohlwend 93]. As seen in this technical report, similar performance results now exist for CMMI-based improvement.

The results are drawn from organizations throughout the world. Their process improvement efforts cover both small and large organizational units, and they do business in a variety of sectors and domains. They apply CMMI model practices to systems engineering and various other engineering disciplines in addition to software. While most of the results come from higher maturity organizations, notable improvement also have been achieved by lower maturity organizations.

Credible quantitative results exist for all six performance categories discussed in the report: cost, schedule, productivity, product quality, customer satisfaction, and return on investment. Moreover, many of the organizations described in this report that have achieved improvements in product quality and customer satisfaction also have achieved higher productivity, cost performance, and schedule performance. Better quality may not always be free, but it can occur with better project performance as a result of disciplined process improvement.

Organizations that base their process improvement activities on CMMI models can and have achieved marked performance improvements, but more remains to be learned. While case studies provide a great deal of valuable detail and context, their results cannot necessarily be generalized elsewhere. A better understanding of the reasons for varying success also is necessary. An equally important task is to obtain more evidence about the statistical relationships between process capability and program performance, along with the organizational and product characteristics that may affect them both.

Several quantitative studies of improvement based on the SW-CMM systematically make comparisons across many projects or organizations [Clark 97, Deephouse 95, El Emam 00, Goldenson 95, Goldenson 99, Harter 00, Herbsleb 97, Jung 03, Krasner 99, Krishnan 99, Lawlis 95]. Those studies find evidence of considerable differences in product quality and efficient delivery that vary predictably with differences in process capability and organizational maturity. Work currently is underway at the SEI and elsewhere to conduct similar studies that focus explicitly on CMMI-based improvement.

Appendix A CMMI Performance Results Sources Listed by Organization

With the exception of the original materials provided for use in this report, this appendix includes the publicly available sources for all of the results that are reported in this document. Other references in the document are listed in the References section.

URLs are valid as of the publication date of this document.

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**IBM Australia
Application
Management
Services**

Nichols, Robyn & Connaughton, Colin. *Software Process Improvement Journey: IBM Australia Application Management Services*. A Report from the Winner of the 2004 Software Process Achievement Award (CMU/SEI-2005-TR-002). Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University, 2005. <http://www.sei.cmu.edu/publications/documents/05.reports/05tr002.html>

JPMorgan

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Corporation**

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Lockheed Martin Integrated Systems—Systems and Software Resource Center	Weszka, Joan. "Transition from SW-CMM to CMMI: The Benefits Continue!" CMMI Technology Conference. Denver, CO, November 17-20, 2003. http://www.sei.cmu.edu/activities/cmmi/results/pdfs/2003-CMMI-014.pdf
Motorola Global Software Group	Henry, Daniel; McCarthy, Larry; & Chitnis, Sanjay. "CMMI Transition at Motorola GSG." CMMI Technology Conference. Denver, CO, November, 2003. http://www.sei.cmu.edu/activities/cmmi/results/pdfs/2003-CMMI-017.pdf
NCR	Scott, Walter. "The Business Benefits of CMMI at NCR Self-Service." ESEPG. London, June 2004. http://www.sei.cmu.edu/activities/cmmi/results/pdfs/04-306c.pdf
Northrop Grumman IT Defense Enterprise Systems	Pflugard, Alan. "Business Value and Customer Benefits Derived from High Maturity." CMMI User Group & Conference. Denver, CO, November 2002. http://www.sei.cmu.edu/activities/cmmi/results/pdfs/2002-CMMI-001.pdf
Northrop Grumman IT, Defense Enterprise Solutions	Hollenbach, Craig. "Quantitatively Measured Process Improvements at Northrop Grumman IT." CMMI User Group & Conference. Denver, CO, November 2003. http://www.sei.cmu.edu/activities/cmmi/results/pdfs/2003-CMMI-018.pdf
Raytheon Corporation	Shelton, Gregory. "CMMI - The Current State." CMMI User Group & Conference. Denver, CO, November 2003. http://www.sei.cmu.edu/activities/cmmi/results/pdfs/2003-CMMI-021.pdf
Raytheon Network Centric Systems	Pelkowski, David & Lanier, Kelly. "A Practical Application of CMMI Level 5 Practices: A Case Study of the Future Scout and Cavalry System (FSCS) Program circa 2001." ASEE Workshop on Software Engineering Process Improvement. February 8, 2003. http://www.sei.cmu.edu/activities/cmmi/results/pdfs/pelkowski-lanier.pdf
Raytheon North Texas	Freed, Donna. "CMMI Level 5: Return on Investment for Raytheon N TX." CMMI Technology Conference. Denver, CO, November 2004. http://www.sei.cmu.edu/activities/cmmi/results/pdfs/2004-CMMI-006.pdf

Reuters

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Software
Engineering**

Petersen, Peter Voldby & Johnson, Kent A. "Using Balanced Scorecard to Help Achieve CMMI Maturity Level 4." European SEPG. London, June 13-16, 2005.
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Services**

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Management**

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http://www.sei.cmu.edu/activities/cmmi/results/pdfs/03_302c.pdf

**The Boeing
Company**

Vu, John. "The Process Improvement Journey of Boeing Information Services, Wichita." Working Draft, February, 2005. Used with permission.
<http://www.sei.cmu.edu/activities/cmmi/results/pdfs/vu2.pdf>

**Tufts Associated
Health Plans**

Hoffman, Thomas. "HMO Tufts Health Plan Revamps IT Processes: Improves Project Delivery, Cuts Software Defects." *Computerworld*. March 28, 2005.
<http://www.sei.cmu.edu/activities/cmmi/results/pdfs/hoffman.pdf>

Appendix B The CMMI Performance Results Web Site

The CMMI Performance Results Web site can be found at <http://www.sei.cmu.edu/cmmi/results.html>. Figure 50 contains a screenshot of the Performance Results main page.

The SEI updates performance results periodically and may be able to use your evidence if you are willing to share it with others publicly or under the promise of non-disclosure. Results from service, acquisition, systems engineering, hardware and software development organizations are welcome.

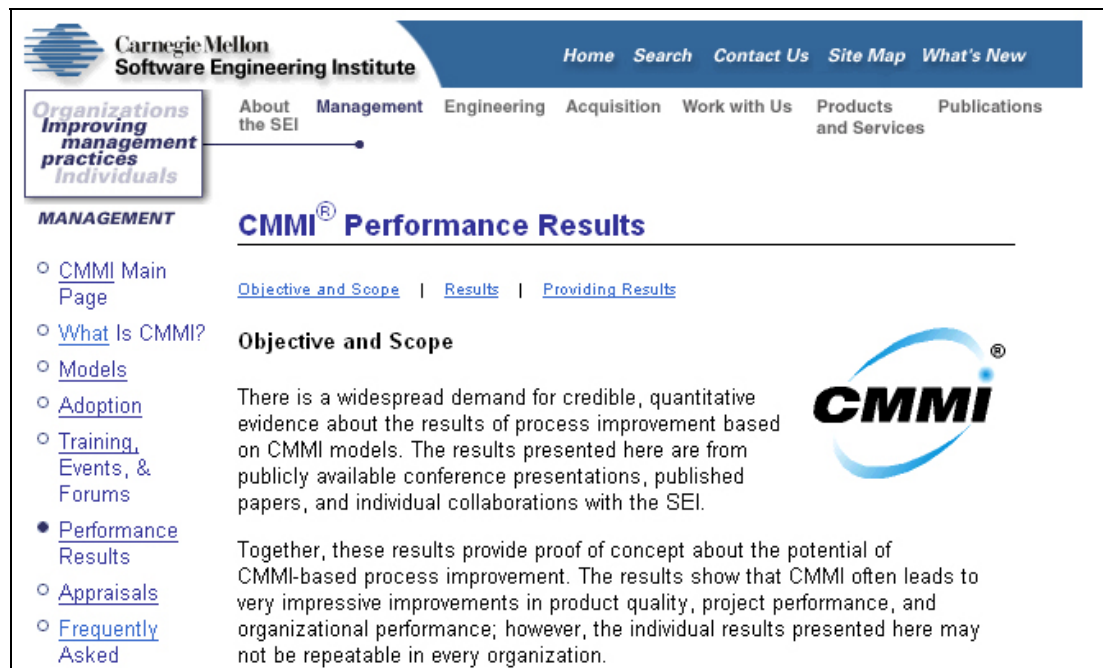


Figure 50: Screenshot of Performance Results Main Page

Brief statements and graphical examples of the results can be displayed by one of the six performance categories described in this report (Figure 51) or by organization (Figure 52). Figure 53 shows a screenshot of the Assertion Statement Detail page, and this page can be seen by clicking View for any of the assertion statements. Full source documents are available for some assertion statements and can be seen by clicking View on the Assertion Statement Detail page.

CMMI[®] Performance Results

View by Performance Category

The performance results examples contain brief assertion statements and their sources and sometimes are accompanied by graphic illustrations. To view the graphic or source for a statement, click the View link.

[Cost](#) | [Schedule](#) | [Productivity](#) | [Quality](#) | [Customer Satisfaction](#) | [Return on Investment](#)

Cost		
	Assertion Statement	Organization
View	20 percent reduction in unit software costs as the organization integrated its engineering processes	Lockheed Martin Management and Data Systems
View	15 percent decrease in defect find and fix costs as the organization integrated its engineering processes	Lockheed Martin Management and Data Systems
View	Reduced cost of poor quality from over 45 percent to under 30 percent over a three year period as the organization moved from SW-CMM maturity level 5 towards CMMI maturity level 5	Siemens Information Systems Ltd.
View	5 percent improvement in cost performance index with a 34 percent decline in variation as the organization improved from SW-CMM maturity level 4 to CMMI maturity level 5	Raytheon North Texas Software Engineering
View	Costs dropped 48 percent from a baseline prior to SW-CMM maturity level 2 as the organization moved toward CMMI maturity level 3	DB Systems GmbH

Figure 51: View by Performance Category

Lockheed Martin Management and Data Systems

The performance results examples contain brief assertion statements and their sources and sometimes are accompanied by graphic illustrations. To view the graphic or source for a statement, click the View link.

[Cost](#) | [Productivity](#) | [Customer Satisfaction](#) |

Cost

Assertion Statement

- [View](#) 20 percent reduction in unit software costs as the organization integrated its engineering processes
- [View](#) 15 percent decrease in defect find and fix costs as the organization integrated its engineering processes
- [View](#) 4.5 percent decline in overhead rate as the organization improved from SW-CMM maturity level 3 to CMMI maturity level 5

[top](#) ▲

Productivity

Assertion Statement

- [View](#) 30 percent increase in software productivity as the organization integrated its engineering processes

[top](#) ▲

Customer Satisfaction

Assertion Statement

- [View](#) Increased award fees by 55 percent compared to an earlier SW-CMM baseline at maturity level 2

[top](#) ▲

Figure 52: View by Organization

CMMI[®] Performance Results

Assertion Statement Detail

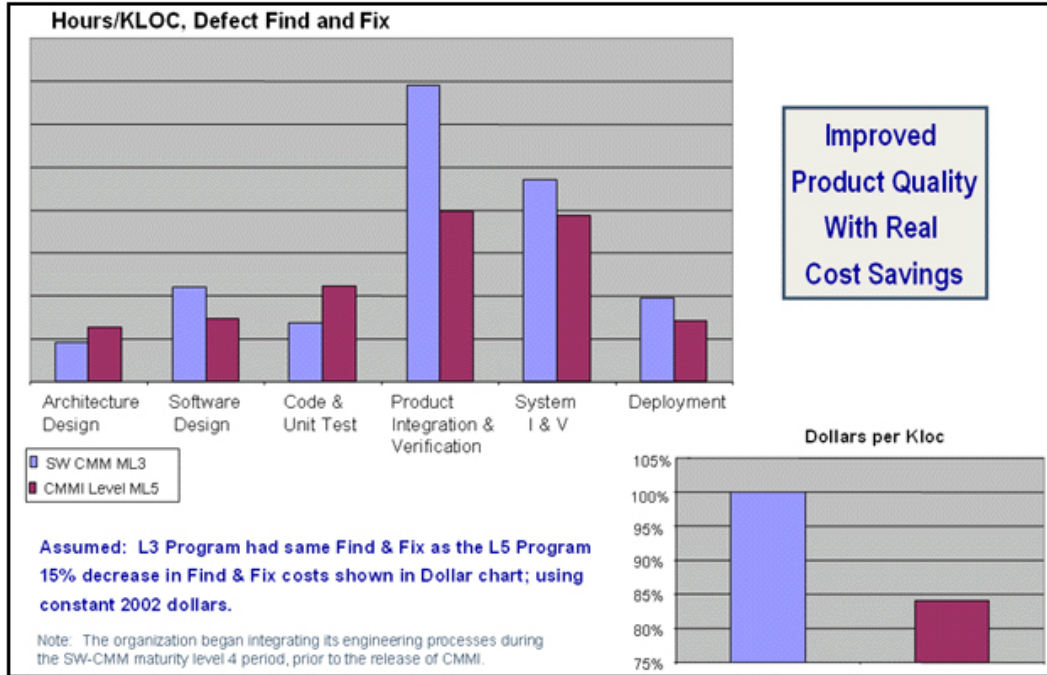
Statement

15 percent decrease in defect find and fix costs as the organization integrated its engineering processes

Organization

Lockheed Martin Management and Data Systems

Graphic



Source



Lockheed Martin Integrated Systems and Solutions. "Key Business Indicator Trends During the Journey from SW-CMM Level 2 to CMMI Level 5 at Lockheed Martin Management & Data Systems." McLoone, Peter. CMMI Technology Conference. Denver, CO, November 2003.

Figure 53: View Detail

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13. ABSTRACT (MAXIMUM 200 WORDS) There is a widespread demand for factual information about the impact and benefits of process improvement based on Capability Maturity Model® Integration (CMMI®) models. Much has been learned since the Software Engineering Institute (SEI) published a special report on this topic over two years ago. There now is evidence that process improvement using the CMMI Product Suite can result in improvements in schedule and cost performance, product quality, return on investment, and other measures of performance outcome. This technical report summarizes much of the publicly available empirical evidence about the performance results that can occur as a consequence of CMMI-based process improvement. In addition, the report contains a series of brief case descriptions that were created with collaboration from representatives from 10 organizations that have achieved notable quantitative performance results through their CMMI-based improvement efforts. The report is meant for members of engineering process groups, middle and first-line management, and other potential process improvement participants who wish to learn more about how CMMI can contribute to measurable improvements. It also may be useful for executives and senior managers who are faced with decisions about the allocation of scarce resources for improvement efforts.				
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