Performance Results from Process Improvement

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It is my pleasure to introduce this issue of the DACS Software Tech News. The articles described in the pages that follow provide compelling empirical evidence of improved project performance and product quality that have resulted from CMMI-based process improvement.

Of course, the results sometimes are normalized to avoid disclosing proprietary or other sensitive information. Yet, the articles all provide details meant to give you, the readers, a good sense of the CMMI-based processes that were followed, and how their measurement results were used to inform management and technical decisions.

The organizations described in this issue's articles vary widely in their size, sectors, product domains and process capabilities. The articles by Pete McLoone and Sharon Rohde; and Millee Sapp, Bob Stoddard and Tom Christian describe high maturity organizations in the defense industry. Commercial organizations are the subject of the articles by David Garmus and Stasia Iwanicki; Angel Liu; and Khaled El Emam. While most of the organizations described here have demonstrated high levels of either process capability or organizational maturity, one of them has not. Several of the organizations do maintenance as well as development work. Two are small organizations, and others do much of their work in small projects.

Most of the articles are quantitative case studies that describe the experiences of individual organizations. Such evidence can be quite useful in a benchmarking sense for other organizations that face similar challenges. They clearly show what can and has happened under the right circumstances; however, they cannot necessarily be applied elsewhere.

More generalizable comparative analyses of the circumstances under which performance outcomes vary across programs or projects also are needed. Studies of that kind are vital to understand the extent to which performance outcomes vary as a function of differences in process enactment. Moreover, process capability does not always guarantee successful program performance or product quality. We need to know much more about the varying organizational circumstances and product characteristics that may mediate the effects of differences in process enactment.

Organizations that successfully enact capable processes may in fact reasonably expect to see concomitant improvements in performance, be they measured in terms of cost, schedule, quality, predictability, customer satisfaction, return on investment or other measures of business value. Yet that still begs the question of what it takes to achieve sustainable improvement in the process enactment itself. Not all improvement initiatives are implemented successfully. Additional empirical research is needed here as well.

Research of this kind badly needs to be informed by the development and analysis of rigorous process-performance models. The work of David Raffo on process modeling and simulation has great potential in this context.

Studies that systematically make comparisons across many projects or organizations do exist; however, most are based on the SW-CMM [1-11]. They 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 understanding and explaining variation in program performance as a function of CMMI-based improvement. Similar work is underway at this writing at Motorola, Lockheed Martin Integrated Systems & Solutions, and Northrop Grumman Mission Systems. Results from these and other studies will appear in future issues of the DACS Software Tech News, SEI reports and other venues. In the meantime, enjoy reading what follows here.

Dennis R. Goldenson, Pittsburgh, Pennsylvania, 18 February 2007

References
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About the Author

Dr. Dennis R. Goldenson is a senior member of the technical staff of the Software Engineering Institute (SEI). A principal author of the Measurement and Analysis Process Area for Capability Maturity Model Integrated (CMMI®) models, he also has served as technical lead for the SEI’s empirical investigations into the performance outcomes of CMMI®- based process improvement. Previously, he was co-lead of test and evaluation for CMMI®, and he was the international trials coordinator for the SPICE project in support of ISO/IEC 15504.

He came to the SEI in 1990 after teaching at Carnegie Mellon University since 1982. He began working on software development over 40 years ago, initially as a research programmer for custom statistical software, then as a lead programmer/designer for an early decision support system. Immediately prior to coming to the SEI, he was co-principal investigator of a large National Science Foundation funded project for the development and evaluation of integrated programming environments.

His work focuses on improving the practice of measurement and analysis, the improvement of process models and appraisal methods, and the impact and transition of process improvement and other engineering technologies. Related interests are in survey research, experimental design, the visual display of quantitative information, the quantitative analysis of textual information, and tools to support collaborative processes.

Over the course of his career, he has published many papers and made many professional presentations. He holds a Ph.D. and M. A. from the University of Minnesota, and a B. A. from Northwestern University.

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Where to Look for Performance Results from CMMI®

DACS ROI Dashboard
(See http://www.thedacs.com/databases/roi/)

The DACS has an on-going initiative to gather data and information about software process improvement from the open literature and present it to viewers in graphical format in a tool called the ROI Dashboard ©, which is available, free of charge, from the DACS website. The Dashboard allows viewers to see at a glance the range of performance results from CMMI®, and other process improvement areas have been reported from multiple sources. The Dashboard article in this issue describes the available graph types and details for using the tool.

SEI CMMI® Performance Results Web Site
(See http://www.sei.cmu.edu/cmmi/results.html)

This web site provides performance results that originate from publicly available conference presentations, published papers, and individual collaboration with the SEI. Results are presented by organization or by performance category, and the site provides the capability to view summary data or navigate to the details, including the actual source of the information.
Trends of Key Business Indicators During the Journey from SW-CMM® Level 2 to CMMI® Level 5

Introduction

Lockheed Martin Integrated Systems & Solutions (IS&S) specializes in developing horizontally-integrated solutions for network-centric operations, to enable defense and intelligence organizations to act with greater speed, precision and effectiveness. IS&S is a Business Area of Lockheed Martin Corporation, headquartered in Gaithersburg, MD, and geographically distributed throughout the United States and the world. IS&S has approximately 15,000 employees with an estimated $5 Billion in annual revenues. IS&S was formed primarily from the Lockheed Martin Management & Data Systems (M&DS) and Mission Systems business units in late 2003.

IS&S has a long history of process improvement based upon Capability Maturity Models (CMMs). Specific milestones in this journey are as follows:

- 1996-1997: Performing at SW-CMM® Level 3; formally certified at this level in 1996
- 1998-1999: Performing at SW-CMM® Level 4; formally certified at this level in 1998
- 2000-2001: Performing at SW-CMM® Level 5; formally certified at this level in 2000
- 2002-present: Performing at Capability Maturity Model®, Integrated (CMMI®) Version 1.1 Staged SE/SW Level 5; formally certified at this level in 2002, maintained certification at this level in 2005 for SE/SW/IPPD/SS.

While IS&S has improvement related data for specific CMMI® based improvement projects, we wanted to discern whether there was noticeable effects (positive or negative) on indicators typically used by senior management for setting business objectives.

Analyses of these indicators show consistent value in pursuing CMM*-driven process improvement. For example, award fees increased and overhead rates declined; software productivity increased, while unit software cost and defect find and fix costs decreased. The purpose of this article is to review the yearly results and trends of these key business indicators since 1993. The data through 2003 reflect history from the M&DS business unit. The IS&S Business Area is continuing to use and improve the M&DS process architecture, policy, and practice framework.

Business Objectives Mapped to Indicators

Successful achievement and maintenance of process maturity comes from a strong thread of enterprise-level objectives and implementation plans flowing down to program-level objectives, information needs, and indicators. At the enterprise level, annual goal-setting is conducted by executive management; and each goal is assigned to a senior executive. Each goal has a plan which is statused at the monthly executive review with emphasis on quantitative information. Implementation plans for engineering goals include process changes piloted by a set of target programs prior to rollout to a wider audience of programs across the enterprise.

Enterprise goals for process efficiency and product quality are flowed down to programs through the management chain. Programs are required to have smooth process initiation using early intervention to manage risks, with senior functional engineering managers persistent in process focus. The following indicators address process efficiency of IS&S’ program process standard, end-to-end, as well as the quality of the products produced by our processes:

1. Award Fee
2. Overhead Rate
3. Software Productivity
4. Software Unit Cost
5. Defect Find & Fix Cost

The discussion that follows addresses the analysis of each of these indicators in more detail.

Results of Enterprise Analyses of Key Business Indicators Award Fee

Award fees are an important indicator of customer satisfaction for programs using this contract mechanism. The following graph compares award fee results to CMM® Levels and shows customer satisfaction continuing to increase as process maturity becomes higher.
Performance Outcomes of CMMI®-Based Process

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Overhead Rate

The trend in overhead rate indicates if overhead costs are affected by CMM® related-process improvement. There can be concern that overemphasizing CMM® high maturity levels increases overhead, and therefore, total cost. However, the following graph shows IS&S overhead rate has steadily declined since the SW CMM® Level 3 time-period. This decline in overhead rate demonstrates that CMM®-related efforts have likely had a positive effect on overhead costs, as well as direct engineering labor. CMMI®-based process improvements do not come with overhead baggage.

Software Productivity

The graph below illustrates a comparison of productivity rates before and after implementing two IS&S initiatives, NW/IPQ. Both are defined as follows:

- New Ways of Doing Business (NW) is a collective term for several methodology/tools/process initiatives including Architecture Based Design, Scenario Based Testing, and Design Adequacy Assessments.

![Overhead Rate Graph]

Near the end of the SW CMM L2 period, the overhead pools were changed. A SW CMM L2 Overhead is therefore not included.

![Software Productivity Graph]
Performance Outcomes of CMMI®-Based Process

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- In-Process Quality (IPQ) refers to Quality Awareness throughout the lifecycle, early defect detection through the use of inspections, and defect prevention driven by defect causal analysis.

This analysis refers to these two initiatives collectively as NW/IPQ.

Pre-NW/IPQ corresponds to the time-period of SW CMM® Levels 3 and 4 while Post-NW/IPQ corresponds to the time-period of SW CMM® Level 5 and CMMI® Level 5. Software productivity increased in Programs A and B as compared to the Pre-NW/IPQ Baseline. Post-NW/IPQ programs during CMMI® L5 use showed steady and consistent increases in software productivity with CMM®-based process improvement.

Software Unit Cost

Software Unit cost was computed based upon labor rates, overhead rate, and productivity. To compute Software Unit Cost (UC) = LR x WR x UL x ADJ where

LR = average hourly labor rate for engineers and technicians
WR = wrap rate, or overhead rate
UL = Unit Labor (i.e., Hours/LOC or the inverse of productivity)
ADJ = Adjustment factor to provide a constant dollar value over time

A reduction in Software Unit Cost was realized with Post-NW/IPQ and CMMI® L5, a real “bottom-line” savings for the enterprise.
Defect Find & Fix Cost

In this analysis, the defect find & fix cost of software developed by a SW CMM® Level 3 program was compared to that of a CMMI® Level 5 program. The defect densities (Defects/KLOC) for each phase are multiplied by the number of hours to “Find & Fix” a defect, obtaining Hours/KSLOC for each phase as shown below.

Hours/KLOC and Dollars per KLOC graphs are used to compare the software development process between SW CMM Level 3 Program and CMMI Level 5 Program. The graph below shows the Defect Find & Fix Cost (i.e., Dollars/KLOC) for software from a CMMI® Level 5 program is less than that of a SW CMM® Level 3 program. These analyses of Defect Find & Fix costs show improved product quality and realizable cost savings for the enterprise.

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Conclusion

Enterprise analyses of several key business indicators consistently show value in pursuing CMM*-driven process improvement. IS&S senior management believes a process focus has positive effects on other functions within the company; and, it does make a difference to our customers.

Necessary to achieve these business objectives is a commitment to CMM*-based process improvement at all levels of management and staff. In addition, a strong enterprise process infrastructure, supporting tools, training, and communications are also critical to its success. Sufficient enterprise, function, and program resources are essential to implementing the process infrastructure, together with customers who fully support a mature way of doing business.

About the Authors

Peter McLoone, Lockheed Martin Integrated Systems & Solutions (IS&S), has over 20 years experience with systems and software engineering within the defense industry plus ten more in the commercial world. During the last nine years, he has managed the IS&S Enterprise Measurement Program that has used the CMMI* and earlier maturity models as a framework.

Sharon L. Rohde, Lockheed Martin Integrated Systems & Solutions (IS&S), has over 16 years experience with systems and software engineering within the defense industry. In the last 8 years, her focus has been process and quantitative management. As Deputy Coordinator of the IS&S Enterprise Measurement Program, she assists in providing the measurement process infrastructure, data analyses to facilitate program-level quantitative management, establishing the organization’s process capability baselines, and aligning organizational process performance with business goals.

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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

*This article first appeared in Diane L. Gibson, Dennis R. Goldenson and Keith Kost, Performance Results of CMMI®-Based Process Improvement, SEI Technical Report (CMU/SEI-2006-TR-004), August 2006. It is reprinted here with permission from the SEI and the authoring organization.

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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

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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 1 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 level 5 was achieved ranged from -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].

As seen in Figure 2, the performance effects are even more striking with respect to schedule variance. 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.

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.

**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.**
Cost, Schedule and Quality Improvements

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Reference


About the Authors

Millee Sapp is the Software Engineering Process Group (SEPG) Lead for the Software Engineering Division in the Avionics Management Directorate at Warner Robins Air Logistics Center at Robins Air Force Base, GA. Sapp has been involved in process improvement as an SEPG lead for 12 years. She is an authorized lead assessor for both the Software Capability Maturity Model (CMM®) and the Capability Maturity Model Integration (CMMI®). She is currently the Air Force representative on the Change Control Board for the CMMI® project.

Sapp graduated in 1982 from Georgia Institute of Technology with a degree in Management Science. She also completed the Software Professional Development Program in Software Engineering at the Air Force Institute of Technology (AFIT) in 1993.

Robert W. Stoddard is responsible for the development, maintenance, and delivery of new Measurement courses in public and client offerings for the SEI. He provides Measurement consulting to external clients and support to internal SEI projects. He has 7 years with Motorola and Motorola University as both Distinguished Member of Technical Staff and, lastly, as Director of Quality; 13 years with Texas Instruments Defense Systems & Equipment Group (DSEG) as a site Software Quality Engineering Manager; 4 years with the U.S. Army Finance Corps, 1st Infantry Division, serving as an Automation Officer; 2 years as an SEI Resident Affiliate from Texas Instruments; 1 year as an SEI Resident Affiliate from Motorola; Achieved ASQ Certifications in: Quality Engineering, Reliability Engineering, Software Quality, Auditing and Six Sigma Black Belt; Achieved Certified Motorola Six Sigma Black Belt in 1994 and Certified Motorola Six Sigma Master Black Belt in 2003; Elected to 3 year term as an IEEE Reliability Adcom Committeee Member with duties to begin as Treasurer. He is currently working on his PhD in Reliability Engineering at the University of Maryland and holds an MS in Systems Management from Univ. of Southern California, and a BS in Finance & Accounting from the Univ. of Maine.

Dr. Thomas F. Christian, a Senior Level executive, is the Technical Adviser, Systems Engineering, for the Aeronautical Systems Center at Wright-Patterson Air Force Base. He entered federal service in 1968 as an aerospace engineer at the Warner Robins Air Materiel Area. Following completion of his doctoral research in 1973, he worked in both the nuclear power and manufacturing industries. In 1980, Dr. Christian re-entered federal service at the Warner Robins Air Logistics Center. He served as Director of the 402d Software Maintenance Group when this article was written.

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Improved performance in software development can be achieved by investing in best software development practices. Results can be measured by reduced project duration, decreased effort and better delivered product quality. This article will discuss how one organization identified the improvements by using a combination of quantitative measures and qualitative values. Based on the knowledge gained, the organization has utilized the results to advance their process improvement programs and improve their development practices throughout.

The desire to achieve process improvement was driven by senior level management. Management wanted results that would directly impact stated business goals and objectives, which included:

- Reduction of project costs (mostly effort)
- Improvement in their delivery (project duration) of software
- Achievement of better product quality by minimizing defects delivered
- Improved overall organizational performance relative to industry benchmark data points

The organizational strategy to achieve these goals was centered on the implementation of best practices. In order to achieve the findings and the results that followed, senior management had a well defined vision of what they wanted to accomplish, and they agreed to dedicate the resources necessary to realize the desired results. The ability to properly set management expectations and to gain their support was enhanced by the introduction of a measurement model that objectively and quantitatively generated meaningful results.

Introducing the Measurement Model

The key to successful performance management is measurement. The inclusion of performance measurement to manage and direct decisions is becoming more commonplace. Organizations have long recognized the need to establish strategic goals and objectives. Equally important, however, is the identification of an appropriate set of measures that will provide quantitative evidence that those goals and objectives have been achieved.

A basic measurement model that was advanced by the Practical Software and Systems Measurement (PSM) program suggests that an organization follow these three steps:

1. Identify the needs of the organization
2. Select measures appropriate to measuring whether the needs have been met
3. Integrate measurement into the software development process.

The management of this organization identified the needs of their organization. The David Consulting Group (DCG) was requested to help the organization select the appropriate measures and to create a measurement model that would result in the quantification of process performance levels. Furthermore, DCG was called upon to utilize a measurement model that would provide the ability to compare internal performance measures to industry benchmark levels of performance.

The basic measurement model used included the collection and analysis of both quantitative and qualitative elements. The quantitative elements included four basic measures: size, effort, duration and defects. The qualitative elements included a variety of data points that were used to evaluate levels of competency regarding process, methods, skills, tools and management practices.

Collected on a project by project basis, quantitative data can be displayed in a measured profile that indicates how well a project is performing. Standard industry measures such as function points per effort month, defect density and project duration must be calculated. If function points are used to measure project size, there is an opportunity to make comparisons to industry data points that are also based on function points.

The qualitative data (again collected on a project by project basis) results in a matching capability profile. This profile data identifies the attributes that contribute to high or low yields of performance, such as those indicated through SEI’s Capability Maturity Model Integrated® (CMMI®).

These two elements (quantitative and qualitative) come together to form what is commonly viewed as an organization’s baseline of performance. The baseline values are compiled from a selection of measured projects and represent the overall performance level of the organization.

Results can vary significantly. Some projects perform very well (i.e., they have low cost and high quality), and other projects do not perform well at all. Quantitative data provides senior management with an objective view of
Improved Performance Should Be Expected

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The qualitative data provides the opportunity to examine the attributes of the projects to determine why certain projects have outperformed others. Baseline measures on a sample set of representative projects can provide senior management with the information they needed to make informed decisions. This analysis effort leads an organization to the identification of their best practices and opportunities for improvement.

The organization in this article wanted to determine the impact that SEI CMMI® Level 3 processes had on their performance. In order to determine this improvement, the organization had to first compare its previous baseline of performance and establish a composite profile of contributing attributes.

Project data was collected and analyzed. Averages for size (function points), productivity (function points per effort month), duration (calendar months) and effort (labor) were computed. Using a composite profile, a mapping of the current project attributes for the organization was developed. In parallel, another model was developed for projects of a similar size with a mapping of attributes that matched CMMI® Level 3 characteristics.

The Findings

The impact of achieving CMMI® Level 3 for this organization was significant. For the same size of enhancement projects (approximately 133 Function Points), productivity (Function Point / Effort Month) was projected to increase by 132%, project duration reduced by 50%, effort reduction by 50% and defect density reduced by 75%. This modeling technique helped this organization to evaluate the potential benefits of CMMI® process improvement.

The potential impact indicated above may appear to be dramatic, but significant gains in productivity and reduction in defects should be expected over time as the organization matures.

In Summary

There are a variety of ways in which measurement data may be used to learn more about:

- An organization’s level of performance
- Key factors that contribute to high or low yields of productivity
- The organization’s level of performance as compared to industry data points
- The potential impact of strategic initiatives

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Black Belt -- (weeks 1, 2 and 3)

* Weeks are scheduled approximately one month apart

Week 1
Measuring for Performance-Driven Improvement 1: An SEI Authorized Course: (DMAIC Yellow Belt for Software Development Certification – from Six-Sigma Advantage, Inc.)
Location: ITT-AES 12975 Worldgate Drive Herndon, VA 20170
Cost: $2,625/Attendee
Register by April 30th

Week 2
Software Design for Lean Six Sigma (Combined with Week 1, LSS Green Belt Certification - from Six-Sigma Advantage, Inc.)
Location: ITT-AES 12975 Worldgate Drive Herndon, VA 20170
Cost: $3,199/Attendee
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Week 3
Black Belt Advanced Practices (Combined with Weeks 1 and 2, LSS Black Belt Certification - from Six-Sigma Advantage, Inc.)
Location: ITT-AES 12975 Worldgate Drive Herndon, VA 20170
Cost: $3,699/Attendee
Register by June 30th

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Improved Performance Should Be Expected

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The utilization of a measurement model that includes both a quantitative perspective and a qualitative perspective is most important. It is from this vantage-point that an organization can access both the measured performance profiles along with an understanding of the process profile elements that contributed to the results. The process profiles have the added advantage of recommending a direction for future improvement strategies.

Readers should not assume that similar outcomes will be achieved in their organizations. The prudent action would be to take your own measures and create your own organizational performance baseline. Utilizing industry accepted measures, such as function points, will allow you to perform the necessary comparative analysis. The investment in a baseline study is relatively insignificant in comparison to the value of the information gained and the potential return from process improvement practices.

About the Authors

David Garmus is a Founder of The David Consulting Group (see www.davidconsultinggroup.com), a CMMI® Approved Transition Partner and PSM Transition Organization that supports software development organizations in achieving software excellence with a metric-centered approach. David is Past President of the International Function Point Users Group (IFPUG) and a member of the IFPUG Counting Practices Committee. He received a BS from the University of California at Los Angeles and an MBA from the Harvard University Graduate School of Business Administration.

Ms. Stasia Iwanicki, Vice President, Director of Software Process Improvement and IT Improvement Practices, for the David Consulting Group, is an experienced process improvement leader, who has successfully lead large scale improvement programs in many Fortune 500 companies. She has over 18 years experience specializing in IT process improvement programs including Software Development, Six Sigma, Process Management, and Project Management. She is a certified Project Management Professional and Six Sigma Black Belt.

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Background

The Organization and Its Products

The Motorola Software Group (MSG) develops and maintains custom software for many Motorola products and services. MSG provides technical leadership and expertise to deliver advanced solutions for software that must be used seamlessly throughout the corporation and its customers worldwide. With a flexible pool of over 6000 engineers, MSG Software Design Centers are distributed throughout the world.

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

Work throughout the Motorola 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 MSG 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.

MSG 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. MSG 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, MSG 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

MSG 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 MSG 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 MSG 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 MSG 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.

*This article is an update and enhancement of material that first appeared in Diane L. Gibson, Dennis R. Goldenson and Keith Kost, Performance Results of CMM®-Based Process Improvement, SEI Technical Report (CMU/SEI-2006-TR-004), August 2006. It is reprinted here with permission from the SEI and the authoring organization.
Motorola Software Group’s China Center:

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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 MSG China’s transition to CMMI® include the following:

• The MSG 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 MSG China to deploy a COTS enterprise project management system as a common project management platform. Customized by Motorola corporate, it supports MSG 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 MSG 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 MSG 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 MSG 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, MSG 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.

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Motorola Software Group’s China Center:

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**Performance Results**

Cost of quality, estimation accuracy, and product quality all have improved markedly as the Motorola 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 MSG central data warehouse. The results are based on 191 projects of the China Center from 2000 through 2006. In addition to the results presented here, MSG China regularly manages earned value quantitatively.

As a result of improved verification processes, particularly product peer review and software test processes, MSG China was able to reduce its overall cost of quality by over one third, 34.85 percent, from its pre-CMMI® baseline (see Figure 1). The cost of poor quality remained under control at less than 5 percent during the same period.

As seen in Figure 2, 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

![Figure 1: Cost of Quality](image1)

![Figure 2: In Process Faults per Thousand Lines of Code](image2)
The DACS Gold Practice Initiative:

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Motorola Software Group’s China Center:

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lines of code found prior to release by 13.01 percent from its pre-CMMI® capability.

There was a noticeable spike upward in faults found prior to release in 2006; however, the increase in fact is an example of successful process improvement. The China Center initiated a Digital Six Sigma project in that year to improve its inspection process to reduce costly fault leakage. Approximately 20 percent of the code inspections conducted from January 2005 through June 2006 had reported zero faults; however, a causal analysis also found instances of ineffective implementation of the Center’s audit processes. Improvement actions included:

- Defined inspection process non-compliance criteria were added to the Center’s automated inspection tool.
- Additional process monitoring mechanisms were added to the tool (e.g., preparation status alarming, a material size control chart, a non-compliance control chart, and re-inspection alarming).
- An improved fault prediction method was implemented via the inspection tool.
- Improvements were made to the existing code inspection, audit and quantitative project management guidelines.

As expected, there was in fact an increase in faults detected during the code inspections following these improvements in the Center’s fault detection process. However, other indicators showed that overall quality was sustained, as was cost of quality during the same time period.

Particularly through their improved project planning, estimation, and tracking practices, MSG China was able to improve its initial effort estimation accuracy by almost a third, 56.94 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, 91.77 percent, over its performance at SW-CMM® maturity level 5. The percentages shown in Figure 3 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.

With a sustained on-time delivery rate of 100 percent, the MSG China Center has consistently received high scores on its customer satisfaction surveys, which are conducted at the conclusion of every project (Figure 4). The surveys follow standard MSG 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 MSG 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.
The Motorola MSG China Center has grown in both staff size and business volume since beginning its journey to CMMI® maturity level 5. By the end of 2006, the China center's staff was almost double what it had been in 2003. Its business volume and revenue increased substantially by 60 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.

About the Author

Ms. Angel Qi Liu is the manager of Software Engineering and Quality Department, Motorola Software Group (MSG) China Center. She has been with Motorola for 7 years and now is leading process management, quality management, technology change management and training functions which support more than 1200 SW staff within MSG China Center across 3 sites. She led the organization effort on continuous process improvement, CMMI® transition program and successfully appraised at CMMI® L5 in Sep 2005. She is also the principle contributor to the success of Y2000 CMM® assessment to bring the organization to the high maturity level as the first CMM® L5 organization in China. She is a Motorola Green Belt and once took the leadership as project manager in Digital Six Sigma projects on a cost reduction initiative and measurement system improvement and other process automation and process improvement projects.

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TrialStat Corporation: On Schedule with High Quality and Cost Savings for the Customer*

By 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 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

* This article first appeared in Diane L. Gibson, Dennis R. Goldenson and Keith Kost, Performance Results of CMMI®-Based Process Improvement, SEI Technical Report (CMU/SEI-2006-TR-004), August 2006. It is reprinted here with permission from the SEI and the authoring organization. The article is an abridgement and extension of work that also appears in Mary Beth Chrissis, Mike Konrad, and Sandy Shrum, CMMI: Guidelines for Process Integration and Product Improvement, Second Edition, Boston: Addison-Wesley, 2007.
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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.

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TrialStat Corporation: On Schedule

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• 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 1 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.

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

Figure 1: Ability to Meet Schedule Targets

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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 Group* (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 2, 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.

The results in Figure 3 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].

Figure 3 shows the estimated cost savings of each using each of the ten Clinical Analytics 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.

*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.

Figure 2: Post-Release Defect Density

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Figure 3: Cost Savings to the End User

References


About the Author

Dr. Khaled El Emam is a faculty member at the University of Ottawa in Canada, where he has a joint appointment on the Faculty of Medicine and in the School of Information Technology and Engineering. He holds the Canada Research Chair in Electronic Health Information. He is also the co-founder and Chief Scientist at TrialStat Corporation, which is a small Canadian company that provides software in support of medical clinical trials.

Also, as a Senior Scientist at the Children’s Hospital of Eastern Ontario Research Institute, he is leading the eHealth research program. In addition, he is an Associate Professor at the University of Ottawa, Faculty of Medicine, and a Canada Research Chair in Electronic Health Information. Previously, Dr. El Emam was a senior research officer at the National Research Council of Canada, where he was the technical lead of the Software Quality Laboratory, and prior to that, he was head of the Quantitative Methods Group at the Fraunhofer Institute for Experimental Software Engineering in Kaiserslautern, Germany. In 2003 and 2004, Dr. El Emam was ranked as the top systems and software engineering scholar worldwide by the Journal of Systems and Software based on his research on measurement and quality evaluation and improvement. Currently, he is a visiting professor at the Center for Global eHealth Innovation at the University of Toronto (University Health Network) and at the School of Business at Korea University in Seoul. He holds a PhD from the Department of Electrical and Electronics Engineering, King’s College, at the University of London (UK).

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The DACS has been collecting (from open source literature) Return On Investment (ROI) data from software process improvement activities for over 10 years. The earliest results of those collection efforts were first published in 1996 and then updated in 1999 in a DACS report titled “A Business Case for Software Process Improvement.” That report still gets downloaded on average 250 times per month from our DACS Reports web page (see http://www.thedacs.com/techs/roispi2/). It is still one of our most frequently requested documents.

That report examined and modeled the benefits of such improvements as the software CMM®, inspections, and cleanroom software engineering, using spreadsheets to provide a mechanism for estimating the likely impact and benefit of applying similar improvements in the reader’s organization.

From that early collection effort it was clear that much of the reported improvements were made against a small number of benefit attributes such as impact on cost, on schedule, and on quality. Subsequently, DACS efforts then turned to capturing, codifying, and representing the results in a common database format and continuing to update this database as new data emerges in the open literature.

The DACS ROI Dashboard© takes the next step by providing a web-based set of graphical and analytical tools interfaced to this database to provide ways for users to look at and reason about the reported data. It is available (free of charge) through the DACS website at http://www.thedacs.com/databases/roi/.

This article will summarize a few of the key capabilities available from the dashboard as related to CMMI® reported results. Figure 1 presents the RIO Dashboard© home page where visitors select improvements of interest and their display preference.

**Getting Started**

From the Dashboard home page input window on the left, the user selects one or more improvement areas of interest. Then, on the right, the user chooses his/her preferred display...
type (Box Plot, Bar Plot, or Text Display) and then clicks “Submit”. The resulting data will be presented in the chosen format. Figure 2 provides a visual comparison of a box plot and bar plot of the same data. See Figure 5 for a sample Text Display.

The following paragraphs provide a detailed explanation of these three presentation formats. All three graph types are dynamic in that they allow the user to drill down to the detailed data and sources, simply by clicking on the box, bar, line, point or the links embedded within the Text Display.

**Box Plots**

Figure 3 presents a graphical definition of a Box Plot, also called a box and whiskers plot. A Box Plot displays the empirical distribution of a single variable (such as impact on quality). Half of the distribution is in the center box. Whiskers, at the top and bottom of the box, show the extent of most of the remainder of the distribution. Finally, outliers and extreme values are plotted beyond the whiskers. Tukey (1977) first described Box Plots.

The Box Plot shows various statistics. Box Plots on the DACS ROI Dashboard© display two measures of central tendency, the mean and the median. Traditional Box Plots do not display the mean, which is the quotient of the sum of the data points and the number of data points. The median is such that half the sample is less than its value. If the number of data points, n, is odd, the median is the (n + 1)/2 th point. Otherwise, the median is the mean of the (n/2) th and the (n/2 + 1) th point. The median is less sensitive to extreme values and outliers; it is also easier to interpret for non-Gaussian (non-bell-shaped) and non-symmetric distributions.

The lower and upper edges of the box, known as “hinges”, approximate the first and third quartiles of the distribution. (The median is the second quartile.) The first quartile is such that a quarter of the data points are less than its value. If n + 1 is divisible by four, where n is the number of data points, the first quartile is the (n + 1)/4 th point. The lower hinge is the median of the points less than or equal to the median. In cases where the first quartile is found by interpolating between two data points, the hinge will typically come out as a different interpolation. Tukey defined hinges for ease of calculation. The upper edge is found, similarly, as the median of the points greater than or equal to the median. The upper hinge approximates the third quartile, which is such that three quarters of the distribution is less than its value. Note that the central half of the distribution is between the two quartiles. The interquartile range is a measure of the variability of the data.

**Bar Graphs**

Figure 4 presents the defining characteristics of a bar graph. The statistics shown on a bar graph consist of the mean and multiples of the standard deviation.

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The DACS ROI Dashboard

Continued from page 31.

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- Extreme value – greater than 3 box lengths above the hinge approximating the third quartile
- Outliers – greater than 1.5 box lengths above the hinge approximating the third quartile
- Largest observed value neither an outlier nor an extreme value
- Whisker
- Hinge approximating third quartile
- Box
- Mean
- Median
- Hinge approximating first quartile
- Whisker
- Smallest observed value neither an outlier nor an extreme value
- Outlier – greater than 1.5 box lengths below the hinge approximating the first quartile
- Extreme value – greater than 3 box lengths below the hinge approximating the first quartile

**Figure 3:** Defining the Box Plot

---

Largest observed value

Mean

Smallest observed value

Within one standard deviation

Within two standard deviations

Within three standard deviations

**Figure 4:** Defining a Bar Graph

continues on page 33
The mean is defined by the following equation:

$$\bar{x} = \frac{x_1 + x_2 + \ldots + x_n}{n}$$

where $n$ is the number of data points and $x_1, x_2, \ldots, x_n$ are the data points. The standard deviation is defined by the following equation:

$$s = \sqrt{\frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \ldots + (x_n - \bar{x})^2}{n - 1}}$$

For Gaussian (bell-shaped) distributions, 68.3% of the population distribution is within one standard deviation of the mean, 95.4% is within two standard deviations, and 99.7% is within three standard deviations.

**Text Display**

The Text Display, illustrated in Figure 5, provides various distribution-free and parametric statistics about each attribute (metric) of the improvement area for which data exists:

- Total Data Points represents the number of observations that report on a given attribute. For example, Figure 5 shows that there are 3 observations related to the percentage of defects found.
- Minimum provides the minimum value of all observations for a particular attribute
- Maximum provides the maximum value
- Median provides the median value as described earlier
- Mean provides the average value as described earlier
- Standard Deviation represents the one standard deviation value of all observations
- 25th Percentile represents the lower “hinge” value such that a quarter of the data points are less than its value (the median of the observations below the median)
- 75th Percentile represents the upper “hinge” value such that a quarter of the data points are greater than its value (the median of the observations above the median)

Note, the reader may click on the specific hyperlinked metric or data point count to navigate to detailed fact sheets relating to data and data sources.

**Observations about the Reported ROI Dashboard© Data**

In reasoning about the data presented in the dashboard, the reader needs to be aware that the dashboard contains the data available to the DACS. Thus, certain attributes of some improvement areas have limited quantities of observations (less than 5 observations). The reader can place the most confidence in the data with the most observations.

The DACS has also consciously tried not to infer anything from reports. If a report (literature) didn’t explicitly make a claim about some result of the improvement, we did not infer it. For example, if someone made a claim about the impact on quality from CMMI©, we did not infer that some portion of that impact may have been because of inspections being performed (another Dashboard improvement area reported).

For many attributes, most reports provided percent-change observations. In most cases, this is because of the proprietary nature of the underlying data. For example, percent change on schedule variance or percent change in rework.

The “Impact on Quality” attribute was not consistently reported in the literature and can be found in two different reported attributes: percent of defects found (before product release); percent defect reduction (as measured across the lifecycle). Most reports provided data on percent defect reduction. Some reports also identified reduction in rework, which may also have a significant impact on quality.
CMMI® Results

With the data as of January 1, 2007, if the reader clicks “CMMI® Process Improvement,” “Box Plot”, and “Submit,” box plots of nine performance attributes from CMMI will be displayed. Two of the attribute box plots are shown in Figure 6.

The two attributes shown in this figure represent the reported attributes with the most observations. It is interesting to observe that the mean (47.64%) and median (48.5%) coincide. Coincidentally, these values are very similar to the mean and median defect reduction observed in CMM Software Process Improvement. The largest value (250% from one report) in Figure 5(b) skews the visual display.

Figure 7 provides the Text Display of performance results of all attributes for CMMI®. As can be seen, little reported data exists for cost of the improvement, impact on project cost performance, or impact on rework.

Additional details and analysis specific to the various levels of CMM® and CMMI® can be accessed from the ROI Dashboard home page, by clicking on the hyperlink in the text “To view more details about CMM® and CMMI® improvements click here”. The selection box enables the user to select improvement levels of interest. Figure 8 shows the Box Plot for the attribute “% defect reduction” observed at various CMMI® levels.
The DACS ROI Dashboard©

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Conclusion

The DACS ROI Dashboard© may provide a valuable visual/analytical tool for the engineer or manager, wishing to rationalize or justify investments in improvement, to quickly assess the extent of improvements that have occurred within other organizations. This article provided an introduction to the full capabilities of the tool. Many other improvements are covered in the dashboard and other capabilities exist when you dig further into the tool.

If you have observed results data for any improvement and would like to include them in the Dashboard, please contact the authors at the DACS, or, better yet, complete the SPI data collection survey form accessible by clicking ‘Submit a Case Study’ on the ROI Dashboard home page (see http://www.thedacs.com/databases/roi/submit/). Either way, the DACS will contact you to follow up on your submittal.

About the Authors

Thomas McGibbon works for ITT Advanced Engineering & Sciences as the Director of the Data & Analysis Center for Software (DACS) since 1994. He has over 30 years of experience in software development and software project management. He is author of the DACS Report “A Business Case for Software Process Improvement”. He holds a MS in Software Engineering from Southern Methodist University and BS in Mathematics from Clarkson University. He is a Certified Software Development Professional (CSDP).

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Robert Vienneau is a software engineer for ITT Corporation, Advanced Engineering & Sciences Division and has supported the DACS for over two decades, including analyses of software metrics data, in designing Web page interfaces to DACS databases, in designing and conducting experiments, and in writing and editing State-of-the-Art Reports. He holds a MS in software development and management from the Rochester Institute of Technology and a BS in mathematics from Rensselaer Polytechnic Institute. Mr. Vienneau is a member of the Institute of Electrical and Electronic Engineers (IEEE).

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**About the Software Tech News**

**STN Spotlight**

The DACS has reserved this space to highlight those who are making or have made a significant contribution to the software domain.

**SPOTLIGHT - Dr. David Raffo**

Dr. David Raffo is currently Professor of Business Administration and Computer Science at Portland State University. He is also a Visiting Scientist at the Software Engineering Institute (SEI) and Chief Technologist with Quantel Systems, Inc. Dr. Raffo's research interests include: Product Strategy, Strategic Systems Engineering, Economic Analysis of Systems Engineering Decisions, Globally Distributed Software Development, Process Optimization and Quantitative Analysis. He is one of sixteen academics from around the world who were selected to be Research Members of the International Process Research Consortium (IPRC) which was organized by the Software Engineering Institute and charged with the task of developing an R&D roadmap for the field of software process.

Dr. Raffo has over sixty refereed publications in the field of software engineering and is Editor-in-Chief of the leading international journal in the software process area Software Process: Improvement and Practice. He has received research funding from the National Science Foundation (NSF), the Software Engineering Research Center (SERC), NASA, IBM, Tektronix, Motorola, Robert Bosch, and Northrop-Grumman.

His prior professional experience includes programming as well as managing software development and consulting projects at Arthur D. Little, Inc., where he received the company's Presidential Award for outstanding performance. Dr. Raffo received his Ph.D., ME, and MSIA degrees from Carnegie Mellon University and a BSE from the University of Michigan.

**Dr. Raffo has these thoughts to share with us:**

In this dynamic industry where credible competitors are appearing from every part of the globe, bold steps are needed to integrate business and technical decisions, and to create superior value. Much of our work has focused on using simulation to predict the business value of process improvement. We have built models of the systems and software development processes for military and other government applications as well as for the aerospace, automotive and telecommunications industries. These models can be used to predict the cost, quality and schedule performance associated with an organization's development projects. Managers can then use these models to evaluate strategic quality assurance options (V&V and IV&V); assess the impact of process improvements, new process alternatives, new tools and technology implementations; train managers; benchmark processes; and more. Process simulation models can serve as quantitative project performance models that can be used as test beds to assess the impact of varying organizational and project conditions. They can be used to give specific guidance on when a process improvement or tool is – or is not – likely to be useful. This can be done before an organization expends its scarce process improvement resources or – more importantly – the change inadvertently causes problems for the project. The simple fact is that using process simulation to help with just one decision enables the cost of the process modeling effort to more than pay for itself.

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**About This Publication:**

The *Software Tech News* is published quarterly by the Data & Analysis Center for Software (DACS). The DACS is a DoD sponsored Information Analysis Center (IAC), administratively managed by the Defense Technical Information Center (DTIC). The DACS is technically managed by Air Force Research Laboratory, Rome, NY and operated by ITT, Advanced Engineering and Sciences Division.
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