Carnegie Mellon
Software Engineering Institute

Demonstrating the Impact and Benefits of CMMI®: An Update and Preliminary Results

Dennis R. Goldenson
Diane L. Gibson

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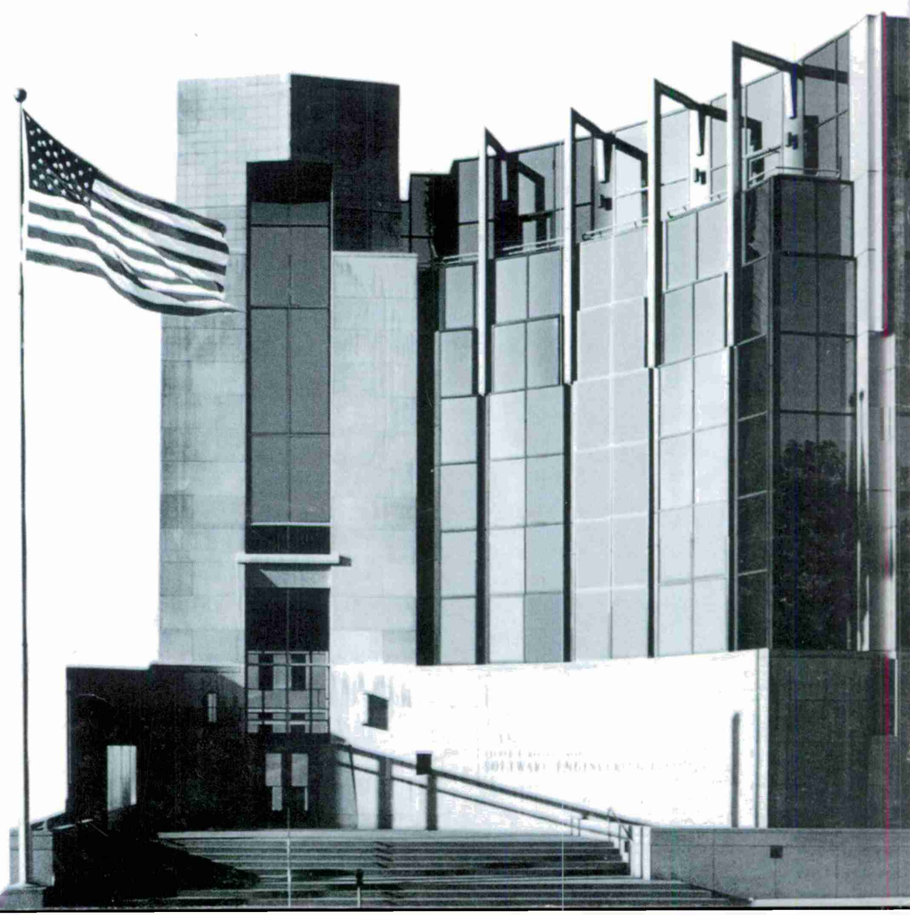

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Software Engineering Process Management Program

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The ideas and findings in this report should not be construed as an official DoD position. It is published in the interest of scientific and technical information exchange.

FOR THE COMMANDER

Christos Scondras
Chief of Programs, XPK

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Executive Summary

While still limited, the results presented in this report provide credible quantitative evidence that Capability Maturity Model® Integration (CMMI®)-based process improvement can result in better project performance and higher quality products. The results are drawn from a total of 12 cases from 11 separate organizations. These include 5 with home offices in the United States and 6 located in Europe and Australia. Their process improvement efforts cover both small and large organizational units.[1] The organizations do business in a variety of sectors and domains including information technology, banking and financial services, automotive and aerospace engineering, simulation, and training. They apply CMMI model practices to systems integration, systems engineering, and software development.

Many possible measures of performance can be used to demonstrate the impact of CMMI-based process improvement. This report presents results that organizations have shared with the Software Engineering Institute (SEI℠) or with the wider community in public forums. We have categorized the results into four primary classes of benefits: cost, schedule, quality, and customer satisfaction. Evidence about return on investment and related cost-benefit matters constitutes our fifth performance category.

The following list summarizes the results from the 12 cases for each of the 5 classes of performance measures.

- **Cost**: Six cases provide nine examples of cost-related benefits, including reductions in the cost to find and fix a defect, and overall cost savings.
- **Schedule**: Eight cases provide evidence of schedule-related benefits, including decreased time needed to complete tasks and increased predictability in meeting schedules.
- **Quality**: Five cases provide evidence of measured improvements in quality, mostly related to reducing defects over time or by product life cycle.

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1 Definitions of "organization" vary, so care must be taken when making comparisons. In some instances, the numbers reported may refer to the organizational scope of an improvement effort. In other instances, the numbers may refer to a larger entity of which that effort may be a part.

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- **Customer Satisfaction**: Three cases show improvements in customer satisfaction, including demonstration of customer satisfaction through award fees.
- **Return on Investment**: Three cases report positive returns on investment from their CMMI-based process improvement.

Abstract

There is a widespread demand for evidence about the impact and benefits of process improvement based on Capability Maturity Model® Integration (CMMI®) models. Much has been documented about the practice of CMM®-based process improvement and its value for the development and maintenance of software and software intensive systems; however, the existing information is sometimes outdated and there are increasing calls for evidence directly based on CMMI experience. This special report presents selected results from 12 case studies drawn from 11 organizations. While still limited, the case studies provide credible evidence that CMMI-based process improvement can help organizations achieve better project performance and produce higher quality products. The report also describes plans for gathering further evidence from organizations using CMMI models.

1 Introduction

Serious process improvement of any kind requires a considerable investment of time and money on the part of the organizations that decide to pursue it. Capability Maturity Model® Integration (CMMI®)-based improvement is no exception, and trustworthy objective evidence about its benefits is essential for addressing a variety of concerns. Increasing numbers of organizations are considering using CMMI models but some remain skeptical about the value of any model-based process improvement. Others are uncertain about the value of adopting the CMMI Product Suite over its source models: the CMM® for Software (SW-CMM) Version 2.0 draft C, the Electronic Industries Alliance Interim Standard (EIA/IS) 731, and the CMM for Integrated Process Development Version 0.98 [CMMI Product Team 02], [SEI 97], [EIA 98], [Bate et al. 97]. Still others need evidence to build commitment and to garner the requisite resources within their own organizations. Furthermore, a growing number of organizations use such information as part of their ongoing quantitative management, and as input for improving their organizational processes and technologies. They would also like to be able to compare their results to those of others.

There is a widespread demand for credible, objective evidence about the impact and benefits of process improvement based on CMMI models. For example, when asked in a recent questionnaire whether their organization needs return on investment (ROI) or other quantitative evidence about the CMMI models, 26 percent of the 554 of those who answered the question said that they "must have it," while another 47 percent said that "it certainly would help to have." Fourteen percent said that they had "already built a good business case." Only 13 percent said that "it's not a real issue for us," typically because their organizations already had decided to adopt the CMMI Product Suite for other reasons [Chrissis et al. 03].

We already know a good deal about process improvement based on the SW-CMM and the value for the development and maintenance of software and software intensive systems. Numerous case studies, conducted over more than two decades, provide evidence of sometimes very substantial improvements in product quality and cost effective delivery that accompany corresponding enhancements in process discipline [Benno & Frailey 95], [Butler 95], [Dion 92], [Dion 93], [Herbsleb et al. 94], [Humphrey et al. 91], [Lebsanft 96], [Lipke & Butler 92], [McGarry et al. 98], [Wohlwend & Rosenbaum 93], [Jung & Goldenson 03].

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A growing number of more broadly based studies systematically make similar comparisons across many projects or organizations [Clark 97], [Deephouse et al. 95], [El-Emam & Goldenson 00], [El-Emam et al. 01], [Goldenson et al. 99], [Goldenson & Herbsleb 95], [Harter et al. 00], [Herbsleb et al. 97], [Krasner 99], [Krishnan & Kellner 99], [Lawlis et al. 95]. These studies, too, find evidence of considerable differences in product quality and efficient delivery that vary predictably with differences in process capability and organizational maturity.

That said, much of the existing evidence is rather dated and, as more organizations consider using CMMI models, there are increasing calls for evidence based on direct CMMI experience. The purpose of this special report is two-fold: to present preliminary results about CMMI impact and to describe ongoing and future work in this area.

Section 2 provides a synopsis of the case studies on which this special report is based. Section 3 follows with a brief discussion of how an organization can demonstrate the impact of CMMI-based process improvement on project performance and product quality. Section 4 presents results from a series of case studies that are publicly available and from others being conducted in collaboration with the Software Engineering Institute (SEI[SM]). Section 5 describes other work underway at the SEI and elsewhere to provide credible evidence about the impact of process improvement based on CMMI models. Section 5 also contains a brief discussion of the limitations of the current work and plans for the future.

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2 This Report

Most of the results presented in this document are drawn from twelve case studies. All but one are from recent papers and presentations. Three cases come from an ongoing SEI series of collaborative studies that were available at the time of this writing.

Most of the case studies in this report are based on evidence provided by organizations that have adopted the CMMI Product Suite. We have also included four recent examples based on experience with the SW-CMM. The SW-CMM is a major source for the CMMI models, and much of the same content is present in CMMI models. Evidence based on the SW-CMM may also remain compelling to those who still are skeptical about any CMM-based process improvement. In addition, all of the organizations that reported benefits from the use of the SW-CMM are currently making the transition to the CMMI Product Suite.

There is less quantitative evidence about CMMI model content that has its legacy in systems engineering, but we have done our best to include such evidence, both in this report and the larger set of in-depth case studies described in Section 5. While much of the evidence still remains qualitative and anecdotal, we also address the value added by integrating processes and practices across disciplines and across a wider organizational scope.

3 Demonstrating Impact on Performance

Process improvement based on CMMI models may be demonstrated in various ways. Some organizations have established new processes or changed existing processes as a result of making the transition to 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, perhaps especially for those who are among the first to have been appraised at higher maturity levels. For example, some organizations had already established processes that were not emphasized or emphasized differently in the SW-CMM.[2] In one sense, their experiences cannot be attributed to CMMI adoption, but their results certainly show the importance of the best practices that are articulated in CMMI models.

Analytic approaches also differ. Some organizations make comparisons over time, across maturity levels, or other major process milestones. Others focus on selected project or organizational processes that can be mapped to CMMI model practices. In addition, qualitative references are made to things done differently as a result of the transition to CMMI models.

Similarly, many possible measures of performance can be used to demonstrate the impact of CMMI-based process improvement. Organizations use the measures that make the most sense given their particular business goals, and organizations often describe CMMI benefits in different ways.

Figure 1 is a high-level depiction of the impact of CMMI-based process improvement. The costs of process improvement are illustrated in the upper left. Process capability and organizational maturity are depicted in the center box, and the box on the right illustrates the benefits of process improvement. 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.

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2 In addition to the Engineering process areas, these notably include Decision Analysis and Resolution (DAR), Risk Management, the maturity level 4 and 5 process areas, the inclusion of Measurement and Analysis at maturity level 2, and the treatment of several of the generic practices.

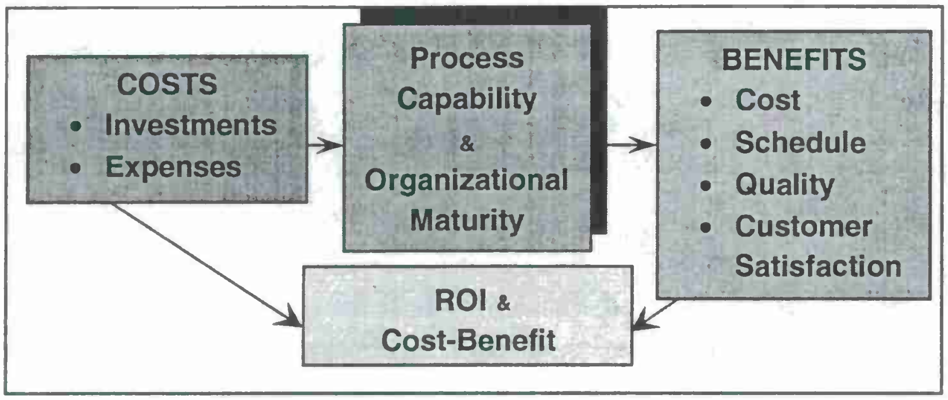

Figure 1: High-Level Model of CMMI Impact

We have classified the performance measures into five broad categories for this report. As shown in the detail under benefits in Figure 1, potential benefits of process improvement might accrue with respect to cost, schedule, quality, and/or customer satisfaction.[3] The fifth category is return on investment and related measures, as shown in the bottom box.

Organizations typically seek to optimize some combination of the four primary classes of benefits, each of which 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 four basic categories might include shorter cycle times, reduced defects, increased productivity, reductions in rework and concomitant effort, enhanced functionality, and maintainability.[4]

As also shown in the detail under costs in Figure 1, there are always costs associated with implementing and institutionalizing process improvement. While cost data are available less often than evidence of benefits, organizations frequently are concerned about ROI and related cost-benefit matters; hence, they constitute our fifth category of performance measures.

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[3] Relatively few organizations measure customer satisfaction systematically. Neither does it fit comfortably into any single one of the other three high-level benefit categories; however, it is important enough in its own right that we call it out here as a primary class of the potential benefits of process improvement.

[4] Other possible performance measures such as employee morale or process compliance *per se* do not map well to the simple benefits classification presented in Figure 1; however, we do discuss them in the case vignettes in Section 4.

4 Preliminary Results

The results that follow are presented in two ways. In Section 4.1 we present a tabular summary organized by our five high-level classes of performance measures, namely product cost, project schedule, quality, customer satisfaction, and return on investment. These are followed by a series of descriptions that provide more detail about each organization.[5] While detailed quantitative evidence is not always provided publicly, each of the organizations included here makes reference to the existence of such evidence in the presentation of its results.

4.1 Overview of Results

4.1.1 Cost

This category covers instances where organizations report reductions in the cost of final or intermediate work products, reductions 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. More detail about each of these instances can be found in the organizational descriptions in the next section.

Table 1: Summary Benefits and Impact: Cost

Result	Model
33% decrease in the average cost to fix a defect (Boeing, Australia)	CMMI
20% reduction in unit software costs (Lockheed Martin M&DS)	CMMI
15% decrease in defect find and fix costs (Lockheed Martin M&DS)	CMMI
4.5% decline in overhead rate (Lockheed Martin M&DS)	CMMI
Improved and stabilized Cost Performance Index (Northrop Grumman IT1)	CMMI
Saved $2 million in first 6 months after reaching CMM ML3 (Sanchez Computer Associates, Inc.)	SW-CMM
20% reduction in average cost variance (Thales Research & Technology)	SW-CMM
60% reduction in cost of customer acceptance (Thales Research & Technology)	SW-CMM
Cost variances decreased as process maturity increased (Thales Training and Simulation)	SW-CMM

[5] The amount of detail provided in the published reports varies considerably. We have done our best to supplement these reports with information from other public sources and our previous familiarity with the organizations involved.

4.1.2 Schedule

This category covers two aspects of schedule: improvements in schedule predictability and reductions in the time required to do the work. Since measures of productivity are generally based on the amount of work accomplished in a period of time, this is included here as well. More detail about each of these instances can be found in the organizational descriptions in the next section.

Table 2: Summary Benefits and Impact: Schedule

Result	Model
Reduced by half the amount of time required to turn around releases (Boeing, Australia)	CMMI
60% reduction in work and fewer outstanding actions following pre-test and post-test audits (Boeing, Australia)	CMMI
Increased the percentage of milestones met from approximately 50% to approximately 95% (General Motors)	CMMI
Decreased the average number of days late from approximately 50 to fewer than 10 (General Motors)	CMMI
Increased through-put resulting in more releases per year (JP Morgan Chase)	CMMI
30% increase in software productivity (Lockheed Martin M&DS)	CMMI
Improved and stabilized Schedule Performance Index (Northrop Grumman IT1)	CMMI
Met every milestone (25 in a row) on time, with high quality and customer satisfaction (Northrop Grumman IT2)	CMMI
10% improvement in first pass yield leading to reduction in rework (Bosch Gasoline Systems)	SW-CMM
15% improvement in internal on-time delivery (Bosch Gasoline Systems)	SW-CMM
Improved predictability of delivery schedule (JP Morgan Chase)	SW-CMM
Schedule variances decreased as process maturity increased (Thales Training and Simulation)	SW-CMM

4.1.3 Quality

Quality improvement is most frequently measured by reductions in the number of defects at different points in the process or overall in the product. However, we recognize that there are other ways to characterize and measure quality. Where these are found, we have included them. More detail about each of these instances can be found in the organizational descriptions in the next section.

Table 3: Summary Benefits and Impact: Quality

Result	**Model**
Met goal of 20 +/- 5 defects per KLOC (Northrop Grumman IT1)	CMMI
Only 2% of all defects found in the fielded system (Northrop Grumman IT1)	CMMI
Reduction in defects found from 6.6 per KLOC to 2.1 over 5 causal analysis cycles (Northrop Grumman IT2)	CMMI
Increased focus on quality by developers (Northrop Grumman IT2)	CMMI
Reduction in error cases in the factory by one order of magnitude (Bosch Gasoline Systems)	SW-CMM
Reduction in number and severity of post-release defects (JP Morgan Chase)	SW-CMM
Most of $2 million savings resulted from early detection and removal of defects (Sanchez Computer Associates, Inc.)	SW-CMM
Improved quality of code (Sanchez Computer Associates, Inc.)	SW-CMM

4.1.4 Customer Satisfaction

Few organizations have reported on measures of customer satisfaction; however, we have included this section because of its importance for many organizations as a measure of the benefits of process improvement. More detail about each of these instances can be found in the organizational descriptions in the next section.

Table 4: Summary Benefits and Impact: Customer Satisfaction

Result	**Model**
Increased award fees by 55% compared to an earlier SW-CMM baseline at maturity level 2 (Lockheed Martin M&DS)	CMMI
Received more than 98% of possible customer award fees (Northrop Grumman IT1)	CMMI
Earned a rating of "Exceptional" in every applicable category on their Contractor Performance Evaluation Survey (Northrop Grumman IT2)	CMMI

4.1.5 Return on Investment (ROI)

ROI can be calculated using a variety of costs and benefits. More detail about each of these instances can be found in the organizational descriptions in the next section.

Table 5: Summary Benefits and Impact: Return on Investment

Result	Model
5:1 ROI for quality activities (Accenture)	CMMI
13:1 ROI calculated as defects avoided per hour spent in training and defect prevention (Northrop Grumman IT2)	CMMI
Processes for earlier defect detection, improved risk management, and better project control implemented after showing positive return on investment during pilot (Thales TT&S)[6]	CMMI

4.2 Organizations Reporting CMMI Benefits

4.2.1 Accenture

Accenture is a management consulting and technology services organization employing more than 75,000 people in 47 countries. After achieving SW-CMM maturity level 3 in some parts of the organization, Accenture shifted its focus to CMMI for Systems and Software Engineering (SE/SW) with integrated product and process development (IPPD) V 1.02. The improvement effort was focused on six large projects in their US Government Operating Unit. These groups had already achieved ISO registration, and were using an integrated work approach with multi-disciplinary teams which included their clients. They accomplished their transition to the CMMI models in 18 months, from May 2001 to December 2002, at which point they held a Standard CMMI Appraisal Method for Process Improvement (SCAMPI[SM]) V 1.1 appraisal and achieved maturity level 3.

As shown in Figure 2, Accenture expended a total of 8,045 hours on its transition to the CMMI Product Suite. Sixty-four percent of the total was spent on process development, with the rest allocated to planning, requirements, and design of new processes and process improvements.

6 TT&S has not made its quantitative results on return on investment publicly available.

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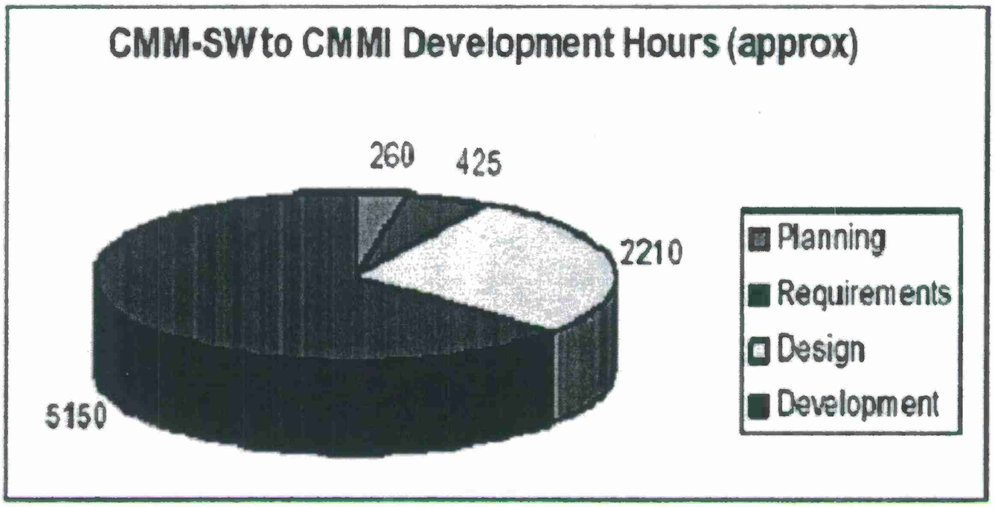

Figure 2: Accenture Transition Hours

In its CMMI implementation, Accenture focused on their processes related to the Decision Analysis and Resolution process area (PA). They applied those practices to their processes related to the Technical Solution, Requirements Management, and Project Monitoring and Control PAs. They concentrated on the model's generic goals as well as the Organizational Environment for Integration PA and the IPPD concept of Shared Vision. The unit reported several lessons learned from this experience. By focusing early on Measurement and Analysis and "thinking level 4 and 5," they gained greater management capability. Like so many others, they reaffirmed the importance of securing management sponsorship, providing support to projects during their transition, and running their process improvement efforts like projects. Accenture reported that it was possible to achieve an ROI of 5:1 from hours invested in quality activities [Bengzon 03].

4.2.2 Boeing Australia, Limited

Boeing Australia, Limited, a wholly-owned subsidiary of The Boeing Company, is a high technology aerospace enterprise that develops systems for both defense and commercial markets. With their head office in Brisbane, Queensland, Boeing employs more than 1,400 people in 13 locations around the country [Boeing 03].

Between 1996 and 1999, a series of reviews of major projects that develop software-intensive systems for Australian defense organizations raised many concerns and issues about process performance. As a result, the Australian Defence Materiel Organisation (DMO) developed objectives for reform and sponsored a broad examination of the potential utility of capability maturity models and methods for the Australian defense industry. They determined that improving processes based on a continuous representation of the CMMI models would best meet their needs for 1) coverage of both systems and software engineering, 2) acceptance by suppliers nationally and internationally, and 3) the DMO strategy of assessing risk against desired capability profiles.

They began by mapping the CMMI Product Suite to ISO/IEC 15504 [ISO 03], and participated in several early pilots of the SCAMPI appraisal methodology [Marshall et al. 01]. In 2001, they decided to continue applying both the CMMI Product Suite and 15504 to evaluate the maturity of a supplier's processes.[7]

Boeing Australia has a heritage of improvement based both on EIA/ IS-731 [EIA 98] and the SW-CMM before making the transition to the CMMI Product Suite. As part of a broader presentation that reviews many general topics which might be of interest to organizations planning to implement the models, Stevenson cites Boeing's submarine project as an example of pertinent CMMI results.[8] These include a 33% decrease in the average cost to correct a defect over an 18-month period. The necessary time for the delivery of a release was cut in half, with an increase in the ability to configure builds. Stevenson also reports a 60 percent reduction in the preparation, conduct, and rework from pre-test and post-test audits, resulting in audits passed with few to no outstanding actions. More qualitatively, he notes that Boeing Australia developers have become increasingly focused on eliminating defects across all products, improving quality, and finding ways to improve their processes.

4.2.3 General Motors Corporation

General Motors Information Systems and Services was formed in 1996 to provide information technology management and technical capability within the corporation. Process improvement work began immediately. From 1996 to 2000 they focused on defining the system delivery process with a small, central group that attempted to create a "quantum change" across the organization using a shared intervention strategy. In 2000 they refocused their leadership effort and involved more practitioners in process improvement. They approached improvement using a more balanced and gradual transition approach, which focused on organizational and process capabilities and the impact of change on the organization [General Motors 03], [Hofmann et al. 01].

Hofmann et al. describe their improvement effort as a "CMMI-style improvement approach" [Hofmann et al. 03]. Using an appraisal tool to "enable consistent, on-site data capture and real-time data analysis," General Motors organizations use internal appraisals to identify gaps between their processes and the CMMI framework of best practices. Appraisal results are

[7] Some of the information is provided here with permission from a proprietary presentation about Boeing's experience using capability maturity models.

[8] This information comes from a presentation by Terry Stevenson titled "Investing in Process—Is There a Return?" The presentation was made at the Software Engineering Australia 2002 Conference in Gold Coast, Queensland Australia, September 2-4, 2003.

reported to senior management. Improvement plans are developed and executed on a regular six-month basis.

The organization also cites the early implementation of a measurement program as a key to its success. By starting early, they gradually increased their analytic capability as they gathered more improvement data. They measured organizational awareness and process compliance, and collected product measures. Organizations within information technology (IT) developed and executed six-month improvement plans, which were driven by the results of causal analyses performed on their measurement data.

As noted in Figure 3, General Motors organizations met their schedules more consistently when they made the transition to CMMI models. The number of project milestones met increased from about 50 percent to about 85 percent. Similarly, they reduced the average number of days late, from more than 50 to fewer than 10. Notice that the major shift in both charts—most noticeable in the second—occurs after they shifted to using CMMI models [Hofmann et al. 03].

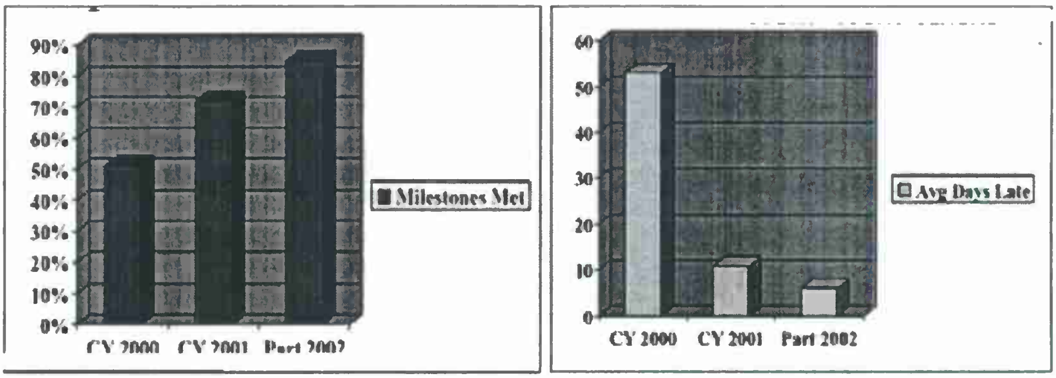

Figure 3: General Motors Schedule Data

4.2.4 Lockheed Martin Management & Data Systems

Lockheed Martin Management & Data Systems (M&DS) provides systems integration, systems engineering, software development, and program management in support of defense, civil, international, and commercial customers. M&DS is a $2.3 billion unit of Lockheed Martin Corporation with approximately 9,000 employees at facilities in Pennsylvania, Arizona, California, Colorado, and the Washington, DC area [Lockheed Martin 03].

M&DS has been deeply involved in process improvement for more than ten years. They were assessed at SW-CMM Level 2 in 1993. They also have a long heritage of integrating both software and systems engineering. M&DS established a foundation in systems engineering in the early 1990s. In 2000, M&DS achieved maturity level 5 in both the CMM for Systems Engineering (SE-CMM) and in the SW-CMM [Newswire 01]. After 18 months of additional effort, they were appraised at CMMI maturity level 5 in 2002 [Ring et al. 02].

Their journey from SW-CMM maturity level 2 to CMMI maturity level 5 (1995-2002) has been characterized by continuing improvement.[9] For example, they have documented a 4.5 percent decrease in their overhead rate. Moreover, they steadily captured a greater percentage of available award fees over the years, now receiving 55 percent more fees compared to the baseline that remained unrealized at SW-CMM maturity level 2.

Concurrent with the period from 2000 to 2002 in which they achieved maturity level 5 against both the SW-CMM and CMMI models, M&DS implemented a number of design-related engineering methodologies, tools, and process initiatives. They also focused on improving the quality of their processes for defect identification, prevention, and removal. Notable performance improvements in these 3 years include an increase in software productivity by 30 percent, a decrease in unit software cost by 20 percent, and a 15 percent decrease in costs to find and fix defects.

4.2.5 Northrop Grumman Information Technology[1]

Northrop Grumman Information Technology, which is part of the larger Northrop Grumman Corporation, generates about $4 billion sales annually, has 22,000 employees, and provides information, engineering, and business solutions for government, commercial, and international enterprises. The majority of their work is in software-intensive systems. Northrop Grumman Information Technology maintains an ongoing commitment to quality, noting on its Web site that the organization has "made continuing process improvement one of our highest priorities" [Northrop Grumman 03]. Their Defense Enterprise Solutions (DES) business unit achieved a CMMI maturity level 5 rating in December 2002.[10]

DES exemplifies how a high maturity organization can undertake continuous improvement. Projects define goals that are compatible with the organization's defined business objectives. The projects then track and measure their performance using common measures for their tailored processes, make corrections, and feed the corrections back into the organization's set of standard processes. For example, their optimizing strategy for defect detection and prevention maps nicely with the Causal Analysis and Resolution process area in the CMMI models. Defect data are regularly collected and analyzed, looking for both special and common causes of

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9 The M&DS process improvement journey began before the existence of the CMMI Product Suite; however, the important point is that their earlier performance improvements are attributable to best practices that have since been incorporated into the CMMI models. Additional effort was necessary to achieve CMMI maturity level 5, and the existence of the CMMI models also facilitated further improvements in performance.

10 DES was created in January 2002 by joining several previously separate organizational units from Northrop Grumman and its recent corporate acquisitions. Those units followed separate processes, and they ranged in maturity level from SW-CMM level 2 through SE-CMM and SW-CMM level 5. The organization's commitment to quantitative management and continuous improvement enabled them to combine the units and improve their overall process performance in a very short period.

variation. Pareto and other root cause analyses are performed, actions are taken to remove root causes and prevent future defects. Changes are made to the organization's defined process and the projects' tailored processes, and technological innovations are introduced where applicable. Tests or peer reviews then are conducted following the new or modified processes, and the cycle begins again.

Figure 4 displays results from their defect density review process in one large project. They set a goal of 20 +/- 5 defects per thousands lines of code (KLOC). Notice on the left side of the graph that they found significant variation in defects per KLOC. After identifying the special causes of variation and implementing an improvement in the process, they saw substantially less variation. Only two percent of all defects were found in the fielded system [Pflugrad 02].

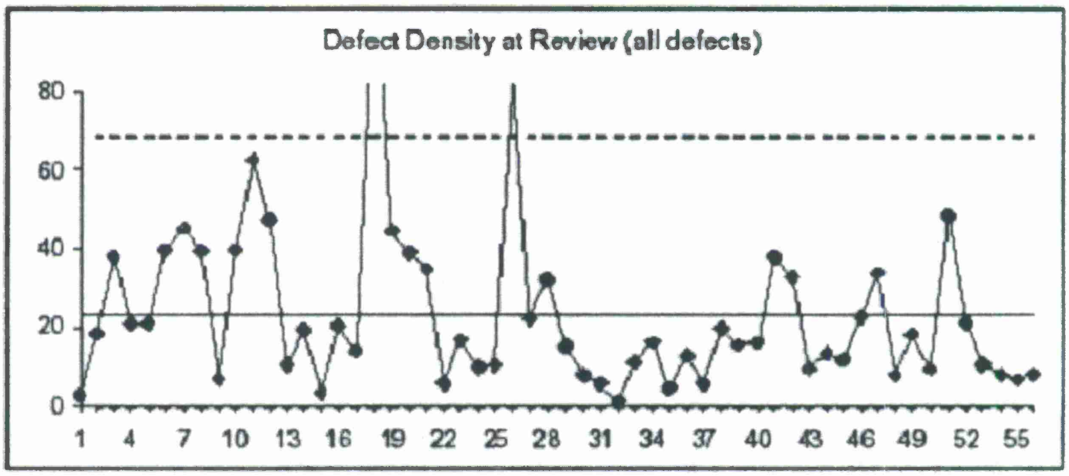

Figure 4: Northrop Grumman Defect Density Reviews

Pflugrad presents similar effects for the same project's cost performance index (CPI) and schedule performance index (SPI) as a result of improvements in processes for estimation and earned value tracking. In the area of customer satisfaction, they are receiving more than 98 percent of the possible award fees from their customer, compared to a goal of equal to or greater than 95 percent [Pflugrad 02].

As shown in Figure 5, a decline in defect density on another project was accompanied by an increase in customer satisfaction. Interestingly, the defect density comparison was added in the later time period, as they moved toward maturity level 5.

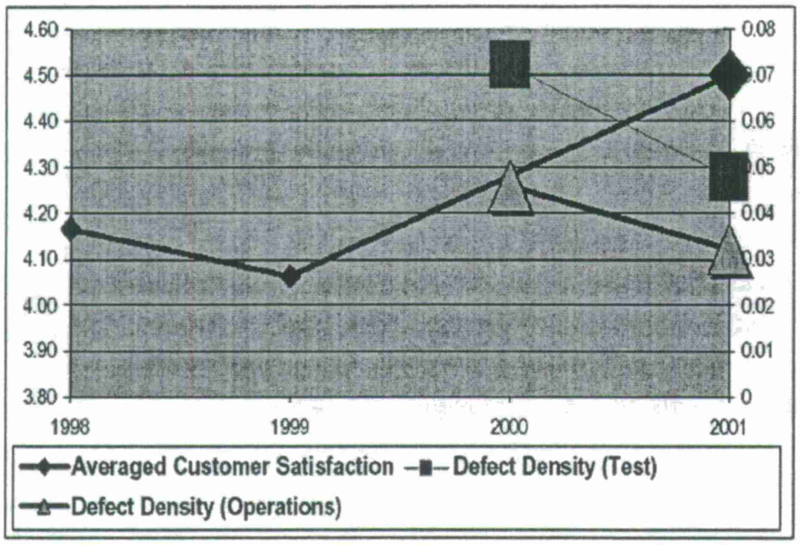

Figure 5: Northrop Grumman Defect Density and Customer Satisfaction

4.2.6 Northrop Grumman Information Technology₂

Northrop Grumman used the Personal Software Process[SM] (PSP[SM]) in conjunction with CMMI maturity level 5 practices on another project that built an Inventory Tracking System. The developers used the PSP to collect individual data. These data were aggregated to facilitate the measurement of time in phase, defect density by phase, review rates and effectiveness, and schedule performance. They also measured requirements volatility, product size, earned value, defect density, and customer satisfaction as part of their implementation of Quantitative Project Management at maturity level 4. Finally, through their maturity level 5 optimizing process that implements the Causal Analysis and Resolution PA, they performed causal analyses on defects for each build cycle. At that time, they captured data by unit and build on defect injection, removal, severity, defect type, and fix time.

Figure 6 shows results over five builds of the tracking system. Northrop Grumman was able to identify particularly important defect types after the first three defect prevention cycles. Following the first three builds, they undertook a number of countermeasures (e.g., revising a design document template, revising peer review checklists, emphasizing the need for adequate review time, and performing "global" reviews on certain types of defects). As seen in Figure 6, defect density found in the peer reviews decreased markedly after the second cycle. After a noticeable upturn on the fourth build, defect density again decreased considerably on the fifth build. Hoffman concludes that "[causal analysis] cycles can provide a tremendous cost savings for a very modest effort, quite rapidly." Indeed, he reports a return on investment of 13:1, calculated as defects avoided per hour spent in training and defect prevention.[11]

SM Personal Software Process and PSP are service marks of Carnegie Mellon University.

11 See Hoffman, G., "Integrating PSP[SM] and CMMI® Level 5," May 2003. This slide presentation may be found in the Software Engineering Information Repository at http://seir.sei.cmu.edu.

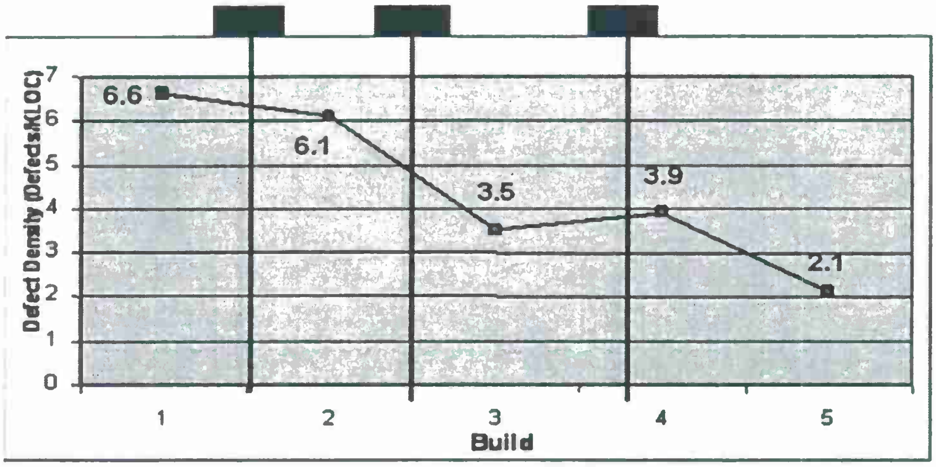

Figure 6: Northrop Grumman Build Cycles

Other benefits that Hoffman attributes to their process improvement effort include

- meeting every milestone (25 in a row) on time, with high quality and complete customer satisfaction
- an increased focus by developers on product quality
- earning a rating of "Exceptional" in every applicable category on their Contractor Performance Evaluation Survey
- finding that their technical staff are providing superior estimates and demonstrate enhanced understanding because they see their data being used immediately and are involved in a full plan-do-check-act cycle

4.2.7 Thales Air Traffic Management (ATM)

The Thales Group, a global electronics company with 65,000 employees in more than 30 countries, generated 11.1 billion euros in revenues in 2002. They have three major business units: Aerospace, Defence, and Information Technology. Air Traffic Management (ATM) is one of three major units in the Aerospace zone [Thales ATM 03a]. "Thales ATM's mission is to support the Air Transportation Community on a worldwide basis by building safe, efficient and inter-connectable Communication Navigation Surveillance/Air Traffic Management (CNS/ATM) systems. Our solutions are based on consistent global development processes, programme management and systems engineering, combined with a predictable quality baseline.... Quality is at the heart of what we do. We are dedicated to continual improvement of our own processes...." [Thales ATM 03b].

Thales ATM has progressed from SW-CMM maturity level 3 to CMMI maturity level 4. Goeyse et al. describe how their high maturity CMMI practices have supported meeting their business objectives [Goeyse et al. 03]. Measurement practices are supported by training and an organizational metrics dictionary. They have identified decisions requiring Decision Analysis and Resolution techniques within their process diagrams. Risks are tracked, monitored, stored in a database, and actions are taken where necessary. They have brought an increasing number of processes under statistical process control, for example, production and verification of requirements, design, and code processes. They also use measurement results to direct their process improvement efforts. Program, company, and team objectives are established based on process performance and measured by company metrics. Objectives are set by business needs and customer negotiation and addressed through improvement initiatives. Each improvement is piloted and ROI is measured before it is rolled out to the organization. Goeyse et al. highlight earlier defect detection, improved risk management, and better project control as major benefits of the Thales ATM process improvement effort, although they do not provide specific quantitative results [Goeyse et al. 03].

4.2.8 Thales Training & Simulation (TT&S)

Thales TT&S is part of the aerospace business unit, which is one of three major areas in this international company. With about 2,000 staff in Australia, France, the United Kingdom, and the United States, TT&S develops simulation, systems, and training services for both military and civil applications [Richard 03a], [Richard 03b].

TT&S initiated an effort in 1992 to improve their software processes based on SW-CMM. They achieved maturity level 2 in March of 1995, and level 3 in October 1996. After exploring the use of the SE-CMM to better manage their systems engineering processes, they turned their focus to CMMI V 1.0.

Their goal was to achieve CMMI maturity level 2 for project management, systems engineering, quality, purchasing, and the hardware and software interfaces with systems engineering. To that end, they developed and implemented process and organizational changes, using the Measurement and Analysis PA to link their process changes with their business objectives. Specifically, they identified financial and quality objectives which were cascaded down through the organization to the business units and departments, and they put tools and practices into place to measure achievement of these objectives. New processes were introduced to the organization through training, coaching, management meetings and other tools and methods of deployment. They conducted over twelve internal assessments in eight areas, beginning in March 2000. They achieved CMMI maturity level 2 in one of the earliest SCAMPI appraisals in September 2001.

Thales TT&S reports a number of lessons learned [Richard 03a], [Richard 03b]. First, they found that conducting internal "CBA IPI like" assessments on a quarterly basis has provided progress measures which allow them to react quickly if adverse trends are identified. This practice was initiated as a way to avoid regression after successful implementation of CMM-based changes. It also helps them with deployment of new processes and to gather data to evaluate achievement of their objectives. They view the experience gained during their implementation of the SE-CMM and SW-CMM as a key factor in their success with the CMMI Product Suite.

Richard presents data on funds invested in the organization's SEPG to provide training, conduct internal appraisals, document their processes using an intranet application, and support their SCAMPI appraisal. He states that analysis of data collected on software has shown that project cost and schedule variances decreased as TT&S process maturity increased [Richard 03a], [Richard 03b].

4.3 Organizations Reporting Benefits from SW-CMM

The following vignettes show recent evidence of impact and benefits attributed to process improvement based on the Software CMM. We include them here since the SW-CMM is one of the source models for CMMI. Moreover, all of these organizations are moving to CMMI models.

4.3.1 Bosch Gasoline Systems

The Bosch Group is comprised of three business sectors: Automotive Technology, Industrial Technology and Consumer Goods, and Building Technology. The Automotive Technology Sector, which includes Bosch Gasoline Systems, generates two-thirds of the group's sales, which reached 23.3 billion euros in 2002.

The Gasoline Systems Division has 19,022 employees, 1000 of whom work on engine control units, software development, and calibration. They recognized that software had become an increasingly critical part of their product and processes, and that it was requiring a growing percentage of their development time and costs [Bosch 03].

Process improvements had been attempted prior to 2001, but with little success [Stolz et al. 03]. The Bosch Gasoline Systems management board then included process improvement and adoption of the SW-CMM reference model in their business goals. The current software process improvement initiative started in April 2001. The organization is a large, matrixed structure. Stolz et al. describe their senior management steering group, involvement of both line managers and experienced staff, and the use of measurement to conduct audits and internal assessments as critical success factors [Stolz et al. 03]. Their measurement "cockpit" report displays graphs for 17 projects and 6 processes: Project Planning, Project Tracking and Oversight, Software Quality Assurance, Requirements Management, Configuration Management, and Subcontract Management. Their results overall show a positive trend.

Stolz et al. summarize qualitatively several benefits of having achieved SW-CMM level 3:

- clearly defined project requirements
- improved predictability of their work packages
- clearly defined interfaces for change requests and requirements management

- improved ability to manage complex systems and projects
- better project and risk management [Stolz et al. 03]

Quantitative improvements include

- a 15 percent improvement in internal on-time delivery
- a 10 percent improvement in first-pass yield leading to reduction in rework
- a substantial (order of magnitude) reduction in error cases over 2 years [Stolz et al. 03]

Next steps include 1) moving to the CMMI Product Suite and applying it to software, systems, and hardware development; 2) expanding their process improvement program to include sales, hardware, and component development; and 3) tracking their progress against CMMI maturity levels.

4.3.2 JP Morgan Chase & Company, Investment Bank Technology

Investment Bank Technology, a unit of JP Morgan Chase and Company, is a global IT organization supporting a global financial services firm. They provide technology and applications development support for business lines in nine countries. Quality systems and software applications are increasingly critical to financial institutions, as is rapid development of new technology. The financial impact of a software defect can be enormous.

The Investment Bank Technology unit in the United Kingdom began to implement process improvement based on the SW-CMM with one pilot project in 2001; they now have 28 teams that have been appraised at SW-CMM maturity level 2. The first team to successfully improve using the CMMI Product Suite achieved a maturity level 3 rating in 2003. They are now using CMMI models along with several other improvement techniques, including Six Sigma, across the organization.

The unit reports several benefits in quality and time from these process improvements, including

- reduction in and reduced severity of post-release defects
- improved predictability of delivery schedule

Notably, their CMMI maturity level 3 team has reported a major increase in through-put resulting in more releases per year. Ongoing analyses are showing a substantial return on investment.[12]

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[12] This information is taken with permission from a proprietary presentation delivered at the SEI.

4.3.3 Sanchez Computer Associates, Inc.

Sanchez Computer Associates, with annual revenues of $93 million in 2002, provides integrated software and services for banking, securities, customer integration, wealth management and outsourcing to nearly 400 financial institutions in 21 countries [Sanchez 03a]. They set their sights on SW-CMM maturity level 3, using what they called the "Big Bang" approach. This consisted of documenting current processes, identifying and filling gaps, then training and rolling out the changes. They were appraised at SW-CMM maturity levels 2 and 3 in just more than 15 months. They report the following benefits:

- a robust training program
- the application of process to activities other than programming, such as documentation
- improved code quality
- a savings of $2 million in the first 6 months, primarily from early detection and removal of defects

Sanchez Computer Associates state in a news release that: "Achieving a CMM Level 3 rating sets us apart from our competitors and identifies us as an organization committed to creating institutionalized processes and procedures, which, in turn, allow us to deliver consistent quality to our customers" [David Consulting 03], [Sanchez 03].

4.3.4 Thales Research & Technology, UK

As part of a general tutorial on process improvement, Marsh and Vigier present an overview of the techniques and methods used at Thales Research & Technology in the United Kingdom for their CMMI based process improvement effort [Marsh & Vigier 03]. In the presentation, they use an earlier SW-CMM example from another Thales unit to demonstrate the value of process improvement. The results show marked improvements in cost performance as the unit progressed from SW-CMM maturity level 1 to maturity level 3. Figure 7 shows a classic reduction in both the average and variability of cost deviation. In addition, the sidebar shows a 60 percent reduction in cost of customer acceptance, due to reductions in defects found at customer acceptance and resultant late acceptance.

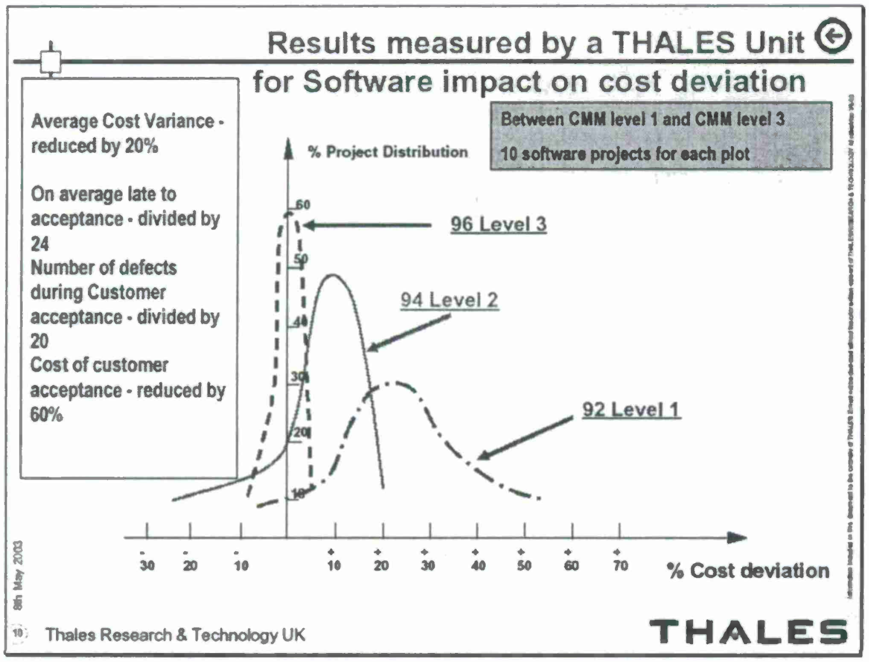

Figure 7: Thales Research & Technology, UK

What is of particular interest here is the fact that SW-CMM results are used to forecast the benefits of process improvement using CMMI models.

5 Current Work and Plans for the Future

In this section, we describe the ongoing effort at the SEI and elsewhere to document the impact and benefits of process improvement based on CMMI models. The section begins with a description of an ongoing series of in-depth case studies. That is followed by a short summary of our literature review. Next is a brief discussion of the limitations of case study results, such as those presented in this report as well as the ongoing series of case studies. While case studies provide a great deal of valuable detail and context, their results cannot necessarily be generalized elsewhere. Finally, we outline our plans to address the limitations of using case studies alone along with our plans for the future.

5.1 In-Depth Case Studies

In addition to this special report, the SEI has initiated a broader research effort to provide credible, objective evidence about the value of CMMI-based process improvement. As a first step, we have entered into collaborative relationships with several early adopters to conduct in-depth case studies of their experiences with process improvement based on CMMI models. Our emphasis is on quantitative results about the impact and value added by CMMI. The quantitative analyses are being augmented by qualitative descriptions of the participating organizations and their process improvement efforts.

Some of the results presented in this report have been normalized to protect proprietary information. The same will be done in future analyses. SEI staff members are reviewing the data and results to better understand them and confirm their accuracy. We at the SEI also are providing assistance with study design and analysis as appropriate. In addition, participating organizations are asked to provide their evidence and contextual information following a standard format to facilitate summarization and quality assurance. For example, they are 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.

As in this report, evidence to be presented will include a variety of performance dimensions. In addition to return on investment and related cost-benefit measures, these include cost, productivity, cycle time, predictability of cost and schedule, and product quality. Where available, additional evidence will be presented about the conditions of successful adoption, transition, and documented improvement; these may include discussion of the pitfalls and obstacles to successful adoption and use.

Results from the first round of these case studies are included in a track on CMMI impact and benefits at the 3rd CMMI Technology Conference and User Group in November 2003. The track also includes five presentations that were submitted to the conference without our prior knowledge. We expect to include them and others in an ongoing series of such studies. The conference track also includes a presentation summarizing the first 15 cases along with supplementary evidence provided by others. In addition, the track includes a roundtable panel of experts who discuss what is necessary to better make the case about the benefits of CMMI-based process improvement. A list of the track participants may be found in the Appendix.

5.2 Literature Review

As part of our ongoing research, we are conducting a review of recent literature. Sources of information reviewed thus far include the Software Engineering Process Group (SEPG), European SEPG, and Software Technology Conference (STC) conference proceedings from 2000 through 2003, and the CMMI Technology Conference and User Group proceedings for 2001 and 2002. We also have conducted several systematic searches through journal references and related publications. We have looked first for recent quantitative results, although we also have flagged publications with compelling qualitative results. Thus far, we have found few published results with quantitative evidence about the impact and benefits of CMMI models. The same is true for recent reports based on the SW-CMM.

5.3 Generalizability

The results presented in Section 4 provide useful early evidence about the benefits of CMMI-based process improvement. But what does it take to enhance the quantity and quality of such evidence? Additional objective evidence also is needed about the conditions of successful adoption and transition to CMMI-based process improvement.

These twelve case studies are confined to selected reports from early adopters of CMMI models. In that sense, their results are existence proofs of what can happen under the right organizational and technical circumstances. Many of them are exemplary organizations that have chosen to share their experiences publicly. Over time we will need to include a more broadly based sample. Our field also needs to pay more attention to issues of measurement, validation, data quality, and analytic methods.

Along with the cases presented in this report, the organizations participating in the other, in-depth case studies described in Section 5.1 are chosen on the basis of their access to existing quantitative evidence and/or their willingness to collaborate proactively on future studies. However, they by no means can be construed as a comprehensive sample of all organizations that have begun to implement process improvement programs based on CMMI models. CMMI V 1.1 was released in January 2002. It still is fairly new and many organizations are just starting to apply it. Only a relative few of them have come forward to share evidence of quantitative results from their initial improvement efforts.

5.4 Next Steps

More credible quantitative information about CMMI impact exists than has been made available publicly thus far. As of June 2003, for example, 100 SCAMPI V1.1 appraisals had been conducted and reported to the SEI. Fully one-fourth of them were appraised at high maturity levels, 4 of them at level 4 and 21 at level 5. Of course, all maturity level 5 and many level 4 organizations ought to have some quantitative evidence about the impact of process improvement. A growing number of less mature organizations also now appear to have such evidence.[13] Our task is to design future studies that better reflect the experiences of the wider CMMI community.

The SEI will continue to work collaboratively with organizations that are willing to provide credible objective results about their experiences using CMMI models. Relatively little quantitative evidence currently exists publicly about the impact and benefits of systems engineering processes.[14] We will pay particular attention in future in-depth case studies to documenting the results of disciplined engineering processes in largely software organizations. We also will address CMMI impact in other disciplines in addition to software and systems engineering.

Case studies can provide much useful detail that helps explain their results in proper context, but there is always a trade-off between breadth and depth. As just mentioned in Section 5.3, results from selected case studies are not necessarily generalizable to a wider population. In addition to our collaborative case studies, we will solicit self-reported cases via the Software Engineering Information Repository (SEIR) [SEI 03]. As part of that effort, and in addition to qualitative lessons learned, we will begin to collect and benchmark standard measures of effort and performance over a larger group of organizations than we can possibly work with

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13 See, for example, the organizations in the Appendix who report on doing Causal Analysis and Resolution related activities at lower levels of organizational maturity. The existence of the Measurement and Analysis process area at maturity level 2 in CMMI models also appears to be encouraging earlier attention to gathering and using such evidence to help inform decision making.

14 Organizations that have used the SW-CMM sometimes have covered systems engineering processes in their improvement efforts; however, quantitative results about the engineering processes *per se* are not widely available.

individually. In a related vein, we will conduct surveys and related studies of CMMI impact and factors that affect its success.

Other emphases for fiscal year 2004 and beyond may include

- CMMI adoption and impact in small and medium enterprises
- research and development on the costs and benefits of CMMI appraisal methods
- guidance on calculating ROI and related cost-benefit information

6 Summary and Conclusion

The results presented in this report provide credible early evidence that CMMI-based process improvement can result in better project performance and higher quality products. The results are drawn from organizations in Europe and Australia as well as the United States. Their process improvement efforts cover both small and large organizational units. They do business in a variety of sectors and domains, and they apply CMMI model practices to systems integration, systems engineering, and software development.

As noted in Section 3, many possible measures of performance can be used to demonstrate the impact of CMMI-based process improvement. We have gathered here results that organizations have shared with us or with the wider community in public forums. As shown in Figure 1, we have categorized the results into four primary classes of benefits: cost, schedule, quality, and customer satisfaction. Evidence about return on investment and related cost-benefit matters constitutes our fifth performance category. The following list summarizes the results from the twelve cases for each of the five classes of performance measures:

- **Cost**: Six cases provide nine examples of cost-related benefits, including reductions in the cost to find and fix a defect, and overall cost savings.
- **Schedule**: Eight cases provide evidence of schedule-related benefits, including decreased time needed to complete tasks and increased predictability in meeting schedules.
- **Quality**: Five cases provide evidence of measurable improvements in quality, mostly related to reduction of defects over time or by product life cycle.
- **Customer Satisfaction**: Three cases show improvements in customer satisfaction, including demonstration of customer satisfaction through award fees.
- **Return on Investment**: Three cases claim a positive return on investment from their CMMI-based process improvement, and two of these provided the actual results of their calculations.

The twelve cases presented here are based on selected reports from early adopters of the CMMI Product Suite. They are exemplary organizations that have chosen to share their experiences publicly; however, they do not constitute a sample of all organizations that are or will be using the CMMI models to guide their process improvement efforts. Their results are evidence of what can happen under the right circumstances; however, additional evidence also is needed about the factors that may help explain failure as well as success.

There is quite a bit of variety among these results; however, as Herbsleb et al. note in their widely read 1994 report, the results also come from a variety of organizations [Herbsleb et al. 94]. The diversity of the organizations is echoed in the diversity of the information they gather and report as evidence that their hard work at process improvement is paying off. We hope that this report will prove to be useful for readers who wish to use the CMMI Product Suite to enhance their own process improvement efforts. Our hope also is that this and subsequent studies will inform the further development and evolution of the CMMI Product Suite.

Appendix 3rd Annual CMMI Technology Conference and User Group: Track on Impact and Benefits of CMMI

Author(s)	Organization(s)	Title
Session 1: Presentations		
David Struble	Raytheon	Automating Support for CMMI Level 5 Organizational Improvement
Donna Freed	Raytheon	CMMI Process Deployment for Software
Doug Brindley, KV Seshadri Iyer	Software Productivity Research MitoKen Solutions	Measurable & Predictable Model Based Improvement
Session 2: Presentations		
Sarah Bengzon	Accenture	Moving On to CMMI (SW/SE/IPPD) Level 4
Gary Natwick	Harris Corporation	Understanding the CMMI Validation PA
Rick Hefner, Dean Caccavo	Northrop Grumman Mission Systems	CMMI Benefits at Northrop Grumman Mission Systems
Session 3: Presentations		
Ralph Williams	Cooliemon, LLC	Establishing and sustaining a Successful Process Group (PG)
Rolf Reitzig	cognence, inc.	Understanding and Improving Software Engineering Economics
Joan Weszka	Lockheed Martin	Transition from SW-CMM to CMMI: The Benefits Continue!
Session 4: Presentations		
Pete McLoone	Lockheed Martin Management & Data Systems	Key Business Indicator Trends During the Journey from SW-CMM Level 2 to CMMI Level 5 at Lockheed Martin Management & Data Systems

Craig Hollenbach	Northrop Grumman IT	Quantitatively Measured Process Improvements at Northrop Grumman IT
Larry McCarthy	Motorola	CMMI Transition Experience and Results at Motorola
Session 5: Presentations		
Ralph Williams	Cooliemon, LLC	CAR at Maturity Level 1
Ruth Buys	CMS Information Services, Inc.	Evidence of CMMI Impact
Dennis Goldenson, Diane Gibson	Software Engineering Institute	Why Should I Switch to CMMI? Initial Evidence about Impact and Value Added
Session 6: Round Robin Panel		
Terry Rout, Joe Jarzombek, Khaled El-Emam, Bob Stoddard, Scott Lucero	Software Quality Institute OASD (NII) IA National Research Council, Canada Motorola OUSD (AT&L / Defense Systems)	Evidence about the Benefits of CMMI: What We Already Know and What We Need to Know

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