Carnegie Mellon
Software Engineering Institute

Benefits of Improvement Efforts

Peter Capell, PhD

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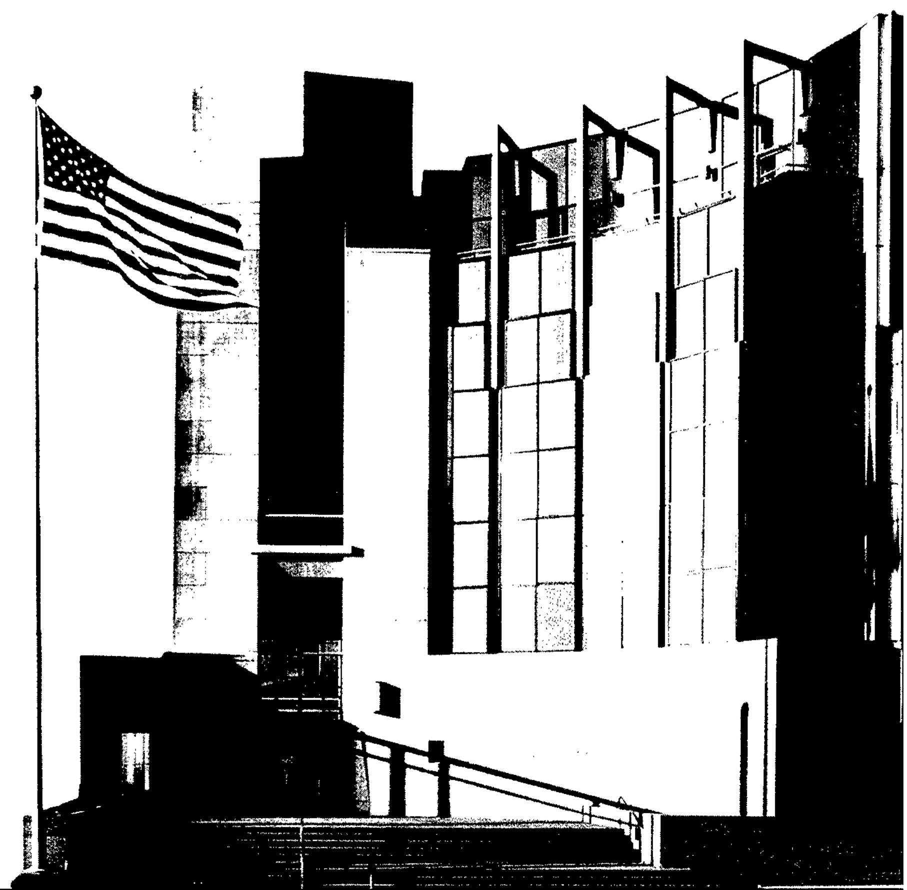

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Acquisition Support Program

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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

Today, organizations that acquire and build defense weapons systems are confronted by numerous challenges. These include evolving missions, advancing technologies, volatile funding, and the need for faster deployment. In addition, the growing use of software-intensive systems (SIS) presents its own set of challenges. Acquirers and contractors must assure that SIS meet reliability, performance, and interoperability requirements under very tight time and budget constraints. Process improvement methods and principles can help acquirers and contractors to manage risks and meet the challenges they face.

To determine the type and extent of the benefits that process improvement methods can deliver, the author reviewed technical and academic literature, examined practitioners' Web sites, and surveyed process improvement efforts that have been applied to large-scale, software-intensive systems. During the course of reviewing the articles, documents, books, and Web sites, several themes became apparent:

1. All improvement efforts are based on the concept and the goal of eliminating errors in process upstream.
2. While improvement efforts are typically driven by cost and measured by return on investment, quality attributes such as security and stability are often of more value to the success of the overall project.
3. Most improvement efforts will yield benefits as long as those efforts follow general rules and use appropriate methods.

This special report documents these themes by describing programs and activities that have implemented process improvement, their results achieved, and in many cases, the process improvement techniques used. Section one describes the rationale for surveying the process improvement efforts of large-scale SIS programs and projects. Section two describes concepts driving process improvement and how they apply to the acquisition community. Section three presents elements of successful improvement efforts. Section four describes the research methodology used for this report. Section five describes selected improvement efforts.

Abstract

This special report surveys the process improvement efforts undertaken by programs and projects that incorporate software-intensive systems. It describes the specific process improvement efforts undertaken and reports on the benefits achieved. In so doing, the report demonstrates the potential of process improvement activities to help contractors and acquirers meet their performance, budget, and delivery time requirements. Additionally, the report identifies several recurring themes:

1. All improvement efforts are based on the concept and the goal of eliminating errors in process upstream.
2. While improvement efforts are typically driven by cost and measured by return on investment, quality attributes such as security and stability are often of more value to the success of the overall project.
3. Most improvement efforts will yield benefits as long as those efforts follow general rules and use appropriate methods.

Finally, the report makes the case for applying process improvement methods and tools throughout the acquisition effort.

1 Introduction

1.1 Purpose

This reports surveys the process improvement efforts of large-scale programs and projects that incorporate software-intensive systems. The report was developed under the Army Strategic Software Improvement Program (ASSIP) to demonstrate (a) the benefits of process improvement activities, (b) the rationale for a coordinated and sustained program of improvement, and (c) the shared characteristics of successful process improvement efforts.

ASSIP is a long-term program dedicated to dramatically improving the acquisition of software-intensive systems. The ASSIP is focused on acquisition programs, people, production, sustainment, and institutionalizing continuous improvement. Stakeholders include program executive offices, program managers, taxpayers, contractors, their suppliers, and the acquisition workforce. The market customer is the soldier, the user of products delivered to conduct a military mission.

This report answers the fundamental question asked by many ASSIP stakeholders: "Why should I invest in process improvement?" The report describes various programs and activities that have implemented process improvement, documents their successes, and, and in many cases, identifies the specific process improvement techniques used. The report also draws several conclusions that can be applied by acquirers.

1.2 Findings

In general, military acquisition focuses on delivering quality weapons systems at the most reasonable cost. This mission is a challenge given constantly changing threat situations, evolving technologies, and changeable funding streams. Currently, there is very little literature on improvement to the processes of acquisition in particular. However, examples from military and defense-contractor sources that are similar to the Army's acquisition efforts suggest that process improvement activities can help acquisition organizations to improve productivity, increase quality, and reduce costs.

The processes related to Army acquisition are not mysterious or intractable in relation to improvement. Within any system, it is certain that efficiencies and improvement opportunities will be identified if an analysis having integrity and precision is used. In every case, the formula for these improvements is fairly simple and involves the following steps:

1. Identify a bottleneck, issue, problem, or opportunity.
2. Describe the context in which this issue, problem, or opportunity exists.
3. Identify a high-leverage point within the existing state.
4. Clearly describe and define the target state of improvement.
5. Develop the roadmap by which the gap between the current state and the desired state is to be closed.

This formula has been proven in hundreds of efforts. A number of these efforts have been documented in the sections that follow.

2 Why Invest in Process Improvement?

The premise of this report is that improving an acquisition organization's workforce business process, practices, and products is worthwhile and should be pursued. Results are realized as cost savings, reduced time-to-market, enhanced quality, and improved predictability in meeting cost and schedule estimates. The following sections develop and support this premise.

2.1 Measuring Return on Investment

Every action must help the organization to achieve its goal. In business, where the goal is profitability, virtually any strategic action is viewed according to its potential return on investment (ROI) computed in terms of cost of the effort relative to the expected benefit. However, businesses find that the notion of ROI goes well beyond expenditures in dollars because so many important qualities have a greater value than dollars and cents. In Army acquisition, where the goal is to deliver quality defense weapons systems at a reasonable cost as fast as possible to the warfighter, having this wider notion of ROI is especially important. Many military systems are first and foremost mission-critical systems. Errors in the management and oversight of the acquisition of the system can result in the failure of the mission and the loss of life and limb. Qualities such as safety, security, and system stability represent "costs" that are woven into the fabric of a system. Yet their worth far exceeds that of money.

One example, the Space and Naval Warfare Systems Center (SSC-SD), was engaged in developing the SmartNet scheduling tool for High Performance Computing Environments. A range of organizations use this tool including the NASA Earth Observation System (EOS), the National Security Agency, the USS Coronado, and Florida State University. SSC-SD efforts to improve its software development processes in order to achieve Capability Maturity Model® (CMM®) Level 3 reduced software change requests 45% over 18 months. More importantly, these efforts led to faster software delivery to users and better overall performance.

Whether the ROI is measured in dollars saved, improvements in productivity, enhanced performance, or other attributes, the ability of process improvement to positively affect change is clear. Applying process improvement techniques to the acquisition community should yield similar results, thereby helping the community to deliver higher quality defense weapons systems to the warfighter as fast as possible and at the most reasonable cost.

2.2 Benefits of Process Improvement

The most significant finding in this study is that genuine improvement efforts will almost always result in dramatic, positive returns on investment affecting the organization, its people, practices, and products.[1]

In the case of the SmartNet effort mentioned in the previous section, the standardized language and Key Process Areas of the CMM enabled disparate groups to work together toward a common improvement goal. The effort resulted in a number of benefits over and above "faster software delivery to users and better overall performance." These additional benefits included the following

- better documentation
- software delivery closer to scheduled date
- higher quality software
- higher customer satisfaction
- improved employee morale
- better communication among the team
- less overtime required to get the job done
- employees better educated
- increased employee pride in their work and increased responsibility and accountability for their work

The ability of process improvement activities to positively affect people, practices, and products has been well documented. Ultimately, however, an acquisition organization exists to serve its customers. Improving how an acquirer provides a product or service is not the same as delivering it to the warfighter, and it is important as a matter of appropriate separation of concerns to recognize that improvement is an aspect of the acquirer's business and not its business itself.

2.3 Reported Benefits by Project

The table below represents highlights of the larger set of selected examples. Clearly, no table can do justice to the stories that support the findings. Therefore, expanded versions of some of these examples have been included in Section 5 and a reference for each of the efforts studied is included in the Sources section.

[1] This statement requires us to ask, "What is *genuine*?" According to Phillip Crosby, W. Edwards Deming, and Joseph Juran, a *genuine* improvement effort is characterized by the following attributes
- active, participating support of most senior levels of management
- clear definition of business objectives that are linked to the improvement effort
- careful isolation of one or, at most, several variables for scrutiny
- careful use of appropriate measures
- application of methods to ensure the integrity of the measured results

Table 1: Summary Table of Improvement Benefits

Organization	Result
Abrams Project Manager (PM)	• Empowered the PM Abrams organization and facilitated M1A2 SEP development • "Leveled the playing" field with the contractor by providing a common language and set of standards • Captured the knowledge and expertise of current PM Abrams personnel for future employees • Paved way for transitioning the PM Abrams to support organizations through documented policies, procedures, and practices
Accenture	Reported 5:1 benefit as a ratio of hours spent on Capability Maturity Model Integration (CMMI) process activities
Air Force Institute of Technology	Cost Performance Index (CPI): The multiple comparison test showed significant differences between CMM Levels 1 and 2 and between CMM Levels 1 and 3. As the organization increased in CMM maturity, its CPI general approaches 1.00 with generally decreasing variation. Schedule Performance Index (SPI): At all CMM rating levels, the SPI remains close to 1.00. However for projects less than 80% complete, the performance of Level 1 organizations was consistently below an SPI of 1.00. As the institute exceeded the 80% completed milestone, it increased its SPI to meet the required 1.00
Boeing Australia	• Decreased cost to correct a defect (measured over 18 months) 33% • Decreased time to deliver releases 50 % • Reduced preparation, conduct, and rework from pre-test and post-test audits 60% (resulting in audits passed with few or no outstanding actions).
General Motors	• Increased the percentage of milestones met from approximately 50% to approximately 95% • Decreased the average of milestones days late from approximately 50 to fewer than 10
Hughes Aircraft	Saved $2 million dollars annually Other improvements include certain quality of life attributes such as: • Fewer overtime hours • Lower employee turnover • Better organizational image
Jet Propulsion Laboratory	Reduced defect identification and correction time from as much as 17 hours to less than 2 hours
JP Morgan - Chase	• Reduced post-release defects • Reduced severity of post-release defects • Improved predictability of scheduled deliveries
Litton Data Systems	Reduced the number of errors found during systems integration 30%

Lockheed Martin MD & S	• Reduced overhead rate 4.5% • Increased software productivity 30%
Motorola Government Electronics Division	Achieved an ROI of 6.77 to 1 for a typical 100,000 Software Lines of Code (SLOC) project. Such a project would span 18 months and require 20 software engineers. In dollar amounts, Motorola saved $611,200 after investing $90,180 in a typical project.
NASA Goddard	• Reduced cost of software development by 55% • Decreased cycle time by 40% • Reduced post-release defect rate by 75%
Northrop Grumman Electronics Systems	Moving from Level 3 to Level 4 resulted in 20% annual gains in productivity for the 5-year reporting period. This represented a 10% gain over their previous annual improvement achievement. The acceleration resulted in a $25 million annual cost avoidance over the 5-year time span.
Northrop Grumman IT	• Achieved 13:1 ROI calculated as defects avoided per hour spent in training and defect prevention • Met milestones 25 times in a row (with high quality and customer satisfaction) • Increased focus on quality over "firefighting" • Earned rating of "exceptional" in every applicable category on its Contractor Performance Evaluation Survey
Oklahoma City Air Logistics Center	• Saved $11.3 million over 8 years • Reduced defects 90% from baseline project to second project • Reduced average cost of a TPS maintenance action 20% over the last two years • Achieved 10X increase in productivity based on source code produced from baseline to most recent project due to technology as well as CMM improvements
Raytheon Northeast Software Engineering Center	• Reduced Cost-Performance Index variability by 36% • Reduced Schedule Performance Index variability by 70% • Reported productivity gains in the following percentages: – 1997-1999: 30% – 2000: 9% – 2001: 11% – 2002: 6%
Sanchez Computer Associates, Inc.	• Saved $2 million in first 6 months due to early detection and removal of defects • Created a robust training program • Applied process improvement activities to functions other than programming
Schlumberger	• Reduced validation cycles 54% • Improved productivity 100% • Increased on-time delivery of software from 51% to 94% • Reduced post-release defects from 25% to 10%
Thales TT&S	Decreased cost and schedule variances as process maturity levels increased

3 Elements of Successful Improvement

3.1 Common Patterns

Regardless of the driving need behind the improvement effort, a basic pattern appears in every review of successful improvements. This basic pattern can be outlined as follows:

1. Establish a suitable pilot environment in which changes can be safely applied.
2. Establish a very clear picture of events and activities as they are conducted today in exacting terms.
3. Following a clear description of what is happening today, create an equally clear picture of how the original needs to change—again, in very specific terms.
4. Develop a strategy to make the new changes (including ancillaries such as training and modifications to resources).
5. Assess the effects of the change (What was the ROI?).
6. Plan the next increment.

3.2 Significant Findings

This investigation resulted in the following findings:

- All the improvement efforts described in this report required investments in tools, methods, infrastructure, and behavior change. Culture change is a constant in any substantial organizational improvement effort.
- Success with process improvement is not a trivial undertaking, nor does it happen overnight. In many cases, it took anywhere from two to five years for the changes and the measurable benefits to be realized.
- Success requires leaders who will provide environments that support innovative change, as well as the commitment and participation of those involved to make change happen.
- Improvements conducted in isolation will not be as meaningful without consideration of the whole organizational environment.

In the course of this investigation, it also became apparent that there are subordinate rules and principles that drive these successful improvement efforts:

- Understand and articulate the overall goal for improvement.

- Gain a clear picture of the "lay of the land"—the context of the improvement scope of effort.
- Take a holistic approach considering both the social and technical aspects of change.
- Develop a precise map of the interlinked processes of the enterprise.
- Develop a clear understanding of those high-leverage processes that will yield the biggest "bang for the buck" when they are improved.
- Identify the right measures with which to assess the effects of changes to existing processes.
- Proceed carefully and persistently—patience is essential to long-term improvement.
- Start small, test a little, think a little, test a little.

Another lesson learned is that once the infrastructure for improvement is created, new improvements are more easily assimilated into the organization.

3.3 Implications

The implications of the learning garnered through this report of improvement benefits indicate that starting small and demonstrating early, measurable successes is important. Programs may wish to tackle known problems with the known strategies of improvement. Or they may wish to follow model-based approaches that have a more sweeping and general character, having in effect predefined benchmarks. In either case, the general pattern of process description, isolation of desired factors for change, and clear target picture remain invariants in successful improvement activities. These factors may be used to inform and shape the ASSIP response to its own improvement efforts.

4 Research Method

To obtain the data reported here, the author surveyed 34 articles and 10 books selected from 200 articles, books, and resources discovered through Web and library searches. The research covered a wide range of organizations, from prime contractors to programs.

4.1 Selection Criteria

Given the time permitted, the author applied best professional judgment in selecting the reports shown in this work. The criteria for selecting reports were as follows:

- acquisition-related improvements
- organizational demographic scale
- use of sound measurement methods
- respected information sources
- plausible claims
- references from improvement experts

No particular order of importance is implied by these criteria; each was considered important in its own right. The author sought literature reflecting improvement approaches across many different kinds of large and small commercial, military, and industrial domains and found a rich set of cases where many kinds of improvement strategies were applied in differing circumstances.

In terms of the selections made for this report, no particular approach to improvement was favored. The improvement efforts examined in this review were of many types; from homegrown, self-designed efforts to more standard Business Process Re-engineering, Total Quality Management (TQM), and variants. Some studies were of single organizations, and some were comprehensive studies of multiple improvement efforts. Software Engineering Institute process literature was not favored, nor was it excluded. Sources are provided in the Sources section at the end of this report.

The criteria used to select the documents for this study were not formal. Instead, they represent an informal method used to capture as many studies as would be meaningful and relevant in as short a time as was possible. The table below provides a thumbnail sketch as to how the articles were categorized. These criteria are applied here only to articles acquired by online library searches and not PowerPoint presentations or books.

Table 2: Categorization of Articles in this Report

Acquisition-Related Improvement	Organizational Demographic Scale	Use of Systematic Methods	Refereed Source	Cross Referenced
5	22	26	27	10

4.2 Attribute Definitions

Acquisition-Related Improvement – Articles in this category were those whose authors served in acquisition program offices. Their stories of improvements came from their experiences within the acquisition environment.

Organizational Demographic Scale – This category was intended strictly as a "Kentucky windage"[2] assessment of the scope of the improvement efforts described. The question asked by the authors was, "Is this organization similar in scope and scale to the Army?" The corresponding question might be, "Is the improvement experience described in the report simply too small to provide any lessons with evidence of scalability to larger organizations?"

Use of Systematic Methods – Systematic methods would include case studies, analytical methods other than strictly co-relational measurement methods, and more strict quantitative studies. Articles eliminated from this category are opinion pieces and those dealing with conjecture about the achievements that might be possible. Instead, this category was simply a means of keeping a focus upon those studies whose authors made a clear effort to perform their reporting with order and integrity.

Refereed Source – Refereed sources are those whose publication is contingent upon expert review. Professional societies and university publications are the most often refereed. Trade magazines are most often not. Articles in this category were subject to expert professional review.

Cross Referenced – This category was used to identify those articles that were identified in at least several other publications related to improvement. While the finding of all of these articles indicates that in a broad sense they were all cross-referenced within electronic sources of some kind, this category was an attempt to isolate those particular articles that would most often be described as seminal.

[2] "Kentucky windage" is an adjustment made in aiming a projectile to compensate for the effects of wind or target movement. It has the connotation of being an adjustment that is based on subjective criteria (personal experience, judgment, and preference) rather than on objective criteria (e.g., gauges, sights, or other instrumentation). The term may derive from the Kentucky Long Rifles, which had a greater range than previously available firearms and thus required exaggerated adjustments for the effects of wind.

4.3 Analysis of Reports

Assessing the benefits of an improvement program is not easy. The sampled set of studies shown here has been carefully selected in some measure on trust in the integrity of those organizations' competence to conduct these studies and to present their data accurately.

In the art and science of measurement, assessing outcomes is always difficult, especially in a highly complex context where human beings play a large role. The human laboratory is much more difficult to understand and assess than an academic one. Ideally, measuring the return on investment for an improvement effort within an organization will follow certain constraints and controls. Variables would be selected and the context would be described in terms of conflicting factors, extraneous elements, independent and dependent variables, and so on. In real environments, the formalisms of laboratory measurement practices can be compromised – sometimes beyond repair.

Many of these approaches are summarized in the following section. Each summary describes the organization, the process improvement effort, and the results.

5 Selected Improvement Efforts

The following section is a review of literature on selected efforts to improve existing manufacturing, commercial, and service-based enterprises. These systems span a variety of engineering and manufacturing environments, and include the following organizations:

- PM Abrams
- Raytheon
- US Air Force F-16 Logistics Operations Division
- National Aeronautics and Space Administration (NASA), Goddard Space Flight Center DoD
- Data Analysis Center for Software (DACS)
- Software Engineering Institute
- Space and Naval Warfare Systems Center (SSC-SD)
- Air Force Institute of Technology
- Motorola Government Electronics Division (GED)
- Northrop Grumman Electronics Systems (ES)

These examples are provided as a means of allowing readers to look into a selected sampling taken from the wider selection of documents pertaining to organizational improvement. As stated earlier, none of the examples exactly matches the specific attributes of a military acquisition environment. Most of the examples, however, come from environments that are as complex as military acquisition enterprises and are of a similar scale in terms of numbers of employees and scope of operations. In addition, these examples contain lessons that are relevant to the acquisition community.

Each of the following examples contains a description of the highlights of the program, how it was improved, and a specific lesson learned from the experience. In addition, each example is accompanied by a table that provides the salient highlights of the study in these categories:

- Organizational Study Sponsor – the organization that sponsored the improvement effort
- Scope of Effort – the size of the organization involved in the improvement effort
- Improvement Focus and Objectives – the targets for the improvement effort
- Method – the methods used to conduct the improvement effort
- Sample of Reported Benefits – benefits reported in the study, cited verbatim
- Cases and Quotations – quotations and excerpts from cases
- Sample Sites Described – information about sub-sites from an organization that may have been selected to implement improvement programs; divisional information

- Sample of Programs Supported – connections to specific military programs that were supported by a defense contract organization
- Period of Study – dates in which the improvement effort took place
- Publication Date – the publication date of the study
- Source Article – article source information

5.1 PM Abrams

The Abrams M1A2 Main Battle Tank is the workhorse of the U.S. Army and the most advanced ground combat platform in the world. The Abrams M1A2 Systems Enhancement Package (SEP) was designed to enhance the platform's mobility, performance and capability. This advanced digital technology called for over four million lines of code and eight major digital computer systems communicating over an advanced MIL-STD 1553 bus.[3]

The prime contractor, General Dynamics Land Systems Division, had achieved a Software Acquisition - CMM (SA-CMM) Level 3 rating, while the PM Abrams group was Level 1. This difference posed a risk to the acquisition with respect to anticipated communications gaps between acquirer and deliverer. In addition, an internal report indicated a 50% turnover in personnel by 2007, representing the devastating loss of valuable knowledge and experience. To "level the playing field" between acquirer and deliverer and to capture valuable knowledge and experience, PM Abrams set and achieved its goal of an SA-CMM Level 2 rating.

The Lesson: SA-CMM empowered the PM Abrams team. It facilitated common language between acquirer and deliverer. The SA-CMM assessment experience captured valuable knowledge and experience for future PM Abrams personnel and paved the way for transition to support by providing clear documentation and repeatable processes. The SA-CMM experience also set the stage for a program of continuous process improvement with the PM Abrams organization.

Table 3: U.S.Army PM Abrams

Organizational Study Sponsor	U.S. Army PM Abrams
Scope of Effort	Achieve Software Acquisition-Capability Maturity Model Level 2 (Version 1.02) for its System Enhancement Package (SEP) project

[3] Department of Defense Military Standard 1553, Interface Standard for Digital Time Division Command/Response Multiplex Data Bus

Improvement Focus and Objectives	• Prepare the organization to implement the SEP. • Enable the organization to be on the same level "playing field" as the prime contractor. • Document knowledge and expertise of current project personnel for future PM Abrams personnel. • Document knowledge and expertise of current project personnel to help support organizations take responsibility for the effort.
Method	Established a Software Acquisition Process Team (SAPT) to implement Software Acquisition-Capability Maturity Model Level 2 (Version 1.02)
Sample of Reported Benefits	Achieving SA-CMM • empowered the PM Abrams organization and facilitated M1A2 SEP development • "leveled the playing field" with the contractor by providing a common language and set of standards • captured the knowledge and expertise of current PM Abrams personnel for future employees • paved the way for transitioning the PM Abrams SEP to support organizations through documented policies, procedures, and practices
Cases and Quotations	"Without the strong commitment from top management, we probably would not have been able to attain our goals in process improvement," said authors Col. Donald P. Kotchman (U.S. Army, David W. Schepke (PM Abrams Tank Systems), Leonard M. Konwinski (PM Abrams), Edward Andres (PM Abrams Tank Systems), Mike Olsem (Science Applications International Corporation), Randy Schneider (Camber Corporation).
Sample Sites Described	This effort involved the personnel of PM Abrams Tank Systems, along with prime contractor and systems integrator General Dynamics Land Systems Division, and its subcontractors.
Sample of Programs Supported	The Abrams M1A2 Main Battle Tank is the workhorse of the U.S. Army and the most advanced ground combat platform in the world. The Project Manager (PM) Abrams M1A2 Systems Enhancement Package (SEP) is a Pre-Planned Product Improvement (3PI) effort.
Period of Study	18 months, March 2000 – November 2001
Publication Date	2002
Source Article	"Achieving SA-CMM Level 2 at PM Abrams," *CrossTalk*, August 2002

5.2 Raytheon

Raytheon's corporate software improvement effort involved several organizations (Network Centric Systems, Electronic Systems, Space and Airborne Systems, and Missile Systems), and continues to do so today. The effort began in 1987 with the adoption of CMM and has evolved with the adoption of CMMI, Six Sigma, and Integrated Product Development (IPD). The amount of productivity gain reported differed according to the organization and the measures it used. However, gains have continued over the life of the improvement effort.

The Lesson: Process Improvement represents more than a series of activities associated with a particular methodology. It represents an approach to business. Ideally, it should be woven into the corporate culture. Raytheon in particular has made the commitment that CMMI will be applied with an "enterprise view," usable everywhere in the broadest sense. A recent example of the application of this philosophy is Raytheon's Learning Institute, where CMMI will be applied in an organization whose mission is training and performance enhancement.

Table 4: Raytheon

Organizational Study Sponsor	Raytheon: Headquarters – Lexington, MA; $17 billion defense/aerospace; 76,000 employees worldwide
Scope of Effort	Corporate-wide: Multi-site improvement
Improvement Focus and Objectives	Defect prevention, Cost-schedule variance, Productivity
Method	Multi-year roll-out of Software Capability Maturity Model (CMM) improvement program followed by application of CMMI to advanced business units. Application of Six Sigma and Integrated Product Development.
Sample of Reported Benefits	• Northeast Software Engineering Center: Reduced Cost-Performance Index variability by 36 percent. Reduced Schedule Performance Index variability by 70 percent. • Raytheon NCS reports productivity gains in the following percentages: 1999, 30%; 2000, 9%; 2001, 11%; 2002, 6%
Cases and Quotations	"Fixing defects early in the process is much cheaper than later in the life cycle, and contributes significantly to increased productivity and far less rework." – Hope Miller, NCS California Engineering Director "The Tucson Missile Systems Software Center improved its organizational productivity by a factor of 2.5x as it advanced its software maturity." – Dan Nash, Corporate Engineering, Director of Software
Sample Sites Described	• Raytheon Network Centric Systems – 11,000 employees; provides mission integration for communication and information dominance, real-time shared knowledge, and sensor systems. Integrate systems for all branches of the United States military, the National Guard, the Department of Homeland Security, the Federal Aviation Administration, other U.S. national security agencies, and international customers. • Raytheon Electronics Systems – 50,000 employees; business areas include reconnaissance and surveillance systems; specialized aircraft modification;

	command, control, and communications; electronic imaging; and other information-based technologies. • Space and Airborne Systems – 10,000 employees; develops critical space and airborne missions programs, e.g., STSS, Global Hawk Sensors, ATFLIR Targeting, APG-79 AESA Radar, U2 Sensors • Missile Systems – $3 billion business; design, develop and produce missile systems, e.g., air-to air, strike, surface Navy air defense, land combat, guided projectiles, directed energy weapons; products include AMRAAM, Javelin, Excalibur, TOW, Stinger, Tomahawk
Sample of Programs Supported	DD(X), National Polar-Orbiting Environmental Satellite System (NPOESS)
Period of Study	Longitudinal report spanning 1987 to present
Publication Date	2004
Source Article	"System of Systems: Raytheon integrates systems & software processes to reduce defects, improve predictability," Software Productivity Consortium, *Consortium Quarterly*, Special Edition, April 2003

5.3 U.S. Air Force F-16 Logistics Operations Division

The USAF Joint Aeronautical Commanders Group Aviation Logistics Board – Air Force Materiel Command conducted a five-year effort (1997-2002) to reduce sustainment costs. Under the effort, personnel developed a new method of defect analysis and removal named "drill-down analysis." Drill-down analysis emphasizes tracking the causes of errors by identifying the lowest-level high-failure component. This study describes the results of using this method in support of F-16 aircraft sustainment. Savings included $43 million in documented cost containment for 2002, with a projected $900 million savings over the life of the F-16 Program.

The Lesson: Traditionally, improvements in reliability or performance were considered as an expense, and were mutually exclusive with reducing cost. However, the Falcon Flex techniques consistently reduced cost, increased reliability, and in one case, improved performance. In other words, the old ways of thinking are not necessarily valid, and improving one area can affect another area in positive ways.

Table 5: U.S. Air Force F-16 Logistics Operations Division

Organizational Study Sponsor	U.S. Air Force F-16 Logistics Operations Division
Scope of Effort	United States Air Force: Joint Aeronautical Commanders Group Aviation Logistics Board – Air Force Materiel Command
Improvement	Reduced sustainment costs

Focus and Objectives	
Method	Drill-down analysis: Identification of lowest-level high-failure component, followed by cost analysis as to its repair.
Sample of Reported Benefits	• $43 M in documented sustainment cost savings (2002) • $900 M projected savings for the life of F-16 program
Cases and Quotations	"...[I]mprovements in reliability or performance were considered mutually exclusive with reducing cost. 'How much reliability can you afford?' was the common question. However, employment of the Falcon Flex techniques consistently yields reduced cost, increased reliability, and often, as a by-product, improved performance." **Sample case: PSP Memory Card** "The greatest single initiative savings realized thus far has been as the result of a PBA replacement of the F-16 AN/APG-68 Radar System Programmable Signal Processor (PSP) memory card. Falcon Flex drill-down analysis of the PSP revealed that one of 27 different types of electronic cards in the PSP, the memory card, was responsible for approximately one fourth of the annual PSP maintenance cost of nearly $30,000,000. Further, the analysis revealed that the memory card failure pattern was distributed; that is, there was not one or a number of components failing that could provide opportunity for a reduction in card failure frequency by replacing selected components with more robust components, or through card modification. Therefore, a PBA at the card level, to acquire a much more reliable member card, was deemed the most cost-effective solution to reducing the PSP maintenance cost. "Installation of the new memory card commenced in October 1999, and approximately 80% of the United States Air Force F-16 PSPs had been retrofitted by the end of FY02. The number of PSPs requiring repair has decreased annually as an increasing number of the new memory cards have been installed, directly resulting in reduced PSP maintenance cost. Realized savings during the past three years actually exceeded projected savings. Analysis revealed that this was due to a reduction in the frequency of PSP power supply failure, another high-failure PSP assembly. Because the new memory card draws less power than the old memory card it replaced, it appears that less stress is being placed on the power supply, reducing its failure rate. Also, because the new memory card does not use one of the power supply voltage outputs used by the old memory card, the power supply can actually suffer a partial failure and the PSP function will be unaffected. "The net result of the PSP memory card initiative has been that since initiation of installation of the new card, the reduction in the quantity of PSPs requiring repair has saved over $22 in maintenance cost. The cost to retrofit the entire fleet with the new memory card was approximately $5.5; therefore, four times return on the investment has already been realized. Incidentally, in addition to being approximately 100 times more reliable than the old memory card, the new card has twice the memory as the old card, which enables improved PSP performance as an added benefit.

Sample Sites Described	Hill Air Force Base, Ogden Air Logistics Center, Ogden, Utah
Sample of Programs Supported	Falcon Flex (flexible sustainment initiative)
Period of Study	1997 - 2002
Publication Date	2003
Source Article	"Falcon Flex – A Proven F-16 Business Practice," IEEE Systems Readiness Technology Conference, Proceedings 2003 0-7803-7837-7/03

5.4 Goddard Space Flight Center (NASA)

The Software Engineering Laboratory (SEL) applied improvement methods to 120 experiments in process for the Flight Dynamics Division (FDD). The effort covered a 17-year time period (1976-1993). The goal was to document measurable aspects of software engineering practice. However, the effort also had more specific goals, including reducing the average cycle time to produce mission-support software, reduce the defect rate of delivered software, and decrease the cost of software required to support similar missions. SEL personnel developed and applied methods to improve processes. Over the course of the program, the effort achieved an ROI of 7.1 percent to improvement categories for model development (process models), standards development, results analysis, staff training, requirements definition, and definition of experiments. The $25M cost represented 10 percent of the $250M budget spent on software development and maintenance.

The Lesson: In the words of the study's author, "A successful process improvement program does not require a large perturbation or cost to the development organization." Further, the attributes that were improved in this case, such as "staff training," "reduced cycle time," "requirements definition," and "defect prevention" are applicable to any kind of enterprise.

Table 6: NASA Goddard Space Flight Center

Organizational Study Sponsor	National Aeronautics and Space Administration (NASA), Goddard Space Flight Center
Scope of Effort	Software Engineering Laboratory, history of 120 experiments in process for the Flight Dynamics Division (FDD)
Improvement Focus and Objectives	Any measurable aspects of software engineering practice Decrease in defect rate of delivered software Decrease in the costs of software to support similar missions Decrease in the average cycle time to produce mission-support software Measures applied: defects, cost, cycle time

Method	• Created longitudinal baseline of NASA software-intensive engineering projects • Identified software engineering measurement constants • Analyzed the measures relative to process changes • Calculated effort by phase (e.g., system test, requirements analysis) – total hours reported each week attributed to phase currently in execution • Calculated effort by activity (e.g., design, code) -- weekly activity broken down by programmer activity during a specific project week • Created classifications of error types (e.g., computational, logic/control, etc.) • Calculated distributions of effort across activities and phase (e.g., Design = 26% on calendar date X and 23% overall) • Documented code size according to capability (e.g., Orbit/tracking data processing = 250,000 SLOC + percent reused + development duration + effort per calculated in staff years)
Sample of Reported Benefits	Return on investment relative to improvement activities at the NASA Software Engineering Laboratory reported by general categories: • Project Overhead = Forms data, Training (expense = $3M) 1.4% ROI • Data Processing = Archiving results, Maintaining Database, Interviews (expense = $6M) 2.9% ROI • Model Development (process models), Standards Development, Results Analysis, Staff training, Requirements definition, Definition of experiments (expense = $15M) 7.1% ROI
Cases and Quotations	"The total investment that the SEL has made in the improvement effort has been approximately 10 percent of the total software development cost in the FDD. Project overhead represents costs incurred due to developers attending training (in new processes), completing data collection forms, participating in interviews, and providing detailed additional information requested by the analysts. This overhead for data collection and process change is extremely small. It is now nearly impossible to measure except in the cases of very large process changes, such as using a new language (longer training, meetings, etc.). For projects participating in the routine process improvement efforts, the impact is less than 1 percent of the total software cost. A successful process improvement program does not require a large perturbation or cost to the development organization." "SEL activities have cost approximately $25 million in an organization that has spent approximately $250 million on software development and maintenance. There is no empirical evidence to indicate whether this 1:10 ratio would persist when process improvement is expanded to a larger organization. Very preliminary data from SEL experience in carrying out a broader NASA-wide program indicate that project overhead would remain low, and that the data repository could function with 15 persons to support development organizations that are orders of magnitude larger than the FDD."
Sample Sites Described	Software Engineering Laboratory – 300 employees

Sample of Programs Supported	Flight Dynamics Division – System sizes range from 10k – 1.5M SLOC
Period of Study	1976 - 1993
Publication Date	1994
Source Article	"Software Process Improvement in the NASA Software Engineering Laboratory," SEI Technical Report, December 1994, CMU/SEI-94-TR-22, ESC-TR-94-022

5.5 DoD Data Analysis Center for Software (DACS)

The DoD Data Analysis Center (DACS) conducted an extensive literature review of improvement efforts from 1976 to 1994. As part of this review, DACS personnel examined the work of Boeing Space Transportation Systems, Hewlett-Packard, Schlumberger, and other organizations. The study looked for measured defect identification and removal, reduced rework, increased productivity, decreased cycle time, and other factors. Significantly, many of the organizations reported improvements in several areas. For example, Schlumberger reported 54% fewer validation cycles, a 51% increase in on-time delivery, and a25% reduction in post-release defects.

The Lesson: Software and system improvement activities do not exist in isolation. Rather, the results of these activities typically have a domino effect, improving performance and reducing costs throughout the entire development cycle. Again, the dimensions of improvement in these studies; defect prevention, increased productivity, decreased cycle time, and reduced rework—are pertinent to any enterprise.

Table 7: DoD Data Analysis Center for Software

Organizational Study Sponsor	DoD Data Analysis Center for Software (DACS)
Scope of Effort	Department of Defense
Improvement Focus and Objectives	• Defect identification and removal • Reduced rework • Increased productivity • Decreased cycle time • Increased software reuse • Requirements management
Method	General literature review of known studies on the efficacy of improvement efforts
Sample of Reported Benefits	• 54% Fewer validation cycles (Schlumberger) • 100% Productivity Increase (Schlumberger) • 51% Increase in on-time delivery (Schlumberger) • 25% Post-release defects (Schlumberger) • Most defects eliminated before testing (BOEING STS)

	• 31% Reduced rework 7.75:1 ROI (BOEING STS) • 55% Reduced software development costs (NASA SEL) • 40% Decreased cycle time (NASA SEL) • 75% Reduction in post-release defect rate (NASA SEL) • 51% Reduction in defects (per KSLOC) (Hewlett-Packard) • 57% Increase in productivity (Hewlett-Packard)
Cases and Quotations	"O'Connor (1994) described Rockwell International's reuse experience with command and control systems. They used the Synthesis Methodology, as developed by the Software Productivity Consortium (SPC). Reuse is integral to this methodology which forms the foundation of a product family and associated production processes. It defines a systematic approach to identifying the commonalities and variabilities necessary to characterize a standardized product line as a domain. A domain is a product family and process for producing instances of that family. Commonalities reflect work that can be accomplished once and reused to create any product. Variability specifies compile time parameters to customize the application. O'Connor stated that the cost of creating a reuse domain is approximately equivalent to the cost of making a hand-crafted system in that domain of the same size. Although no specific savings were noted, the author did state that the benefits of this reuse methodology were improved productivity, improved product quality, improved responsiveness to customer needs, lower bids on projects, and institutionalization of shared knowledge and expertise among systems in a business area." "In a seven-year period the NASA Software Engineering Laboratory (Basili, 1994 and McGarry 1993) has increased the average level of reuse by 300% from ~20% to nearly 79%. At the same time the error rate has decreased by 75% from 4.5 to 1 error/KSLOC, and the cost of software per mission has decreased by 55% from ~490 staff months to ~210 staff months." "Yamamura and Wigle (1997) state that Boeing's improvement efforts resulted in excellent performance, high customer satisfaction, satisfied employees, and a 97% to 100% award fee for 6 years. The authors state that employee satisfaction grew from 74% to 96% because of the improvements. They state that employees take pride in their accomplishments as they dramatically reduce defects." "Brodman and Johnson (1995) discuss 'spillover' benefits from process improvement, including improved morale and confidence of developers, less overtime, less employee turnover, and improved competitive advantage. The authors describe how increased productivity can mean a more competitive edge in bidding on contracts, and can increase the company's capacity to do work and thus perform more work within a given period of time. Meeting schedule and cost projections can translate to customer satisfaction, repeat business, and decreased time to market and improved product quality translates to more dollars on the bottom line."
Sample Sites Described	• NASA • Boeing Space Transportation Systems • Motorola

	• Tinker AFB • Hughes Aircraft • Litton Data Systems • Jet Propulsion Laboratory • Lockheed Martin • Hewlett-Packard • Cardiac Pacemakers Incorporated • Bull HN Information Systems • Shell Research – Seismic Software Support Center • Raytheon • Schlumberger
Sample of Programs Supported	• Air Force Materiel Command • Several NASA programs reported in earlier section • Space Shuttle • Future Combat Systems • Joint Tactical Radio System • C-17 Airlifter • F-15 Tactical Fighter • Evolved Expendable Launch Vehicle • Unmanned Combat Air Vehicle
Period of Study	1976 – present
Publication Date	1994
Source Article	"A Business Case for Software Process Improvement Revised: Measuring Return on Investment from Software Engineering and Management," A DACS State-of-the-Art Report, Air Force Research Laboratory - Information Directorate (AFRL/IF) 525 Brooks Road, Rome, NY 13441-4505, September 1999

5.6 Software Engineering Institute

The SEI evaluated the software improvement activities of 12 medium- to large-scale industrial, commercial, or defense industry organizations, including Accenture, General Motors, Thales Research and Technology, and Sanchez Computer Associates. The meta-study looked at implementations of CMMI or Software Capability Maturity Model (SW-CMM). In addition to the expected benefits of improved productivity, and reduced rework, the organizations also improved their ability to meet milestones and reduce variances in predicted cost and delivery schedules.

The Lesson: The improvement activities helped the organizations better predict cost, schedule, and delivery. In some cases, those improved forecasting capabilities may be worth more to acquirers and contractors than the associated cost savings. Once again, the specific dimensions, having largely to do with reduction of processing time errors apply to any domain of activity.

Table 8: Software Engineering Institute

Organizational Study Sponsor	Software Engineering Institute
Scope of Effort	12 medium- to large-scale industrial, commercial or defense industry organizations examined in regards to improvement efforts
Improvement Focus and Objectives	Implementation of CMMI or Software Capability Maturity Model (SW-CMM)
Method	Meta-study of the application of CMMI/SW-CMM in medium and large organizations
Sample of Reported Benefits	

Organization	Improvement Description	Category
Lockheed Martin M&DS	4.5% decline in overhead rate	Cost
Northrop Grumman IT	Improved and stabilized Cost Performance Index	Cost
Thales Research and Technology	20% reduction in average cost variance	Cost
Thales Research and Technology	60% reduction in cost of customer acceptance	Cost
Thales Training and Simulation	Cost variance decreased as process maturity increased	Cost
Boeing, Australia	Reduced by half the amount of time required to turn around releases	Schedule
Boeing, Australia	60% reduction in work and fewer outstanding actions following pre-test and post-test audits	Schedule
General Motors	Increased the percentage of milestones met from approximately 50% to approximately 95%	Schedule
General Motors	Decrease the average of milestones days late from approximately 50 to fewer than 10	Schedule
JP Morgan Chase	Increased through-put resulting in more releases per year	Schedule
Lockheed Martin M&DS	30% increase in software productivity	Schedule
Northrop Grumman IT	Improved and stabilized Schedule Performance Index	Schedule

Northrop Grumman IT	Met every milestone (25 in a row) on time, with high quality and customer satisfaction	Schedule
Bosch Gasoline Systems	10% improvement in first pass yield leading to reduction in rework	Schedule
Bosch Gasoline Systems	15% improvement in internal on-time delivery	Schedule
JP Morgan Chase	Improved predictability of delivery schedule	Schedule
Thales Training and Simulation	Schedule variances decreased as process maturity increased	Schedule
Northrop Grumman IT	Only 2% of all defects found in the fielded system	Quality
Northrop Grumman IT	Reduction in defects found from 6.6 per KLOC to 2.1 over 5 causal analysis cycles	Quality
Northrop Grumman IT	Increased focus on quality by developers	Quality
Bosch Gasoline Systems	Reduction in error cases in the factory by one order of magnitude	Quality
JP Morgan Chase	Reduction in number and severity of post-release defects	Quality
Sanchez Computer Associates, Inc.	Improved quality of code	Quality
Northrop Grumman IT	Received more than 98% of possible customer award fees	Customer Satisfaction
Northrop Grumman IT	Earned a rating of "Exceptional" in every applicable category on their Contractor Performance Evaluation Survey	Customer Satisfaction
Accenture	5:1 ROI for quality activities	Return on Investment
Northrop Grumman	13:1 ROI calculated as defects avoided per hour spent in training and defect prevention	Return on Investment
Thales TT&S	Processes for earlier defect detection, improved risk management, and better project control implemented after showing positive return on investment during pilot	Return on Investment

Cases and Quotations

"The following list summarizes the results from the 12 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 positive return on investment from their CMMI-based process improvement, and two of these provided the actual results of their calculations."
Sample Sites Described	• Accenture • Boeing Australia Limited • General Motors Corporation • Lockheed Martin Management and Data Systems • Northrop Grumman Information Technology • Thales Air Traffic Management • Thales Simulation and Training • Thales Research and Technology, UK • Bosch Gasoline Systems • JP Morgan Chase and Company, Investment Bank Technology • Sanchez Computer Associates, Inc.
Sample of Programs Supported	(Omnibus assessment of effects without reference to specific programs)
Period of Study	2002
Publication Date	2003
Source Article	"Demonstrating the Impact and Benefits of CMMI®: An Update and Preliminary Results," Goldenson, D.R., Gibson, D.L., Software Engineering Institute, CMU/SEI-2003-SR-009, October, 2003

5.7 Space and Naval Warfare Systems Center

The Space and Naval Warfare Systems Center (SSC-SD) improved their SmartNet scheduling tool for high performance computing environments. A team was assembled; its members were SSC-SD and SAIC personnel, consultants, and academic collaborators from the Naval Post Graduate School, George Mason University, University of Cincinnati, and Purdue. Their mission was to achieve a CMM Maturity Level 3 for the project, produce a high-quality product with high reliability, while maintaining a high level of control in configuration management. Achieving their goal led to a 45% decrease in software change requests in 18 months.

The Lesson: The standardized language and Key Process Areas of the CMM enabled disparate groups to work together toward a common improvement goal. Almost none of the benefits achieved, such as "better communication," "improved quality" are in any way specific to a development environment.

Table 9: Space and Naval Warfare Systems Center

Organizational Study Sponsor	Space and Naval Warfare Systems Center (SSC-SD)
Scope of Effort	Improve SmartNet scheduling tool for high-performance computing Environments.
Improvement Focus and Objectives	Achieve a CMM Maturity Level 3 for the team/project, and produce a high-quality product with high reliability, while maintaining a high level of control in configuration management.
Method	CMM, along with informal peer and design reviews
Sample of Reported Benefits	Software Process Improvement activities associated with the achievement of CMM Level 3 resulted in 45% reduction in the number of software change requests over 18 months, as well as: • Better overall performance of the software • Better documentation • Software delivery closer to scheduled date • Higher quality software • Higher customer satisfaction • Improved employee morale • Better communication among the team • Less overtime required to get the job done • Employees better educated • Increase employee pride in their work and increased responsibility and accountability for their work
Cases and Quotations	SmartNet Project Manager reported, "Better management control." "According to one employee, the same people who were resistant to implementing SPI activities would not want to work on a project that didn't practice SPI now."
Sample Sites Described	Software Process Improvement activities were implemented by Heterogeneous Computing Team responsible for SmartNet. Team consisted of SSC-SC personnel, SAIC personnel, Consultants, Academic collaborators from the Naval Post Graduate School, George Mason University, University of Cincinnati, and Purdue. In total, the team consisted of 12 full-time and seven part-time staff members plus various academic collaborators.
Sample of Programs Supported	SmartNet is being used by the NASA Earth Observation System (EOS), the National Institute of Health, the Joint Task Force Advanced Technology Demonstration project, the National Security Agency, Navy Simulation Systems, the USS Coronado, and Florida State University, among others.

Period of Study	1995 – 1997
Publication Date	December 1997
Source Article	*Costs and Benefits of Software Process Improvement*, Prenger, Karen D., Naval Postgraduate School, Monterey, CA, December 1997

5.8 Software Productivity Research

Software Productivity Research studied four test program set development projects located in the Test Software Branches of the Oklahoma City Air Logistics Center (OC-ALC), Directorate of Aircraft (LA), Software Division (LAS). The study measured the economic benefit of software process improvement for these projects. Using CMM, as well as internally-developed methods, LAS improvement efforts led to a 7 to 1 ROI and a savings of $11M over eight years, a 90% reduction in defect rates compared to the baseline project, and a 26% reduction in average cost of maintenance actions over 24 months.

The Lesson: While CMM was used as the benchmark, it did not drive the improvement effort. CMM was supplemented by internally developed methods. Additionally, the needs of the organization drove the entire improvement effort, rather than allowing CMM requirements to dictate improvement activities. And once again, "defect rates," "maintenance," and "productivity" are enterprise generic values of improvement.

Table 10: Oklahoma City Air Logistics Center

Organizational Study Sponsor	Oklahoma City Air Logistics Center (OC-ALC)
Scope of Effort	Directorate of Aircraft (LA), Software Division (LAS)
Improvement Focus and Objectives	Goal was to determine the economic benefits of software process improvement.
Method	CMM
Sample of Reported Benefits	See below

Category	Result
Return On Investment	7.5:1, An investment of $1.5M saved $11.3M over 8 years
Defect Rates	90% reduction from baseline project to second project
Maintenance Costs	26% reduction in average cost of a TPS maintenance action over the last two years
Productivity	10X increase in source code produced from baseline to most recent project due to technology as well as CMM improvements

Cases and Quotations	"One key to LAS' success is that they have worked hard to implement a process improvement infrastructure that responds to the true needs of the organization. The SEI CMM is used only as a guide. An improvement is only implemented if the organization sees that it will add value to the processes. Additionally, many improvements that could not be directly traced to the CMM were important to the organization and had major impacts on the improvement efforts."
Sample Sites Described	OC-ALC is located at Tinker AFB, OK. The Software Division consists of over 400 personnel in 7 branches. The study focused four test program set development projects located in the Test Software Branches.
Sample of Programs Supported	• C-141 All Weather Landing System, 1986-1989 • B-1B Electrical Multiplexing System, 1986-1988 • C-5B Automatic Flight Control System, 1987-1990 • F-110 Digital Engine Controller, 1992-1994
Period of Study	Four projects studied took place between 1986 and 1995:
Publication Date	1995
Source Article	"The Economic Benefits of Software Process Improvement," Butler, Kelly L., *CrossTalk*, July, 1995

5.9 Air Force Institute of Technology

The Air Force Institute of Technology tracked cost and schedule data for two centers: the Aeronautical Systems Center (ASC) at Wright-Patterson AFB and the Electronic Systems Center at Hanscom AFB. Cost and schedule data covered a 12-month period. Researchers wanted to determine the link between CMM levels and software development success. Their findings documented the fact that mature organizations (those with higher CMM levels) were likely to have on-baseline cost and schedule performance. Conversely, those organizations that were least mature were likely to have difficulty adhering to cost and schedule baselines.

The Lesson: Figures can often be interpreted different ways and, especially in competitive situations, can be suspect. However this study determined that, on a very fundamental level, a correlation does exist between process maturity and software development success.

Table 11: Air Force Institute of Technology

Organizational Study Sponsor	Air Force Institute of Technology
Scope of Effort	Measured software process improvement data that met the following criteria: • Projects tracked software-specific cost and schedule data in the Cost/Schedule Controls Systems Criteria (C/CSC) format • Contractors were rated according to SEI CMM protocols • Relevance of cost and schedule data to the rating could established
Improvement Focus and Objectives	Determine the correlation between software process maturity and software process success, as measured by cost and schedule indicators
Method	Correlational study of CMM as an improvement vehicle associated with cost and schedule variance
Sample of Reported Benefits	• Cost Performance Index. The multiple comparison test showed significant differences between CMM Levels 1 and 2 and between CMM Levels 1 and 3. As the organization increases in CMM maturity, its CPI general approaches 1.00 with generally decreasing variation. • Schedule Performance Index. At all CMM rating levels, the SPI remains close to 1.00. However for projects less than 80% complete, the performance of Level 1 organizations was consistently below an SPI of 1.00. As they exceeded the 80% completed milestone, it increased its SPI to meet the required 1.00
Cases and Quotations	"The aim of our research was determine the nature of a correlation between the CMM rating and software development success… We observed improved cost and schedule performance with increasing process maturity. Specifically, the least mature organizations were likely to have difficulty adhering to cost and schedule baselines. In contrast, the more mature organizations were likely to have on-baseline cost and schedule performance."
Sample Sites Described	• Aeronautical Systems Center (ASC) Wright-Patterson AFB • Electronic Systems Center (ESC) Hanscom AFB
Sample of Programs Supported	Data on 11 DoD contractors who had been rated by CMM protocols on 31 software projects was collected.
Period of Study	1993 – 1994
Publication Date	1995
Source Article	"A Correlational Study of the CMM and Software Development Performance," Lawlis, Dr. Patricia K.; Flowe, Robert M.; Thordahl Capt. James B., *Crosstalk*, September, 1995

5.10 Motorola Government Electronics Division

The Motorola Government Electronics Division (GED) has embedded a number of software improvement methodologies and programs as part of its corporate culture. These include CMM, Six Sigma, the 10X cycle time initiative, and several internally-developed programs. As part of Motorola GED's continuing improvement program, each of 34 projects evaluates key process areas every quarter. Metrics for each project were compared to relevant baseline projects between 1994 and 1997. Motorola personnel calculated an ROI of 6.77 to 1 for a typical 100,000 source lines of code (SLOC) project. Such a project would span 18 months and require 20 software engineers.

The Lesson: Process improvement activities are not mutually exclusive. Depending on how they are used, they can complement each other, leading to greater gains and returns on investment. In this case, several improvement initiatives were employed in concert.

Table 12: Motorola Government Electronics Division

Organizational Study Sponsor	Motorola Government Electronics Division
Scope of Effort	Motorola GED personnel reviewed 34 projects in various stages of completion for cycle time, quality and productivity metrics.
Improvement Focus and Objectives	As part of Motorola GED's continuing improvement program, each of 34 projects evaluates key process areas every quarter. Metrics for each project were compared to relevant baseline projects.
Method	Primarily CMM supported by: • Six Sigma quality focus • 10X cycle-time initiative • Several internally-developed programs
Sample of Reported Benefits	• ROI of 6.77 to 1 for a typical 100,000 source lines of code (SLOC). project. Such a project would span 18 months and require 20 software engineers. In dollar amounts, Motorola saved $611,200 after investing $90,180 in a typical project.
Cases and Quotations	"Each level of CMM maturity achieved cuts defect density by a factor of two. Cycle time and, to a lesser extent, productivity improve with each maturity level except Level 3, when cycle time and productivity decrease. From this we can conclude that achieving Level 3 involves significant new process introduction, which can negatively affect these two metrics until the project absorbs and learns to tailor the processes."
Sample Sites Described	Motorola GED employs 350 engineers in software development.
Sample of Programs Supported	Motorola GED designs and builds a wide variety of government electronic systems
Period of Study	1994 – 1997
Publication Date	1997

Source Article	"How Software Process Improvement Helped Motorola," Diaz, Michael and Sligo, Joseph, *IEEE Software*, Sept./Oct., 1977

5.11 Northrop Grumman Electronics Systems (ES)

Northrop Grumman Electronics Systems (ES) builds air traffic control systems, sensors for the Defense Meteorological Support Program, radar systems for the F16 and F22 fighters, and other advanced components of defense weapons systems. During the 1996 to 2001 timeframe, the company was engaged in obtaining CMM Level 3 recertification and moving up to Level 4 using CMMI and internally-developed methods. Moving from Level 3 to Level 4 resulted in 20% annual gains in productivity year for the 5-year reporting period. This represented a 10% gain over its previous annual improvement achievement. The acceleration resulted in a $25 million annual cost avoidance over the 5-year time span.

The Lesson: Cost avoidance doesn't necessarily show up on the bottom line. However, it still represents a major benefit and a driving force behind any software process improvement activity.

Table 13: Northrop Grumman Electronics Systems

Organizational Study Sponsor	Northrop Grumman Electronics Systems (ES)
Scope of Effort	Accelerate productivity gains Move to the use of product lines, architecture and systematic reuse
Improvement Focus and Objectives	Obtain SEI Capability Maturity Model Level 3 recertification and move up to Level 4
Method	The process group consists of 30-year veterans, senior management, technical personnel, and retired line managers. They formulated a plan to tie process improvement to business goals. They typically spend $2M on software process improvement. They used CMMI plus internally-developed processes.
Sample of Reported Benefits	Moving from Level 3 to Level 4 resulted in 20% annual gains in productivity year for the 5-year reporting period. This represented a 10% gain over its previous annual improvement achievement. The acceleration resulted in a $25M annual cost avoidance over the 5-year time span.
Cases and Quotations	"Based on the tangible benefits accrued, Northrop Grumman ES has become a true believer in process improvement. Either accelerated productivity or a move to product lines alone would have justified our investments. However, the real scorecard happens monthly at our internal financial reviews. Before our process initiative, we used to spend hours explaining why many of our software projects had problems delivering acceptable products on schedule and within budget. Today, life is easier. We run our software organization like a business. Few of our projects are in trouble. Yes, there are still challenges that we must address. But we aren't scolded any longer for being the problem on

	the project. Other organizations are now taking our place in the hot seat."
Sample Sites Described	Northrop Grumman Electronics Systems (ES) employs more than 600 software engineers working on hundreds of embedded software systems.
Sample of Programs Supported	Northrop Grumman Electronics Systems (ES) builds air traffic control systems, sensors for the Defense Meteorological Support Program, radar systems for the F16 and F22 fighters, and other advanced components of defense weapons systems.
Period of Study	1996 – 2001
Publication Date	2001
Source Article	"The Definitive Paper: Quantifying the Benefits of Software Process Improvement, "Reiver, Don; Chatmon, Al and Walters Doug D., *Software Tech News*, Vol. 5, Number 4

6 Summary

During the course of reviewing the articles, documents, books, and Web sites, several themes became apparent.

1. All improvement efforts are based on the concept and the goal of eliminating errors in process upstream.
2. While improvement efforts are typically driven by cost and measured by return on investment, quality attributes such as security and stability are often of more value to the success of the overall project.
3. Most improvement efforts will yield benefits as long as those efforts follow general rules and use appropriate methods.

These three themes form a framework that can be used to evaluate process improvement activities at large.

This review of many varied types of organizations reveals a few fundamental observations about improvement efforts in general. One key observation is that a process is a process is a process. This is not to say that all organizations are the same, however, all organizations employ activities to achieve their goals and objectives. It is the intelligent manipulation of these activities in specific ways that helps organizations to change for the better.

Feedback

Please send comments to Peter Capell (psc@sei.cmu.edu).

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13. ABSTRACT (MAXIMUM 200 WORDS)

This special report surveys the process improvement efforts undertaken by programs and projects that incorporate software-intensive systems. It describes the specific process improvement efforts undertaken and reports on the benefits achieved. In so doing, the report demonstrates the potential of process improvement activities to help contractors and acquirers meet their performance, budget, and delivery time requirements. Additionally, the report identifies several recurring themes:

All improvement efforts are based on the concept and the goal of eliminating errors in process upstream.

While improvement efforts are typically driven by cost and measured by return on investment, quality attributes such as security and stability are often of more value to the success of the overall project.

Most improvement efforts will yield benefits as long as those efforts follow general rules and use appropriate methods.

Finally, the report makes the case for applying process improvement methods and tools throughout the acquisition effort.

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