Using Cost Benefit Analyses to Develop Software Process Improvement (SPI) Strategies

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13. ABSTRACT *(Maximum 200 words)*

The purpose of this State of the Art Report (SOAR) is to organize the costs and benefits of Software Process Improvement (SPI) strategies, methods, approaches, and alternatives into a form and methodology that enables software managers to identify and select the SPI strategies that are most closely aligned with their business, organizational, and technical goals and objectives. This report examines a cross section of popular SPI methods and approaches, prioritizes them by their costs and benefits, classify and group them according to their characteristics, and guide software managers and developers toward a small collection of highly effective SPI strategies.

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Introduction

The purpose of this report is to organize the costs and benefits of Software Process Improvement (SPI) strategies, methods, approaches, and alternatives into a form and methodology that enables software managers to identify and select the SPI strategies that are most closely aligned with their business, organizational, and technical goals and objectives. This report will examine a cross section of popular SPI methods and approaches, prioritize them by their costs and benefits, classify and group them according to their characteristics, and guide software managers and developers toward a small collection of highly effective SPI strategies.

This report will classify SPI methods and approaches into two broad classes, descriptive and prescriptive SPI strategies, or to be referred to as indefinite and vertical SPI strategies throughout this study, respectively. Indefinite SPI strategies are broadly generalized guidelines that attempt to help software managers and developers successfully produce software based products and services, but are so non-specific that they are difficult if not impossible to successfully use without rare expertise. Vertical SPI strategies are very specific approaches to software management and development, leaving nothing to the imagination, which when properly used, help managers and developers successfully produce software based products and services, requiring much less expertise than indefinite SPI strategies.

The costs and benefits of the various SPI strategies examined in this study will be clearly explained and organized in such a way that software managers and developers will be enabled to evaluate and select from multiple vertical SPI strategies with known, repeatable, and measurable properties that are proven to help them best meet their needs. Hence, this study will achieve these objectives by "Using Cost Benefit Analyses to Develop a Pluralistic Methodology for Selecting from Multiple Prescriptive Software Process Improvement (SPI) Strategies."

General Background

This study examines a few extremely impressive examples of successful Software Process Improvement (SPI). SPI is a highly controversial, and much disputed field.

SPI is the discipline of characterizing, defining, measuring, and improving software management and development processes, leading to software business success, and successful software development management. Success is defined in terms of greater design innovation, faster cycle times, lower development costs, and higher product quality, simultaneously.

The case studies, examples, information, and data examined in this study were the result of a notion called using powerful vertical strategies. Powerful vertical SPI strategies are examined in order to lead the way and encourage others, that have not been successful with SPI, or have yet to try SPI, to use high leverage SPI strategies as methods of making quantum leaps forward in bottom line business, organizational, and technical performance.

This study represents a significant departure from traditional indefinite SPI methods, in that it simply advises organizations to use powerful vertical and universal, or multiculturally transcendent, SPI solutions that are guaranteed to work. Traditional SPI methods direct unskilled and inexperienced individuals to embark on long and indefinite journeys to invent homegrown and highly individualized solutions, having little chance of succeeding.

SPI is a highly controversial field because the technology called "software," our mathematical, engineering, and scientific understanding of it, our ability to manage its development successfully, and the state-of-the-practice are yet in their early infancy. It is software's infancy that results in the exact opposite business, organizational and technical outcome of which is desired:

1. Frequent software project failures
2. High software development costs
3. Unpredictable and uncontrollable software management and development
4. Low software quality
5. Lack of design innovation

Unfortunately, the overwhelming majority of software development practitioners believe that software development will always be a craft industry, a product of highly skilled and highly individualized artists and artistry. In addition, the majority also believe that software management and development are unmeasurable, and thus uncontrollable.

This study illuminates, introduces, and examines a systematic series of examples, case studies, and evidence that software management and development are indeed measurable, and thus extremely controllable. This study represents strong evidence that an extremely sound, stable, and scientific understanding of software technology, management, and development, indeed does exist, and has existed for some time, nearly three decades.

This study will also assert the notion that software is nearing classification as a classical engineering discipline, though still practiced and taught as a craft. Engineering is defined as the practical application of science and mathematics. Identifying SPI strategies that exhibit known, repeatable, predictable, and measurable characteristics challenges software's craft status.

While this paper is largely devoted to a quantitative examination of history, that is the past, it will offer a highly unique, tantalizing, and prophetic glimpse into the future of software technology that few have seen. For it is only by examining history that the future can be clearly seen. Ironically, it is often said that the past must be forgotten, in order to create new and innovative computer programs. Maybe that's why software technology is still in its infancy, because we refuse to learn from the past, in fact we forbid it.

Statement of the Problem

This study proposes to identify, evaluate, classify, and prioritize Software Process Improvement (SPI) strategies into a decision analysis model in order to help software managers and developers choose the SPI strategies aligned with multiple simultaneous categories of business, organizational, and technical goals and objectives.

The first subproblem. The first subproblem is to determine if there is an authoritative definition of SPI, which can serve as a basis to form a common understanding and cultural link with the reader, in order to facilitate the comprehension of the concepts presented by this study.

The second subproblem. The second subproblem is to determine if there is an authoritative or identifiable body of SPI strategies recognized by the software management and development community that will aid the acceptance of the principles advocated by this study.

The third subproblem. The third problem is to survey and evaluate the costs and benefits of various SPI strategies in order to determine if SPI is a worthwhile endeavor, and to identify a pattern of common costs and benefits from which to form a framework for comparison.

The fourth subproblem. The fourth subproblem is to determine if there is a method of differentiating and discriminating between SPI strategies in order to serve as a basis for aligning various SPI strategies into common classes, and eventually compare the classes.

The fifth subproblem. The fifth subproblem is to evaluate and prioritize the SPI classes in order to sharply differentiate and discriminate the costs and benefits of the SPI classes, serving as a basis for grouping multiple similar SPI strategies along with their costs and benefits.

The sixth subproblem. The sixth subproblem is to identify the unique goals and objectives of each SPI strategy, independent of effectiveness, so that software managers may be informed of the costs and benefits of the specific goals and objectives they wish to achieve.

Hypotheses

The first hypothesis. The first hypothesis is that there is an emerging definition of what Software Process Improvement (SPI) means, based on both de facto and international industry standards (though it may need to be enhanced for use in this study). It is further hypothesized that abundant literature exists with authoritative surveys of SPI.

The second hypothesis. The second hypothesis is there is a growing awareness that multiple SPI strategies exist with varying degrees of effectiveness (though many cling to a small number of ineffective SPI strategies).

The third hypothesis. The third hypothesis, still questioned by SPI professionals themselves, is that there are SPI strategies that actually exhibit low costs and favorable benefits, several that consistently exhibit even lower costs and higher benefits, and that a standard method of classifying costs and benefits is emerging.

The fourth hypothesis. The fourth hypothesis is that multiple distinctive classes of SPI methods exist and that the costs and benefits are consistent within classes, and are starkly different across classes.

The fifth hypothesis. The fifth hypothesis is that, not only do multiple SPI classes exist with sharply different costs and benefits, but that the SPI classes can be clearly identified, labeled, described, and prioritized.

The sixth hypothesis. The sixth hypothesis is that business, organizational, and technical goals and objectives can be identified and associated with multiple SPI classes along with their costs and benefits. It is further hypothesized that this will enable the formation of a framework from which to select specific goals and objectives, the associated SPI classes and strategies, and quantify the costs and benefits of those decisions and opted SPI strategies.

Delimitations

The first delimitation. The first delimitation is that this study will not invent a new definition of SPI, leading the reader to believe that this paper is using non-authoritative concepts, views, and ideas.

The second delimitation. The second delimitation is that this study will invent no new SPI strategies that have yet to be scientifically proven but will draw upon costs and benefits of existing authoritative quantitative results.

The third delimitation. The third delimitation is that this study will not evaluate emerging software product technologies, such as the Internet, World Wide Web, Java, HTML, object-relational databases, and other high leverage product strategies. Instead this study will examine process or management approaches, techniques, and methods.

The fourth delimitation. The fourth delimitation is that this study will not examine emerging software design management methodologies, such as product line management, compositional software components, and reusable frameworks (such as PeopleSoft, SAP/R3, and the San Francisco Project). These technologies may be more effective than the SPI strategies examined in this study, but their costs and benefits have yet to be quantified.

The fifth delimitation. The fifth delimitation is that this study will not examine the costs and benefits of using highly qualified software managers and developers. That is, those having graduated from top tier schools such as Harvard, Massachusetts Institute of Technology (MIT), and Stanford, a popular topic of contemporary research.

The sixth delimitation. The sixth delimitation is that this study will not examine systems dynamics theory which hypothesizes that a stable work environment is the most important factor in determining software management and development success.

Definitions of Terms

Decision Analysis. Schuyler (1996) defines decision analysis as the discipline that helps decision makers choose wisely under uncertainty, involving concepts borrowed from probability theory, statistics, psychology, finance, and operations research. Decision analysis involves the use of structured tools and techniques for organizing unstructured problems in order to make sound, profitable, and certain decisions in the face of seeming uncertainty.

Descriptive. McKechnie (1983) defines descriptive as an informal outline, explanation, or figurative portrayal lacking formal detail, elaboration, and precision. Descriptive SPI strategies may indicate which processes are important, and even indicate important characteristics of key software management development processes, yet without giving sufficient guidance to novices, describing only the essence or a small portion of the total strategy that's difficult to understand without deep personal experience.

Indefinite. Braham (1996) defines indefinite as having no fixed limit, not clearly defined or determined, or being uncertain and vague. Indefinite SPI strategies provide no criteria for determining when process improvement has been achieved, and tend to emphasize placing too much emphasis on low leverage or low return-on-investment processes and activities.

Methodology. Braham (1996) defines methodology as a set or system of methods, principles, and rules, as in the sciences. A SPI methodology is a comprehensive set of step-by-step instructions for achieving a specific goal or objective.

Model. Turban and Meridith (1994) and Schuyler (1996) define models as abstract representations of reality and simplified representations that consist of variables and mathematical formulas (e.g., a mathematical equation of a line that has been correlated to profit, loss, performance, or other phenomenon).

Multiculturally transcendent. Braham (1996) defines multicultural as the existence or presence of multiple unique cultural identities, each with their own values, beliefs, and norms, and transcendent as going beyond, surpassing, or exceeding the limits. Therefore, multiculturally transcendent means crossing multiple cultures simultaneously, or having a common or overlapping set of values, beliefs, and norms (e.g., universal applicability to a wide variety of nations, industries, and organizations).

Pluralistic. Braham (1996) defines pluralistic as a condition in which multiple minority groups participate fully in a dominant society. In the context of this study, it will mean that there will be multiple minor and

dominant approaches or choices, each with their own merits, from which to choose, depending on context specific goals and objectives.

Prescriptive. McKechnie (1983) defines prescriptive as a formal, strictly defined, accurately stated, and minutely exact set of rules, orders, steps, or procedures that must be followed without variation. In the context of this study, it will mean that prescriptive SPI strategies contain the entire description of the approach to be used and detailed guidance for novices and non-experts, unlike indefinite or descriptive SPI strategies.

Software Development. The IEEE Standard Glossary (1990) defines software development as the transformation of user needs into a software product, involving requirements analysis, software design, computer programming, and testing (e.g., the combination of multiple computer programming language statements into a product that performs a useful function).

Software Management. The IEEE Standard Glossary (1990) defines software management as the process of planning, estimating resources, scheduling, conducting, coordinating, and controlling software development.

Software Process Improvement (SPI). Harrington (1991) defines process improvement as a systematic methodology that significantly helps businesses simplify and streamline operational processes. Harrington states that the objective of process improvement is to ensure that business processes eliminate errors, minimize delays, promote understanding, are easy to use, are customer friendly, are adaptable, enhance competitiveness, and reduce excess capacity.

Software Process Improvement (SPI) strategy. Combining Harrington's (1991) and McKechnie's (1983) definitions of process improvement and strategy, a SPI strategy is one of many optional methodologies, plans, and tactical maneuvers that will increase the likelihood of successfully achieving one or more business objectives. That is, a SPI strategy is prefabricated management or technical approach that will likely result in successful software development.

Software. The IEEE Standard Glossary defines software as computer programming language instructions, data, information, and documentation that comprise or constitute a software product (e.g., shrink wrapped word processor with disks, programs, and user guides).

Strategy. McKechnie (1983) defines strategy as the science of planning and directing large scale operations, specifically by maneuvering resources into the most advantageous position prior to actual deployment, implementation, and engagement in order to ensure that goals and objectives have a high probability of being successfully achieved.

Vertical. In the context of this study, vertical will be defined as specific, non-ambiguous, prescriptive SPI strategy and tactical approach with known, predictable outcomes for achieving business goals and objectives and successfully producing software products and services. Vertical also means SPI strategies that are prefabricated, portable, and self-contained, which can be deployed and withdrawn from organizational use without having to integrate them into the total horizontal set of organizational processes, procedures, and operations.

Significance

The significance of this study is in several areas, objectively analyzing the results, or costs and benefits, of Software Process Improvement (SPI) strategies and phenomenon. This study will not invent any new SPI strategies or analyze exotic and highly unconventional SPI strategies, but objectively analyze SPI strategies that have roots in the last three decades.

This study will analyze common criteria for evaluating and comparing SPI strategies and help solidify and promote a standard way of measuring and evaluating costs and benefits quantitatively. This will orient the reader toward the existence of tangible evidence for classifying SPI strategies and forming important cultural images of SPI and SPI strategies.

This study will provide a broader, though not unconventional, definition of SPI, SPI strategies and tactics, and present the reader with a wider array of choices in choosing SPI strategies. This study will objectively analyze the effectiveness of both mainstream and unknown SPI strategies, and begin to alert the reader to the existence of a wider array of choices when selecting SPI strategies.

This study is targeted at technical experts, practitioners, newcomers, and passers-by to the field of software management, development, and SPI. This study will exhibit an objective analytical framework to technical experts to begin viewing software management and development as a quantitative and scientific discipline. And, this study will rapidly orient practitioners and newcomers toward the issues involved in choosing SPI strategies, building and delivering software products and services, and guide them away from ineffective SPI strategies and toward effective SPI strategies.

Finally, if this analysis reveals no discriminating criteria for selecting SPI strategies, that will be important to technical experts, practitioners, and newcomers; this will be also significant.

Organization

This study is organized into five integrated chapters or sections, which introduce the context and scope of the study which is to analyze and organize Software Process Improvement (SPI) strategies and their associated information:

Introduction. This chapter introduces the purpose of this study, which is to objectively analyze SPI strategies by using their costs and benefits, determining whether groundwork may be laid for constructing a logical and analytical framework as a tool from which software managers and engineers may choose optimal software product development strategies.

Literature Review. This chapter surveys reported SPI strategies and their associated costs and benefits in order to determine whether a pattern of SPI approaches, common criteria for measurement, and quantitative costs and benefits begin emerging for objective identification, analysis, and organization.

Methodology. This chapter begins to design and construct an analytical framework from lower level building blocks into an integrated and organized structure in which to populate with SPI strategies and cost and benefit information, along with other important software management and development criteria which may aid in analysis and selection.

Cost-Benefit Analyses. This chapter will exercise and execute the analytical framework of SPI strategies, cost and benefit information, and other critical criteria, in order to determine if viable discriminating and differentiating factors indeed do exist, from which to provide software managers and developers with critical business decision making data.

Conclusion. This chapter will report the overall conclusions of this study, its analysis, whether it achieved its goals and objectives, whether any useful management decision making data emerged, and if so, what those critical data are.

Literature Review

The chapter will survey reported results from organizations that have invested heavily in Software Process Improvement (SPI), identify the strategies they've employed, and report the costs and benefits of their efforts whenever possible. Much of the literature is from advanced and very mature organizations that are largely devoid of the fundamentals of introductory SPI principles.

Selecting literature from mature organizations is part of the strategy of this study, deliberately chosen to help beginning organizations catch up with those that are far ahead of them. This chapter and this study will attempt to close the gap between introducing basic SPI principles and their practical application in an advanced way without serving primarily as an introductory tutorial on SPI, but a stepping stone into mature principles for novices and beginners, thus an intermediate guide.

This chapter will intentionally avoid qualitative, introductory, philosophical, and elementary SPI literature, and will focus on high leverage quantitative studies and the quantum performance impacts of employing those SPI strategies. It is unfortunate that a larger body of antithetical literature doesn't exist for comparative analysis. It can be supposed that the small percentage of software producing organizations that actually employ SPI, is the antithetical evidence in of itself. However, making that determination is for another study, not this one.

This chapter attempts to conduct and provide a rapid, yet authoritative, survey of the field of mature SPI strategies. Broad structural issues and topics will be addressed such as:

(a) a common definition and understanding of what SPI is,

(b) common strategies for achieving or not achieving SPI,

(c) strategies for SPI measurement,

(d) common costs and benefits of SPI, and

(e) the prioritization of SPI strategies.

Definitions

Organizing the literature defines SPI as a management science discipline (Rico, 1998) that includes procedures, tools, and training for SPI (Austin & Paulish, 1993), process assessment and evaluation (Szymanski and Neff, 1996), and process perfection (Braham, 1996). SPI also includes having a value-added focus (Szymanski and Neff, 1996), minimizing and eliminating the resources associated with all processes, value-added and non-value added (Garrison and Noreen, 1997a), and increasing customer satisfaction (Harrington, 1991). SPI is popularly known as changing processes very slowly and deliberately over a long period of time (Davenport, 1993). As shown in Table 1, SPI definitions vary widely and are not standardized.

Braham (1996) defines improvement as bringing something into a more desirable or excellent condition, making something better, or increasing something in quality or value. Braham's definition of improvement implies that something is made better than it currently is. Braham makes no judgement as to the current state or quality of what is being perfected, but that improvement means making the current state or quality even better than it currently is.

Harrington (1991) defines process improvement as a systematic methodology that significantly helps businesses simplify and streamline operational processes. Harrington goes on to state that the objective of process improvement is to ensure that business processes eliminate errors, minimize delays, promote understanding, are easy to use, are customer friendly, are adaptable, enhance competitiveness, and reduce excess capacity. So, Harrington is saying that process improvement is the act of eliminating defects, speeding productivity and delivery, enhancing product desirability, satisfying customers, and minimizing the use of organizational resources.

Rico (1998) defines SPI as a discipline of defining, measuring, and changing software management and development processes and operations for the better. Rico defines SPI as a science involving three distinct elements. The first element is capturing, modeling, and characterizing key software management and development processes in a tangible form such as graphical diagrams, step-by-step procedures, or formal notations, languages, and grammars. The second element is measuring the cost, efficiency, and effectiveness of those defined processes and comparing them against business, organizational, and technical goals. And, the third is modifying, changing, simplifying, and streamlining the process until it is reduced to its essential elements, non-essential elements have been removed, and is congruent with goals and objectives.

Table 1: Survey of Software Process Improvement (SPI) Definitions in Literature

	Source of Definition						
Definition	Braham	Harrington	Rico	Szymanski	Austin	Garrison	Davenport
Perfect	✓	✓					
Add Value	✓	✓	✓	✓			
Add Quality	✓	✓	✓		✓		
Productivity		✓	✓		✓		
Speed		✓	✓		✓		
Efficiency		✓	✓	✓		✓	
Reduce Cost		✓	✓			✓	
Advantage		✓	✓				
Profit		✓	✓				
Flexible		✓					
Downsize		✓					
Substitute			✓				
Method			✓	✓	✓		
Define			✓	✓		✓	
Measure			✓	✓		✓	
Simplify			✓	✓		✓	
Add			✓	✓			
Incremental							✓

Szymanski and Neff (1996) define SPI as "a deliberate, planned methodology following standardized documentation practices to capture on paper (and in practice) the activities, methods, practices, and transformations that people use to develop and maintain software and the associated products." Szymanski and Neff go on to explain SPI as a process of defining organizational processes, assessing and evaluating them, eliminating inessential steps, and augmenting organizational processes with value-adding steps. Szymanski and Neff place extra emphasis on modeling all processes in a highly structured and uniform way and examining whether current processes add-value or whether value-added processes need to be introduced.

Austin and Paulish (1993) define SPI as integrated procedures, tools, and training in order to increase product quality, increase development team productivity, reduce development time, and increase business competitiveness and profitability. Austin and Paulish define SPI as a process with its own procedures, tools, and training, while the previous authors merely advocate the definition and modeling of organizational processes without saying how. In addition, Austin and Paulish focus SPI on increasing product quality, productivity, and profitability.

Garrison and Noreen (1997a) define Process Value Analysis (PVA), which is similar to SPI, as systematically analyzing the activities required to make products or perform services, identifying all resource consuming activities as value-added or non-value added, and then minimizing or eliminating the resource consumption of all activities. Garrison and Noreen make no mention of macro level PVA, that is, treating an entire enterprise as a process that is a candidate for elimination (more popularly known as value chain analysis). Figure 1 most appropriately represents PVA from Garrison's and Noreen's viewpoint.

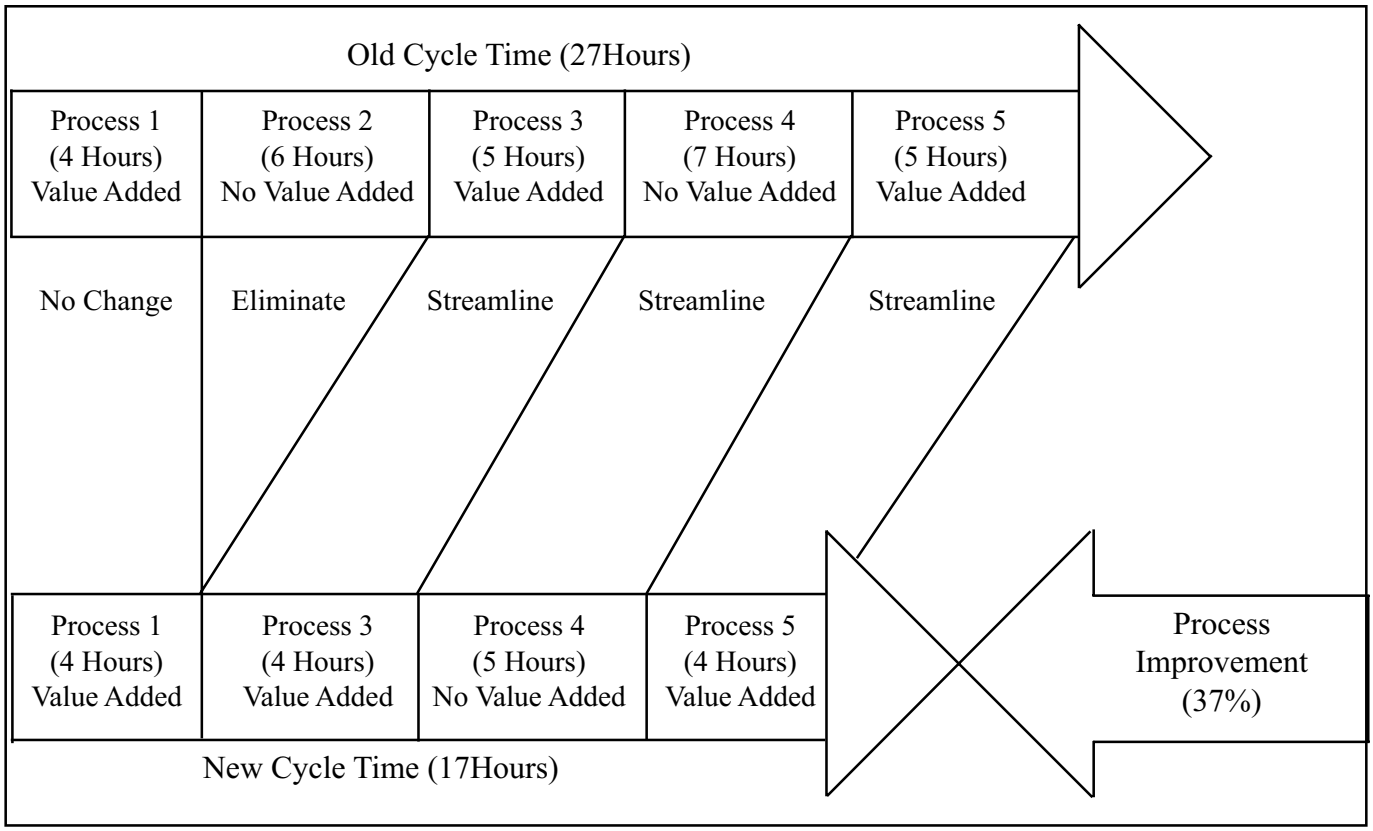

Figure 1. Process Value Analysis (PVA)

A net process improvement of 37% has been effected by elimination of process 2 and streamlining of processes 3, 4, and 5.

Davenport (1993) defines process improvement as involving a low level of change, focusing on minutely incremental change, primarily targeted at polishing existing processes, and overall involving a long term progression of change, more akin to placing a Band-Aid on a severed limb.

Davidson (1993) defines re-engineering, which is similar to SPI, as a method for identifying and achieving radical business performance improvements in productivity, velocity, quality, business precision, and customer service increases of ten or even a hundred fold or more. Davidson defines micro or small-scale process improvement in terms of optimization, short timeframes, local leadership, diverse infrastructure, financial performance focus, single process focus, and multiple projects. Davidson defines macro or large-scale process improvement in terms of transformation, long timeframes, senior leadership, integrated infrastructure, multiple benefit paths, enterprise focus, and massive scale. Davenport (1993) and Davidson by far give the most formal definitions of both process improvement and its close cousin, re-engineering.

Strategies and Alternatives

Table 1 demonstrates that neither a standard definition of Software Process Improvement (SPI) exists, nor a standard set of SPI metrics to measure the costs and benefits of SPI and the various SPI strategies. This section surveys and identifies SPI techniques, methods, methodologies, strategies, and approaches from approximately 72 scholarly studies. The 72 studies range from the Massachusetts Institute of Technology's (MIT) two decade long study of SPI methods from the largest Japanese corporations, Microsoft, and Netscape, the seminal laboratories of IBM, the Software Engineering Institute (SEI), and straight from reports of recent SEI CMM Level 5 organizations.

This section's survey and analysis, like the previous one, revealed a non-standard plethora of SPI strategies consisting of over 451 individual SPI techniques. Eventually, it is the intention of this overall study to identify the relevant SPI strategies, not by qualitative judgement such as keyword analysis or popular survey, but by directly attaching the cost and benefits of the individual SPI techniques to the SPI techniques themselves. This study will attempt to let the data speak for itself and keep qualitative interpretation to a minimum. Thus, it is the intention of this study to be "quantitative" in nature, not qualitative. But, that's a topic for the next three sections and the next two chapters.

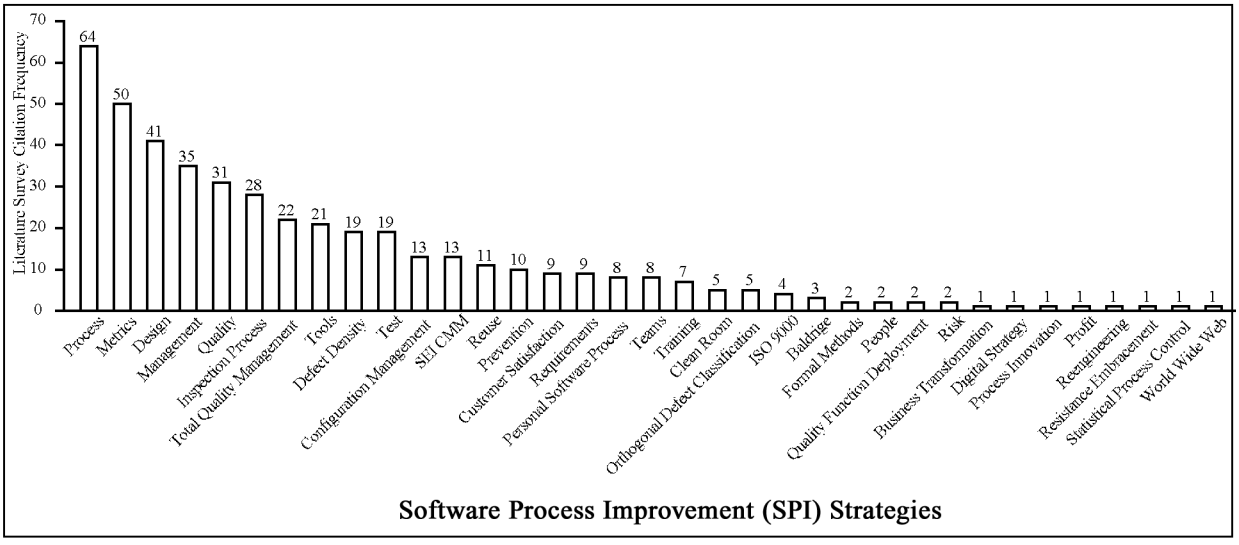

Figure 2. Software Process Improvement (SPI) Strategies from Survey of 72 Case Studies

As shown in Figure 2, 35 categories of SPI techniques were identified by this section's survey of 72 representative studies consisting of 451 individual SPI techniques. The first 17 SPI categories included, Process, Metrics, Design, Management, Quality, Inspection Process, Total Quality Management, Tools, Defect Density, Test, Configuration Management, SEI CMM, Reuse, Prevention, Customer Satisfaction, Requirements, and Personal Software Process. The last 18 SPI categories included, Teams, Training, Clean Room, Orthogonal Defect Classification, ISO 9000, Baldrige, Formal Methods, People, Quality Function Deployment, Risk, Business Transformation, Digital Strategy, Process Innovation, Profit, Reengineering, Resistance Embracement, Statistical Process Control, and World Wide Web.

As shown in Figure 2, Process as a SPI strategy was cited the most often, 64 out of 451 times, or approximately 14% of the time. The World Wide Web, on the other hand, was cited the least often, 1 out of 451 times, or 0.22% of the time. As stressed earlier, this analysis does not imply that Process as a SPI strategy is superior to the World Wide Web, but merely that Process was used 64 times more often than the World Wide Web as reported by the 72 case studies surveyed in this section. The next chapter will attach the costs and benefits of using Process versus other key SPI strategies, in order to help determine which methods are superior, and are thus recommended by this study.

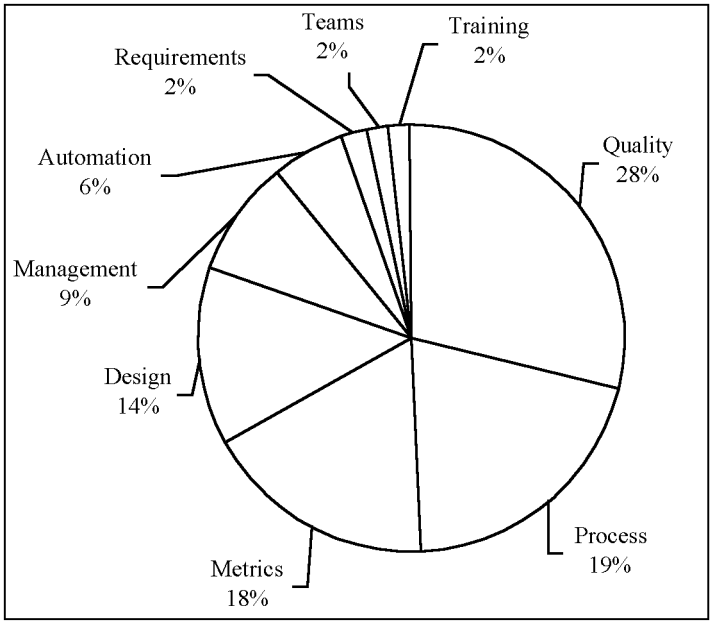

Figure 3. Software Process Improvement (SPI) Strategies Classification

Figure 3 groups the previously identified 35 SPI categories into nine major classes for further analysis. Baldrige, Inspection Process, ISO 9000, Orthogonal Defect Classification, Prevention, Personal Software Process, Quality, Test, and Total Quality Management were all grouped together to form the Quality SPI class, accounting for 28% of the individual SPI techniques. Configuration Management, Process, Profit, Reengineering, and SEI CMM were all grouped together to form the Process SPI class, accounting for 19% of the individual SPI techniques. Customer Satisfaction, Defect Density, Metrics, and Statistical Process Control were all grouped together to form the Metrics SPI class, accounting for 18% of the individual SPI techniques. Clean Room, Design, Formal Methods, Quality Function Deployment, and Reuse were all grouped together to form the Design SPI class, accounting for 14% of the individual SPI techniques. Management, People, Resistance Embracement, and Risk were all grouped together to form the Management SPI class, accounting for 9% of the individual SPI techniques. Business Transformation, Digital Strategy, Process Innovation, Tools, and World Wide Web were all grouped together to form the Automation SPI class, accounting for 6% of the individual SPI techniques. The Requirements, Teams, and Training SPI classes, respectively, account for 2% of the individual SPI techniques.

Again, this doesn't necessarily mean that Quality-oriented SPI strategies are superior to all others, and that SPI approaches like Automation are inferior to all others. In fact, Davenport (1993), Davidson (1993), Reid (1997), and more recently Downes and Mui (1998) have been reporting that Automation as a process improvement strategy is quantitatively and economically superior to all of the others. But, once again, the final determination is for the next two chapters of this study. What this analysis does indicate is that Quality-oriented SPI strategies are a conservative favorite among organizations engaging in SPI, while Automation is emerging and not yet fully embraced. But, this study will examine these issues in further detail in the analysis and conclusions.

Garrison and Noreen (1997b) report that there are two approaches to improving profitability: (a) increasing volume and total revenue while maintaining relative variable and fixed costs and (b) reducing variable and fixed costs while maintaining current volume. Garrison and Noreen go on to report that the most common and historically preferable approach to improving profits is to increase volume and thus total revenue while maintaining relative variable and fixed costs, especially for cost intensive products and services. Garrison and Noreen (1997a) report that two common methods of reducing costs are to: (a) decrease the cost of value adding and non-value adding activities through Process Value Analysis (PVA) and (b) improve quality by reducing the number OF defects through defect prevention and appraisal activities (see Table 2). Garrison and Noreen (1997a) report that cost reducing approaches, such as Process Value Analysis (PVA), Aactivity-Based Costing (ABC), and quality management lead to increased cost control and management and are directly controllable, though cumbersome, and have break-even points of their own that need to be monitored carefully.

Table 2: Defect Prevention and Appraisal Process

Process	Activity
Prevention	System Development
	Quality Engineering
	Quality Training
	Quality Circles
	Statistical Process Control Activities
	Supervision of Prevention Activities
	Quality Data Gathering, Analysis, and Reporting
	Quality Improvement Projects
	Technical Support Provided to Suppliers
	Audits of the Effectiveness of the Quality System
Appraisal	Test and Inspection of Incoming Materials
	Test and Inspection of In-Process Goods
	Final Product Testing and Inspection
	Supplies Used in Testing and Inspection
	Supervision of Testing and Inspection Activities
	Depreciation of Testing Equipment
	Maintenance of Testing Equipment
	Plant Utilities in the Inspection Area
	Field Testing and Appraisal at Customer Site

Garrison and Noreen (1997a and 1997b) set the context for the rest of this section and the remainder of this study. Garrison and Noreen (1997b) report that the most common historical method of increasing profitability has been to increase volume through fixed cost-based advertising. Garrison and Noreen (1997a) report that the more cumbersome and less used approach is to reduce variable and fixed costs by process and quality improvement. This study focuses on the definitions, costs, and benefits associated with process and quality improvement. The remainder of Chapter 2 and the rest of this study focus on the costs and benefits of process and quality improvement methods and approaches, the road less traveled, thus establishing the context for Chapter 3, the methodology.

Arthur (1997) enumerated five techniques that enabled U.S. West to achieve what he called "quantum" or major improvements in software management and development performance, such as 50% improvements in quality, cost, and cycle times (see Table 3). The first technique Arthur reports is to focus directly on the performance results that need to be achieved, such as reducing defects, cycle time, and rework costs, not company-wide training in total quality management (TQM) theory. The second technique Arthur reports is to focus SPI efforts directly on the source of the areas needing improvement, utilizing those directly involved, not company-wide quality circles solving broad-ranging company-wide problems of processes that aren't within the purview of the improvement teams. The third technique Arthur reports is to focus SPI efforts on improving the customer's perception of the product or service, such as low quality, high cost, long delivery times, and poor service, not on solving internal sociological problems that will never impact the customer. The fourth technique Arthur reports is to focus the SPI resources on only the people directly involved in the areas needing improvement, such as those that have a hands-on association to the problem areas, not involving those that don't directly contribute to the problems being solved. The fifth technique Arthur reports is to focus SPI resources on teaching the concise techniques necessary to solve specific problems, not teach theory such as TQM or software process improvement philosophy. Arthur summarizes by stating that organizations should focus improvement efforts, focus on immediate results, use accelerated methods, and define consistent processes using flowcharts, measuring defects, time, and cost.

Table 3: U.S. West's Software Process Improvement (SPI) Principles

Strategy	Technique
Mistakes	Focus on Learning Instead of Results
	Lack of Focus
	Lack of Sponsorship
	Trying to Involve Everyone, Not Just the People Focused on Key Results
	Teaching Theory Instead of Developing Real World Experience
Solutions	Focus Directly on the Performance Results That Need to be Achieved
	Focus Efforts Directly on the Source of Areas Needing Improvement
	Focus Efforts on Improving the Perception of Products or Services
	Focus Resources on those Directly Involved in the Improvement Area
	Focus Resources on the Techniques Necessary to Solve Specific Problems

Humphrey (1989) created a five-stage SPI method known as the Software Engineering Institute's (SEI's) Capability Maturity Model for Software (CMM) beginning in 1987 (see Table 4). The SEI's CMM dates back to an early 1960s era IBM manufacturing process improvement concept and technical report entitled, "Process Qualification—Manufacturing's Insurance Policy" as reported by Harrington (1991). IBM's manufacturing process qualification technique was translated several times over the last three decades into Crosby's (1979) "Maturity Grid," IBM's (Radice, Harding, Munnis, and Phillips, 1985) "Process Grid," Humphrey's (1987) "Process Maturity Grid," and then into Paulk's, Weber's, Curtis', and Chrissis' (1995) "Capability Maturity Model for Software (CMM)." The SEI's CMM is a staged model consisting of five groups or Levels of purportedly important software management processes called Key Process Areas (KPAs). The five CMM Levels are Initial, Repeatable, Defined, Managed, and Optimizing (Humphrey 1989). There are no KPAs for the Initial Level signifying an undefined, immature, or worst state of software management capability (Humphrey, 1989). The KPAs for the Repeatable Level are Requirements Management, Software Project Planning, Software Project Tracking and Oversight, Software Subcontract Management, Software Quality and Software Configuration Management, signifying a defined and repeatable software project-level management capability (Humphrey, 1989). The KPAs for the Defined Level are Organization Process Focus, Organization Process Definition, Training Program, Integrated Software Management, Software Product Engineering, Intergroup Coordination, and Peer Reviews, signifying a defined and repeatable organizational-wide software management process (Humphrey, 1989). The KPAs for the Managed Level are Quantitative Process Management and Software Quality Management, signifying a defined and repeatable organization-wide software measurement and statistical analysis process (Humphrey, 1989). The KPAs for the Optimizing Level are Process Change Management, Technology Change Management, and Defect Prevention, signifying a defined and

Table 4: SEI Capability Maturity Model for Software (CMM)

Level	Key Process Areas (KPA)	Additional Explanation
Optimizing	Process Change Management	Software Process Improvement (SPI)
	Technology Change Management	Information Technology Insertion
	Defect Prevention	(self explanation)
Managed	Software Quality Management	Use of Software Quality Metrics
	Quantitative Process Management	Use of Statistical Management Methods
Defined	Peer Reviews	Software Inspection Process
	Intergroup Coordination	Multi-Program/Project Communications
	Software Product Engineering	Software Design, Development and Test
	Integrated Software Management	Multi-Program/Project Management
	Training Program	Software Engineering Process Training
	Organizational Process Definition	Multi-Program/Project Process Standards
	Organizational Process Focus	Multi-Program/Project Process Definition
Repeatable	Software Configuration Management	(self explanation)
	Software Quality Assurance	Process and Product Auditing
	Software Subcontract Management	(self explanation)
	Software Project Tracking and Oversight	Structured Project Management Methods
	Software Project Planning	Written Software Project Plans
	Requirements Management	Software Requirements Engineering
Initial	None	None

repeatable software process improvement process (Humphrey, 1989). In summary, the SEI's CMM is a five stage process of defining software project management processes, defining organizational wide software management processes, defining organizational wide measurement and statistical analysis processes, and then defining organizational wide software process improvement processes. The SEI (1999) reports that 80% of the software organizations worldwide are at SEI CMM Levels 1 and 2, and therefore have no organizational-wide processes for software management, measurement and statistical analysis, and software process improvement.

Cosgriff (1999a and 1999b), Oldham et al. (1999), and Craig (1999) report that Hill AFB used the SEI's CMM as their primary SPI method, achieving CMM Level 5 in 1998 (see Figure 4). Cosgriff (1999a) cites the use of SEI CMM-Based Assessments for Internal Process Improvement (CBA-IPIs) and Software Capability Evaluations (SCEs) by Hill AFB. However, Oldham et al. (1999) mentions the use of defect density metrics, the Software Inspection Process, and cycle time metrics as key components of Hill AFB's SPI efforts. Craig reports that focusing on the SEI CMM's Software Quality Assurance (SQA) Key Process Area (KPA) is a critical element of Hill AFB's CMM Level 5 organization. Cosgriff (1997b) reports on twelve elements of Hill AFB's SPI efforts, management sponsorship, project planning, operational definitions, software quality assurance, software configuration management, product lines, intergroup coordination, measurement, quantitative process management, software quality management, process change management, and technology change management, mirroring the SEI CMM's KPAs

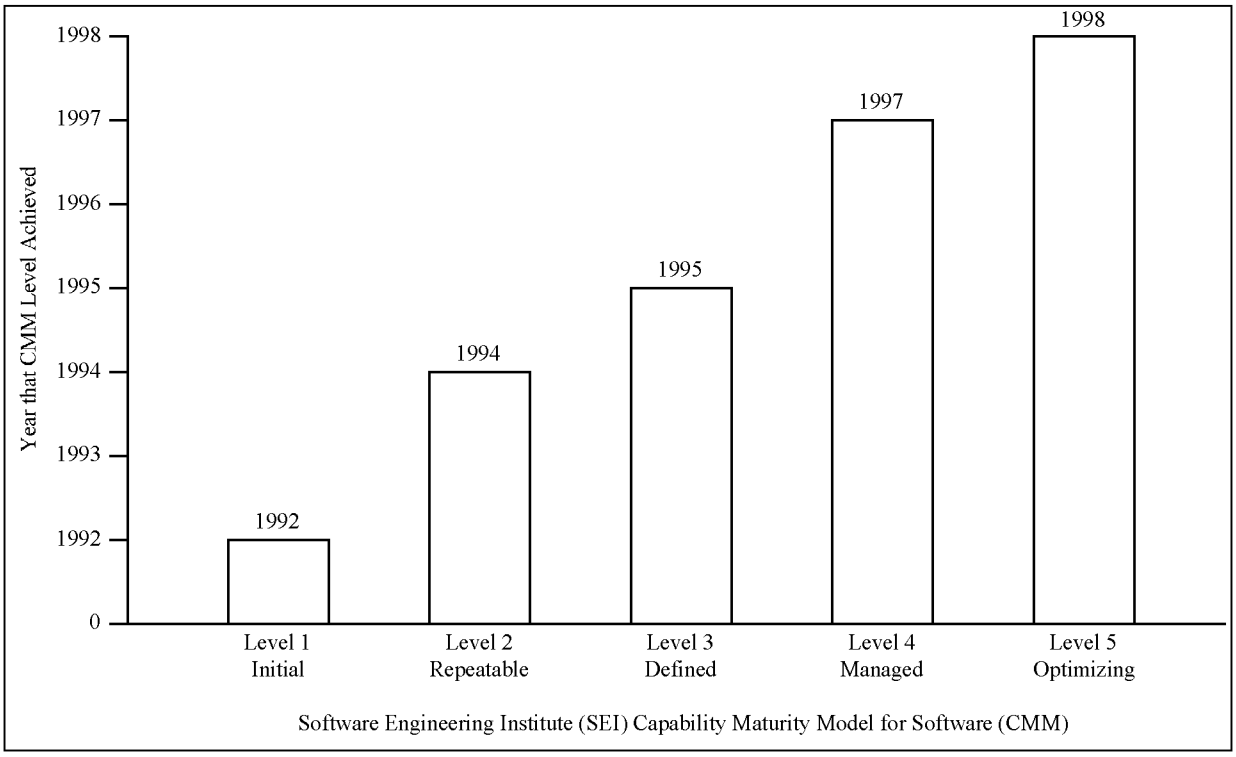

Figure 4. Ogden Air Logistics Center Software Process Improvement (SPI) Journey

Yamamura and Wigle (1997) report that Boeing's Defense and Space Group also used the SEI's CMM as a primary SPI method, achieving CMM Level 5 in 1996. Actually, Yamamura and Wigle report that Boeing's 17 year SPI journey started in the early 1980s (see Table 5). Yamamura and Wigle report that Boeing's SPI efforts occurred in four main phases, defining process standards, use of the Software Inspection Process and defect density metrics, use of cycle time reduction and productivity increase initiatives, and for the last two years, the use of the SEI's CMM. So, Yamamura and Wigle report that having defined processes, using inspections and defect density metrics, and having cycle time reduction and productivity increase initiatives, enabled Boeing to achieve CMM Level 5 after only two years of using the SEI's CMM. Wigle and Yamamura (1997) cite two key elements of Boeing's SPI efforts, charter a Software Engineering Process Group (SEPG) based on continuous SPI (not conducting assessments) and staff the SEPG with key hands-on project members (not ivory tower specialists). Wigle and Yamamura enumerate seven of fourteen SPI techniques, such as obtaining management sponsorship, establishing realistic goals, overcoming individual resistance, educating everyone in the basics, overcoming challenges associated with new SPI teams, establishing an SEPG, and capturing as-is processes first. Wigle's and Yamamura's remaining seven SPI techniques include thoroughly documenting processes, properly interpreting the CMM, defining rapidly deployable processes, formalizing SPI processes themselves, forming appropriate organizational policies, managing compliance with internal or external standards, and using emerging technologies such as intranets to deploy processes.

Jones (1996 and 1997a) reports to have measurements, costs, and benefits for SPI involving 7,000 software projects, 600 software development organizations, and six industries. Jones reports that organizations go through six distinct stages or approaches to SPI. Jones refers to these so-called "six

Table 5: Boeing Defense and Space Software Process Improvement (SPI) Journey

Time frame	Strategy	Technique
1996	SEI CMM Framework	Achieved CMM Level 5
Mid 1990s	Quality Teams	Deployment Process Upgraded Software Process Improvement (SPI) Group Added Software Process Improvement (SPI) Processes
Early 1990s	Process Management	Focused on Increasing Productivity Focused on Reducing Cycle Time Added More Software Metrics and Measurements Conducted Process Evaluations
Late 1980s	Process Management	Focused on Reducing Defects Created Design Review Board Added More Software Metrics and Measurements Updated Software Engineering Processes Introducing a Six-Step Software Engineering Process Conducted Software Engineering Process Training
Early 1980s	Process Definition	Created Software Work Product Standards Created Company Software Engineering Standards Created Basic Software Metrics and Measurements Created Software Engineering Process Library Documented Software Engineering Processes

stages of software excellence" as, management technologies, software processes and methodologies, new tools and approaches, infrastructure and specialization, reusability, and industry leadership (see Table 6). Jones' first three of six SPI methods are, management technologies (referring to improvement of software project planning), software processes and methodologies (referring to improvement of technical activities such as software requirements analysis and design), and new tools and approaches (referring to the insertion of new computer technologies). Jones last three of six SPI methods are, infrastructure and specialization (referring to the formation of functional specialization groups such as software quality assurance), reuse (referring to reusing software life cycle artifacts and software source code), and industry leadership (referring to automation of all software life cycle management and development functions).

Table 6: SPR Software Process Improvement (SPI) Model

Time frame	Strategy	Technique
Zero	Assessment	Software Process Assessments Baselines Benchmarks
One	Management	Project Planning Resource Estimation Project Tracking
Two	Process	Requirements Management Joint Application Design (JAD)
Three	Tools	Computer Aided Software Engineering (CASE) Client/Server Technologies and Strategies
Four	Infrastructure	Establish Configuration Management Function Establish Test and Maintenance Function Establish Software Quality Assurance Function
Five	Reuse	Reuse of Software Architecture and Designs Reuse of Software Life Cycle Artifacts Reuse of Software Source Code
Six	Leadership	Project Management Tool Suites/Environment Software Development Tool Suites/Environment Software Quality/Test Tool Suites/Environment

Diaz and Sligo (1997) report that Motorola's Government Electronics Division (GED) used the SEI's CMM as their primary SPI method for achieving CMM Level 5 as early as 1995 (see Table 7). Diaz and Sligo report that Motorola developed a "Software Quality Management Manual" that defined software processes and began widespread use of the Software Inspection Process, helping Motorola to achieve CMM Level 3 in 1992. Diaz and Sligo report the formation of SPI working groups, creation of software project metrics tracking tools, the use of quality metrics (most likely defect density metrics), and the creation of a "Handbook for Quantitative Management of Software Process and Quality," helping Motorola to achieve CMM Level 4 in 1994. Diaz and Sligo report the formation of defect prevention working groups, "defect prevention handbook," CMM Level 5 metrics tools, and the formation of process and technology change management handbooks, helping Motorola achieve CMM Level 5 as early as

1995. Diaz and Sligo report nine SPI techniques for achieving and maintaining SEI CMM Level 5. Diaz' and Sligo's first four SPI techniques include, focusing on improving new projects, assessing the intent of CMM KPAs, emphasizing productivity, quality, and cycle time, and getting managers committed to SPI. Diaz' and Sligo's remaining five SPI techniques include, involving only hands-on software managers and developers in performing SPI, getting managers to believe in SPI benefits, keeping customers informed, creating organizationally unique process documentation, and overcoming resistance to change.

Haley (1996) reports Raytheon Electronic Systems' Equipment Division used the SEI's CMM as their primary SPI method for achieving CMM Level 3 in 1991 (see Table 8). Haley reports that Raytheon's SPI model consisted of two methods, establishing a SPI infrastructure and SPI measurement and analysis. Haley reports that Raytheon's SPI infrastructure method consisted of four elements, a policy and procedures working group to define processes, a training working group to deploy software processes, a tools and methods working group to identify automated software tools, and a process database working group to manage software process assets. Haley reports that Raytheon's SPI measurement method consisted of two elements, data measurement definitions of key software metrics and data analysis to illustrate how to interpret and manage the key software metrics and measurements. Additionally, Haley reports on two key SPI leverage points or techniques used by Raytheon for achieving and maintaining SEI CMM Level 3, product improvement and process improvement. Haley reports that Raytheon's product improvement leverage point consisted of four elements, participation in system definition by software personnel, requirements definition to identify customer needs, inspections to identify software defects, and integration and qualification testing to formalize testing. Haley reports that Raytheon's process

Table 7: Motorola Software Process Improvement (SPI) Strategy

Year	Position	Target	Strategies, Methods, and Techniques
1989	CMM Level 2	CMM Level 3	Organizational Software Engineering Policy Organizational Software Engineering Procedures Software Life-Cycle Management Manual Cross Functional Software Teams Software Inspection Process
1992	CMM Level 3	CMM Level 4	Senior Practitioner Process Improvement Group Senior Task Leader Process Improvement Group Project Effort Metrics Collection Tool Software Process and Quality Metrics Handbook
1994	CMM Level 4	CMM Level 5	Defect Prevention Working Group Defect Prevention Handbook Chief Software Engineer Group Expansion Project Kickoff (to begin CMM Level 5) Project Self Assessments Level 5 Software Metrics Collection Tool Double Process Improvement Group Process and Technology Change Handbooks Weekly CMM Level 5 Improvement Meetings
1995	CMM Level 5	CMM Level 5	Focus on Improving New Projects Assess Intent of CMM for Each New Project Emphasize Productivity, Quality, and Cycle Time Management and Staff Commitment and Belief

Table 8: Raytheon Software Process Improvement (SPI) Strategies

Strategy	Method	Technique
Infrastructure	Policy & Procedures Working Group	Software Engineering Policy Software Engineering Practices Detailed Procedures and Guidelines
	Training Working Group	Train Everyone Training During Work Hours Overview and Detailed Courses
	Tools and Methods Working Group	Tool Selection and Evaluation Commercial-Off-The-Shelf (COTS) Rapid Pathfinding Tool Laboratory
	Process Database Working Group	Software Engineering Processes Project and Project Kickoff Data Software Quality Data
Measurement	Data Measurement Definitions	Process, Project, and Product Metrics
	Data Analysis	Earned Value Management
Focus Points	Product Improvement	System and Requirements Definition Software Inspection Process Integration and Qualification Testing
	Process Improvement	Software Development Planning Training Pathfinding
Metrics Focus	Product Quality	Defect Density Metrics
	Cost of Quality	Appraisal to Failure Ratios
	Predictability and Productivity	Cost Performance Indices and Coding

improvement leverage point consisted of three elements, software development planning to formalize project planning, training to teach software processes, and pathfinding to establish software development tool sets for software personnel.

McGibbon (1996), Director of the Data and Analysis Center for Software (DACS) at Rome Laboratory in Rome, New York identified the costs and benefits of using various SPI methods. McGibbon developed a quantitative analytical model for evaluating, selecting, and using three principal SPI methods (see Table 9). McGibbon did so by conducting a survey and performing quantitative analysis of SPI methods, costs, and benefits, selecting the most cost-effective and beneficial approaches. McGibbon identified the Software Inspection Process, Software Reuse, and the Clean Room Methodology as three of the best SPI methods, developing a SPI cost model to enumerate concise benefits such as development costs, rework costs, maintenance costs, and development and maintenance savings, for individual users and use. McGibbon chose these three SPI methods analyticaly and quantitatively because of their cost efficiency, defect removal efficiency (their ability to identify and remove defects before software product delivery), and ultimately their ability to result in the production of the highest possible quality products and services at the lowest possible cost. McGibbon also judged and compared these three methods for their ability to result in the lowest possible software maintenance costs. McGibbon optimized his SPI model, approach, and methodology for software quality, in terms of the absence of identifiable defects.

Schafer, Prieto-diaz, and Matsumoto (1994), leading Software Reuse and Domain Analysis experts on three continents, conducted an analysis of eight leading Software Reuse and Domain Analysis methodologies (see Table 10). Schafer, Prieto-diaz, and Matsumoto determined that the eight Software Reuse and Domain Analysis methodologies were composed of five common phases, stages, or processes. Schafer, Prieto-diaz, and Matsumoto identified the five common Software Reuse and Domain Analysis phases to be domain characterization, data collection, data analysis, taxonomic classification, and evaluation. Schafer, Prieto-diaz, and Matsumoto report that the domain characterization phase is composed of five subprocesses, business analysis, risk analysis, domain description, data identification, and inventory preparation. Schafer, Prieto-diaz, and Matsumoto report that the data collection phase is composed of four subprocesses, abstraction recovery, knowledge elicitation, literature review, and analysis of context and scenarios. Schafer, Prieto-diaz, and Matsumoto report that the data analysis phase is composed of seven subphases, identification of entities, operations, and relationships, identification of decisions, modularization, analysis of similarity, analysis of variations, analysis of combinations, and trade-off analysis. Shafer, Prieto-diaz, and Matsumoto report that the taxonomic classification phase is composed of six subphases, clustering, abstraction, classification, generalization, and vocabulary construction.

Table 9: DACS Software Process Improvement (SPI) Strategies

Process	Definition	Goal	Subprocesses
1989	CMM Level 2	CMM Level 3	Organizational Software Engineering Policy Organizational Software Engineering Procedures Software Life-Cycle Management Manual Cross Functional Software Teams Software Inspection Process
1992	CMM Level 3	CMM Level 4	Senior Practitioner Process Improvement Group Senior Task Leader Process Improvement Group Project Effort Metrics Collection Tool Software Process and Quality Metrics Handbook
1994	CMM Level 4	CMM Level 5	Defect Prevention Working Group Defect Prevention Handbook Chief Software Engineer Group Expansion Project Kickoff (to begin CMM Level 5) Project Self Assessments Level 5 Software Metrics Collection Tool Double Process Improvement Group Process and Technology Change Handbooks Weekly CMM Level 5 Improvement Meetings
1995	CMM Level 5	CMM Level 5	Focus on Improving New Projects Assess Intent of CMM for Each New Project Emphasize Productivity, Quality, and Cycle time Management and Staff Commitment and Belief

Table 10: Software Reusability and Domain Analysis Methods

Process	Subprocess	McCain	Prieto	Simos	King	Jaworski	Lubars	Vitaletti	Bailin
Characterize	Business Analysis	✓	✓	✓	✓	✓		✓	✓
	Risk Analysis	✓	✓	✓	✓	✓		✓	✓
	Domain Descriptions	✓	✓	✓	✓	✓		✓	✓
	Data Identification	✓	✓		✓	✓	✓	✓	✓
	Inventory Preparation	✓	✓		✓	✓	✓	✓	✓
Collect Data	Abstraction Recovery	✓	✓	✓	✓	✓	✓	✓	✓
	Knowledge Elicitation	✓	✓	✓	✓	✓	✓	✓	✓
	Literature Review	✓	✓	✓	✓	✓	✓	✓	✓
	Context Analysis			✓	✓	✓	✓	✓	✓
Analyze Data	Object Analysis	✓	✓	✓	✓	✓	✓	✓	✓
	Decision Identification				✓	✓			✓
	Modularization	✓	✓	✓	✓	✓	✓	✓	✓
	Similarity Analysis	✓	✓	✓	✓	✓	✓	✓	✓
	Variation Analysis	✓	✓	✓	✓	✓	✓	✓	✓
	Combination Analysis	✓	✓	✓	✓	✓	✓	✓	✓
	Trade-off Analysis	✓		✓	✓	✓	✓	✓	✓
Taxonomy	Clustering	✓	✓	✓	✓	✓	✓	✓	✓
	Abstraction	✓	✓	✓	✓	✓	✓	✓	✓
	Classification	✓	✓	✓	✓	✓	✓	✓	✓
	Generalization	✓	✓		✓	✓	✓	✓	✓
	Construct Vocabulary		✓	✓	✓	✓		✓	✓
Evaluate	Validation		✓	✓	✓	✓	✓	✓	✓

Lim (1998) reports that Hewlett Packard's Manufacturing Division and Technical Graphics Division used Software Reuse as a SPI strategy from 1983 to 1994. Lim reports that HP's Software Reuse process is composed of four major activities (see Table 11). Lim identifies HP's four major Software Reuse activities as managing the reuse infrastructure, producing reusable assets, brokering reusable assets, and consuming reusable assets. Lim reports that producing reusable assets consists of analyzing domains, producing assets, and maintaining and enhancing assets. Lim reports that brokering reusable assets consists of assessing assets for brokering, procuring assets, certifying assets, adding assets, and deleting assets. Finally, Lim reports that consuming reusable assets consists of identifying system and asset requirements, locating assets, assessing assets for consumption, and integrating assets.

Table 11: Hewlett Packard's Software Reuse Process

Process	Subprocess
Managing the Reuse	Establish Rules, Roles, and Goals That Support Reuse Designate Conventions and Standards Approve Additions, Deletions, and Changes to the Library Commission Component Construction Coordinate Schedules and Resources Align Reuse Goals to Business Goals Establish and Award Incentives Interpret Metrics Data Implement Economic Models
Producing Reusable Assets	Analyze Domain Produce Assets Maintain and Enhance Assets
Brokering Reusable Assets	Assess Assets for Brokering Procure Assets Certify Assets Add Assets Delete Assets
Consuming Reusable Assets	Identify System and Asset Requirements Locate Assets Assess Assets for Consumption Integrate Assets

Kaplan, Clark, and Tang (1995) identified the Clean Room Methodology as a strategically important SPI strategy in wide use throughout IBM from 1987 to 1993. Kaplan, Clark, and Tang report that the Clean Room Methodology is composed of seven subprocesses including, function specification, usage specification, incremental development plan, formal design and correctness verification, random test case generation, statistical testing, and reliability certification model. Kaplan, Clark, and Tang report that the Clean Room Methodology is built on the foundation of formal methods, formal specification, and formal verification (see Figure 5).

Bauer, Collar, and Tang (1992) report that IBM's AS/400 Division used ten general management principles as a primary process improvement method from 1986 to 1990, resulting in winning the Malcolm Baldrige National Quality Award in 1990 and creating an internationally best selling midrange computer system (see Table 12). Bauer, Collar, and Tang report that IBM's process improvement methods included, choosing a visionary leader, creating a visionary team, empowerment, using cross functional teams, segmenting your market, researching your markets, setting priorities, using parallel processes and doing it right the first time, forming strategic partnerships, and exceeding customer expectations. Bauer, Collar, and Tang reported that IBM created a special task force or tiger team to win the Malcolm Baldrige National Quality Award. The tiger team studied the Baldrige Award criteria, created strategic and tactical plans, gathered the evidence, created the application package, and submitted it three years in a row before winning the Malcolm Baldrige National Quality Award. Bauer, Collar, and Tang report that IBM's new AS/400 had already drawn $14 billion in revenues for the IBM Corporation by the first time IBM Rochester initially applied for the Malcolm Baldrige National Quality Award.

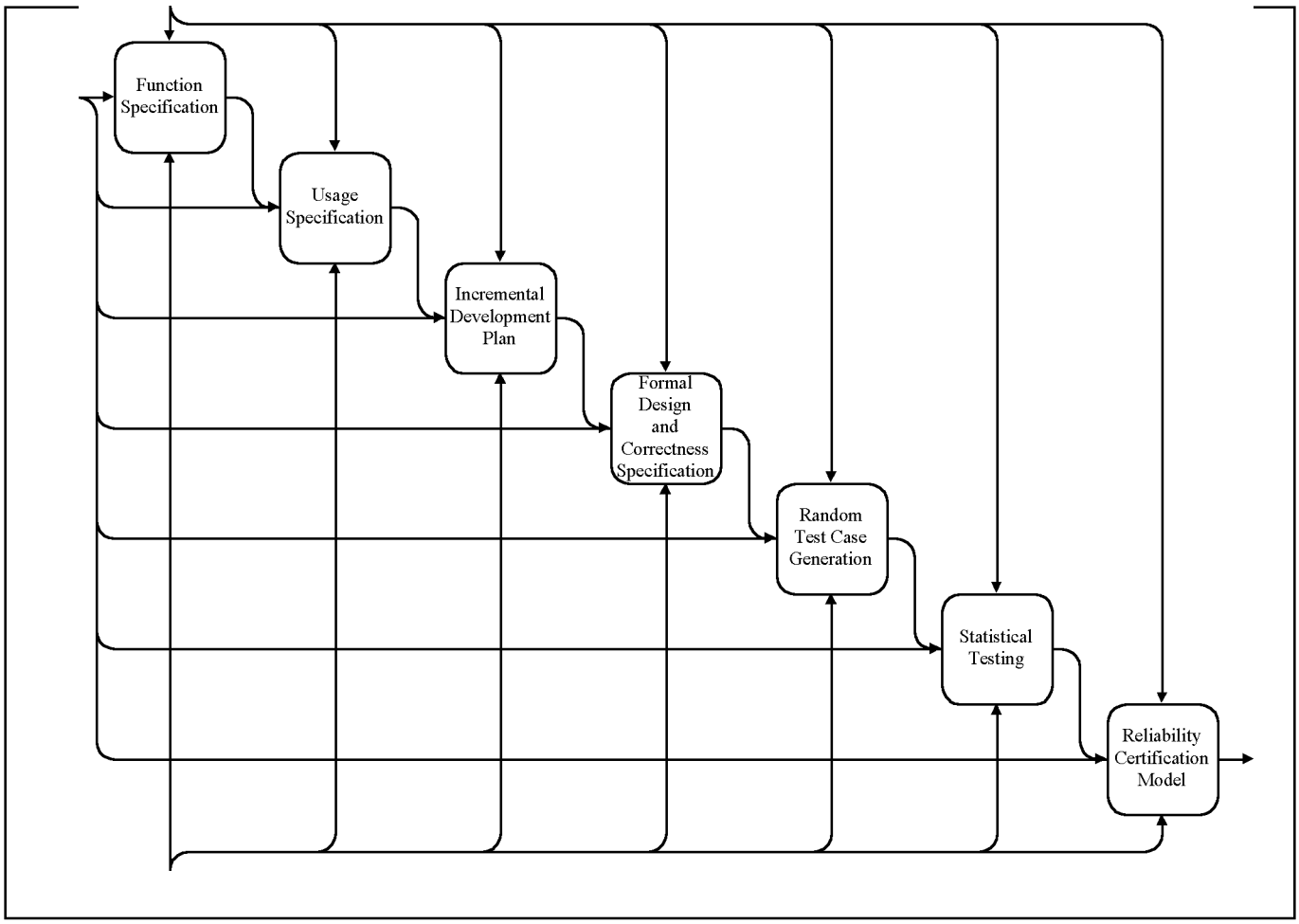

Figure 5. Clean Room Methodology

Sulack, Lindner, and Dietz (1989) report IBM's AS/400 Division used a measurement-intensive software quality management life cycle as a primary SPI method from 1986 to 1989, resulting in winning the Malcolm Baldrige National Quality Award in 1989 and creating an internationally best-selling midrange computer system (see Table 13). Sulack, Lindner, and Dietz report that IBM's software quality life cycle, otherwise known as a Rayleigh life cycle reliability model-based defect removal life cycle, was composed of four major components. Sulack, Lindner, and Dietz report that the four components included a software process life cycle, management techniques and controls, design and development, and product verification. Sulack, Lindner, and Dietz report that IBM's software process life cycle consisted of broad use of the Software Inspection Process to identify defects, an incremental software life cycle to simplify development, and concurrent-overlapping software life cycle iterations to shorten cycle time. (These software process life cycle elements in combination are referred to as a defect removal model-based concurrent incremental software life cycle architecture.) Sulack, Lindner, and Dietz report that IBM's management techniques and controls consisted of change control or software configuration management, design control groups to manage system-wide architecture decisions, and dependency management or interface control groups to manage program wide communication. Sulack, Lindner, and Dietz report that IBM's design and development techniques consisted of establishing development objectives or milestones to achieve goals, establishing performance design points to characterize product performance, and utilizing usability design methods to design optimal human-computer interfaces. Sulack, Lindner, and Dietz report that IBM's product verification techniques consisted of a formalized four-phase test process, milestone testing to establish user-centered testing objectives, and reuse in testing.

Table 12: IBM Rochester Organizational Process Improvement Strategy

	Strategy	Strategic Elements
1.	Visionary Leaders	Articulate Vision Liberate Creative Organizational Energies Inspire People to Perform
2.	Institutionalize Vision	Align Organizational Structure to Vision Resource Strategic Organizational Structures Empower Strategic Organizational Structures
3.	Empowerment	Trust People to Use Their Own Judgement Equip, Train, and Resource People Provide Performance Incentives and Rewards
4.	Multi-Discipline Teams	Form Integrated Cross-Functional Teams Empower Cross-Functional Teams Resource and Incentivize Cross-Functional Teams
5.	Market Segmentation	Select Target Markets Focus on Target Markets Differentiate Products and Services
6.	Market Research	Use Scientific Market Analysis Models and Tools Gather, Analyze, and Model Market Data Simulate and Predict Market Outcomes
7.	Prioritize Resources	Establish Priorities Based on Goals/Objectives Rank Goals, Objectives, Markets and Incentives Allocate and Manage Resources by Prioritization
8.	Parallel Processes	Reject Old, Sequential, and Step-By-Step Methods Pursue Endeavors Concurrently Prevent and Eliminate Defects Early
9.	Strategic Partnerships	Identify External Insights and Expertise Outsource Strategic Products and Services Focus on Core Competencies
10.	Satisfy Customer	Exceed Customer Expectations Determine Customer's Perceptions/Expectations Use Quantitative Customer Satisfaction Models

Table 13: IBM Rochester Software Process Improvement (SPI) Strategy

Strategy	Strategic Elements
Software process life cycle	Software Inspection Process Incremental life cycle Parallel life cycle phases
Management techniques and controls	Change control techniques Design control groups Dependency management
Design and development	Development objectives Performance design points Usability development
Product verification	Four phase test process Testing cycle considerations Reuse in testing Test automation Test staging
Ensuring user acceptance	Internal contract test teams Independent contract testing Communications field testing Migration invitational
Worldwide announcement	Concurrent translation Distribution project office Early shipment program

Kan, Dull, Amundson, Lindner, and Hedger (1994) report IBM strengthened the AS/400 Division's measurement-intensive software quality management life cycle with additional SPI methods from 1989 to 1994, helping IBM become ISO 9000 registered. Kan et al. reports that IBM Rochester's SPI strategy consisted of customer satisfaction management, in-process product quality management, post-general availability (GA) product quality management, continuous process improvement, and performance incentives (see Table 14).

Kan (1991 and 1995) and Kan et al. (1994) report IBM's AS/400 Division used software metrics and models as primary SPI methods from 1986 to 1994. Kan reports that IBM's SPI method consisted of using five major classes of software metrics and models (see Table 15).

The five classes of software metrics and models included software quality, reliability, quality management, structural design, and customer satisfaction elements. Kan reports that software quality metrics and models consisted of product quality, in-process quality, and maintenance elements. Kan reports that reliability metrics and models consisted of exponential and reliability growth elements. Kan reports that quality management metrics and models consisted of life cycle and testing phase elements. Kan reports that structural design metrics and models consisted of complexity and structure elements. Finally, Kan reports that customer satisfaction metrics and models consisted of survey, sampling, and analysis elements. Specific software quality metrics and models reported by Kan include, defect density, customer problems, customer satisfaction, function points, defect removal effectiveness, phase-based defect removal model pattern, special case two-phase model, fix backlog and backlog management index,

fix response time, percent delinquent fixes, and fix quality. Specific software reliability metrics and models reported by Kan include, cumulative distribution function, probability density function, Rayleigh model, Jelinski-Moranda, Littlewood, Goel-Okumoto, Musa-Okumoto logarithmic Poisson execution, and delayed-S and inflection-S. Specific software quality management metrics and models reported by Kan include, Rayleigh life cycle reliability, problem tracking report, and testing phase reliability growth. Specific structural design metrics and models reported by Kan include, source lines of code (SLOC), Halstead's software science, cyclomatic complexity, syntactic constructs, invocation complexity, system partitioning, information flow, and fan-in and fan-out. Specific customer satisfaction metrics and models reported by Kan include, in-person, phone, and mail surveys, random, systematic, and stratified sampling, and capability, usability, performance, reliability, installability, maintainability, documentation/ information, and availability (CUPRIMDA).

Table 14: IBM Rochester AS/400 Software Quality Management System (SQMS)

	Strategy	Strategic Elements
1.	Customer Satisfaction Management	Capability Usability Performance Reliability Installability Maintainability
2.	In-Process Product Quality Management	Defect Removal Model Software Inspection Process Minibuilds Defect Density Metrics Reliability Growth Models
3.	Post-GA Product Quality Management	Problem Tracking Defect Prevention Process Expert Systems
4.	Continuous Process Improvement	Strong Process Discipline Process Benchmarking Software Maturity Assessments Software Metrics Guidelines Yearly Quality Targets Object Oriented Technology Small Teams Workstations ISO 9000
5.	Performance Incentives	General Managers Award Monthly Quality Award In-Process Quality Award Long-Term Quality Award

Table 15: IBM Rochester AS/400 Software Quality and Reliability Metrics and Models

Class	Subclass	Metrics and Models
Software Quality	Product Quality	Defect Density Customer Problems Customer Satisfaction Function Points
	In-Process Quality	Defect Density During Machine Testing Defect Arrival Pattern During Machine Testing Defect Removal Effectiveness Phase-Based Defect Removal Model Pattern Special Case Two-Phase Model
	Maintenance	Fix Backlog and Backlog Management Index Fix Response Time Percent Delinquent Fixes Fix Quality
Reliability	Exponential	Cumulative Distribution Function (CDF) Probability Density Function (PDF) Rayleigh
	Reliability Growth	Jelinski-Moranda Littlewood Goel-Okumoto Musa-Okumoto Logarithmic Poisson Execution Delayed S and Inflection S
Quality Management	Life Cycle	Rayleigh Life Cycle Reliability
	Testing Phase	Problem Tracking Report Reliability Growth
Structural Design	Complexity	Source Lines of Code (SLOC) Halstead's Software Science Cyclomatic Complexity Syntactic Constructs
	Structure	Invocation Complexity System Partitioning Information Flow Fan-In and Fan-Out
Customer Satisfaction	Survey	In-Person, Phone, and Mail
	Sampling	Random, Systematic, and Stratified
	Analysis	CUPRIMDA

Kan, Basili, and Shapiro (1994) conducted a survey of software process and quality improvement methods from the perspective of IBM, the University of Maryland—College Park, and NASA Goddard Space Flight Center's (GSFC) Software Engineering Laboratory (SEL). Kan's, Basili's, and Shapiro's survey identified five broad classes of SPI methods (see Table 16).

Kan, Basili, and Shapiro reported the five classes to be total quality management, customer focus, process and technology, organizational behavior, and measurement and analysis. According to Kan, Basili, and Shapiro, total quality management consists of individual, industry, and academia, customer focus consists of needs analysis, product evolution, and customer burn-in, process and technology consists of

Table 16: IBM Rochester, University of Maryland, and NASA GSFC Quality Survey

Class	Subclass	Specific Technique
Total Quality Management	Individual	Philip Crosby W. Edwards Deming Armand V. Feigenbaum Kaoru Ishikawa J. M. Juran
	Industry	Malcolm Baldrige National Quality Award Motorola Six Sigma Strategy IBM Market Driven Quality Hewlett Packard Total Quality Control Capability Maturity Model Lean Enterprise Management
	Academia	Quality Improvement Paradigm Experience Factory Goal Question Metric
Customer Focus	Needs Analysis	Computer Aided Software Engineering Quality Function Deployment Rapid Throwaway Prototyping
	Product Evolution	Iterative Enhancement and Development Small Team Approach
	Customer Burn-In	Early Customer Feedback IBM Customer Quality Partnership Program
Process and Technology	Prevention	Defect Prevention Process
	Appraisal	Design Reviews Software Inspection Process Walk throughs
	Formal Methods	Vienna Development Method Z Notation Input/Output Requirements Language Clean Room Methodology
	Design Paradigms	Object Oriented Design and Programming Computer Aided Software Engineering Software Reuse
Organizational Behavior	Management	Leadership and Empowerment
Measurement and Analysis	Software Metrics	Quality, Reliability, and Structural Design

prevention, appraisal, formal methods, and design paradigms, organizational behavior includes management, and measurement and analysis includes software metrics. Total quality management techniques are reported to include, Philip Crosby's, W. Edward Deming's, Armand V. Feigenbaum's, Kaoru Ishikawa's, J. M. Juran's, Malcolm Baldrige National Quality Award, IBM Market Driven Quality, Hewlett Packard Total Quality Control, Capability Maturity Model, Lean Enterprise Management, Quality Improvement Paradigm, Experience Factory, and Goal Question Metric. Customer focus techniques are reported to include, Computer Aided Software Engineering, Quality Function Deployment, Rapid Throwaway Prototyping, Iterative Enhancement and Development, Small Team Approach, Early Customer Feedback, and IBM Customer Quality Partnership Program. Process and technology is reported to include, Defect Prevention Process, Design Reviews, Software Inspection Process, Walk throughs, Vienna Development Method, Z Notation, Input/Output Requirements Language, Clean Room Methodology, Object Oriented Design and Programming, Computer Aided Software Engineering, and Software Reuse. Organizational behavior and measurement and analysis are reported to include Leadership and Empowerment and Quality, Reliability, and Structural Design.

Jones (1985), Mays, Jones, Holloway, and Studinski (1990), and Gale, Tirso, and Burchfield (1990) report that IBM Communication Systems designed a software defect prevention process (circa 1980 to 1984), resulting in the invention of IBM's most "powerful" SPI method used by IBM worldwide (Kaplan, Clark, and Tang, 1995). Jones reports that IBM's SPI method consists of five components, stage kickoff meetings, causal analysis meetings, action databases, action teams, and repositories (see Figure 6). Jones reports that stage kickoff meetings are held to remind the stage participants of common errors to avoid. Jones reports that causal analysis meetings are held after the stage is complete to review the defects

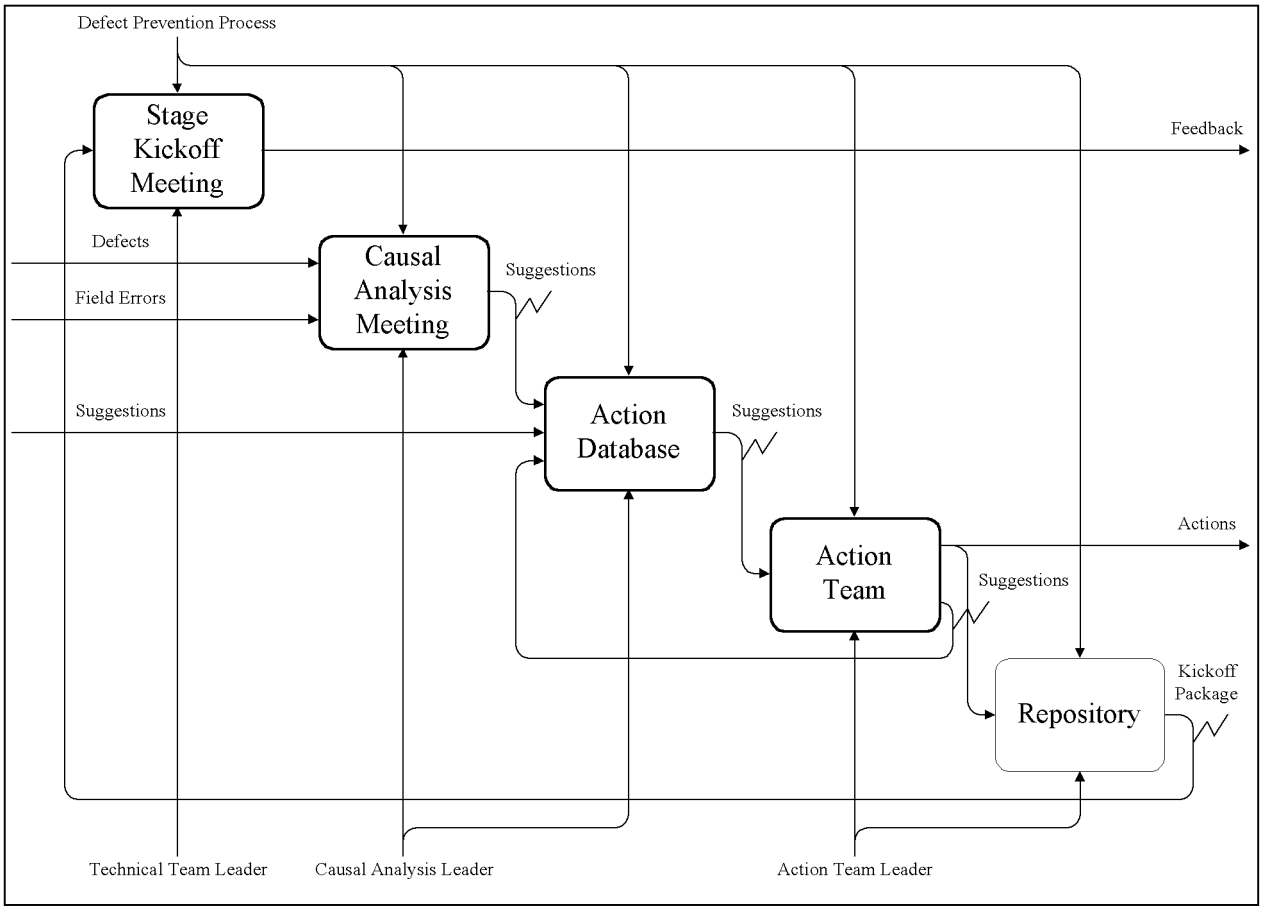

Figure 6. IBM Research Triangle Park Defect Prevention

committed during the stage, and plan defect prevention. Jones reports that an action database is used to formally capture and manage defect prevention measures identified by causal analysis meetings. Jones reports that action teams meet to implement suggestions identified by causal analysis meetings. Finally, Jones reports that a repository is used to store actions for stage kickoff meetings.

Chillarege, Bhandari, Chaar, Halliday, Moebus, Ray, and Wong (1992), Bhandari, Halliday, Chaar, Chillarege, Jones, Atkinson, Lepori-Costello, Jasper, Tarver, Lewis, and Yonezawa (1994), Bassin, Kratschmer, and Santhanam (1998), and Mendonca, Basili, Bhandari, and Dawson (1998) describe Orthogonal Defect Classification (ODC) as a SPI method (see Figure 7). Chillarege et al. and Bhandari et al. report that IBM's Thomas J. Watson Research Center created ODC to perfect and automate defect identification, classification, and prevention.

Chillarege et al. and Bhandari et al. report that ODC is a seven step process of identifying defects, identifying defect triggers, correcting defects, identifying defect types, performing attribute focusing, identifying process improvements, and improving processes. Chillarege et al. and Bhandari et al. report that identifying defects is primarily a result of software verification and validation processes such as the Software Inspection Process, software testing, and even ad hoc sources such as customer discovery. Chillarege et al. and Bhandari et al. report that identifying defect triggers is a process of identifying the activity that was being carried out when the defect was discovered, such as the Software Inspection

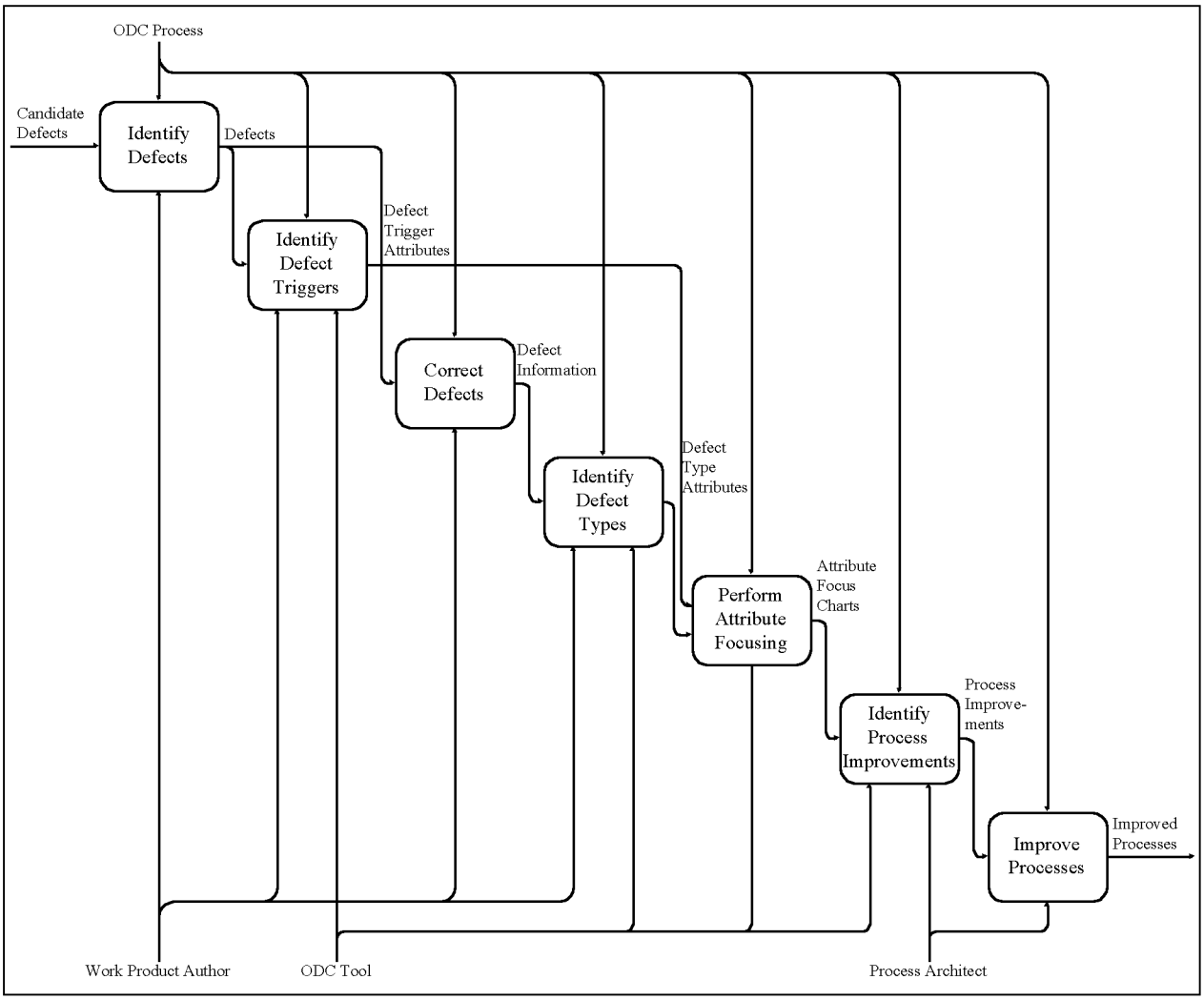

Figure 7. IBM's Orthogonal Defect Classification (ODC) Process

Process, unit testing, function testing, and system testing. Chillarege et al. and Bhandari et al. report that correcting defects is a process of repairing the discovered problem, often times associated with the Rework Phase of the Software Inspection Process. Chillarege et al. and Bhandari et al. report that identifying defect types is a process of identifying the kind of defect that was discovered during structured and ad hoc software verification and validation, such as assignment/serialization, checking, algorithm/method, function/class/object, timing/serialization, interface/OO messages, and relationship. Chillarege et al. and Bhandari et al. report that performing attribute focusing is a process of developing defect trigger attribute distributions which determine the effectiveness of individual software verification and validation activities, and defect type attribute signatures which determine the health of the software work product at any given stage of development. Chillarege et al. and Bhandari et al. report that identifying process improvements is both an automatic and manual process of determining what needs to be done to correct a deficient product and the means of long term process correction based on defect trigger attribute

Table 17: IBM Houston NASA Space Shuttle Software Process Improvement (SPI)

Period	Strategy	Specific Technique
1970s	Project Management	Requirements Analysis Software Architecture Review Board Schedule Measurement Cost Measurement
	Quality Assurance	Problem Report Tracking Design Reviews Code Reviews
	Testing	Independent Testing Simulation Testing Testing on Actual Flight Hardware
1980s	Configuration Management	Customer Configuration Control Board Support Software Board Discrepancy Report Board Requirements Review Board
	Life Cycle Management	Requirements Planning Incremental Release Strategy Independent Verification
	Process Assessments	NASA Excellence Award Malcolm Baldrige National Quality Award IBM Quality Award SKI Capability Maturity Model for Software
	Software Quality Management	Defect Density Metrics Software Inspection Process Defect Prevention Process Software Reliability Modeling
	Organizational Improvement	Requirements Analysis Process Software Inspection Process
1990s	Software Process Enactment	Automated Software Metrics Automated Testing
	Process Ownership Teams	Requirements, Design, and Code Teams Development and Independent Test Teams

distributions and defect type attribute signatures. Chillarege et al. and Bhandari et al. report that improving processes is a manual process of correcting software management and development processes to prevent software process and product failures.

Billings, Clifton, Kolkhorst, Lee, and Wingert (1994) report that IBM Houston's NASA Space Shuttle program used a measurement-intensive software quality management life cycle as a primary SPI method from 1976 to 1993, resulting in CMM Level 5, NASA Excellence Award, IBM Best Software Lab, and IBM Silver Level (see Table 17).

Billings, Clifton, Kolkhorst, Lee, and Wingert report that IBM Houston's SPI strategy consisted of ten principle elements, project management, quality assurance, testing, configuration management, life cycle management, process assessments, software quality management, organizational improvement, software process enactment, and process ownership teams. Project management is reported to have consisted of requirements analysis, a Software Architecture Review Board, schedule measurement, and cost measurement. Quality assurance is reported to have consisted of problem report tracking, design reviews, and code reviews. Testing is reported to have consisted of independent testing, simulation testing, and testing on actual flight hardware. Configuration management is reported to have consisted of a Customer Configuration Control Board, a Support Software Board, a Discrepancy Report Board, and a Requirements Review Board. Life cycle management is reported to have consisted of requirements planning, an incremental release strategy, and independent verification. Process assessments are reported to have consisted of pursuit and receipt of the NASA Excellence Award, pursuit of the Malcolm Baldrige National Quality Award, pursuit and receipt of the IBM Quality Award, and pursuit of the SEI Capability Maturity Model for Software (CMM), receiving a CMM Level 5 rating. Software quality management is reported to have consisted of the use of defect density metrics, the Software Inspection Process, the Defect Prevention Process, and software reliability modeling. Organizational improvement is reported to have consisted of scaling up the requirements analysis process and the Software Inspection Process organization wide. Software process enactment is reported to have consisted of automated software metrics and automated testing. Process ownership teams are reported to have consisted of requirements, design, code, development, and independent test teams.

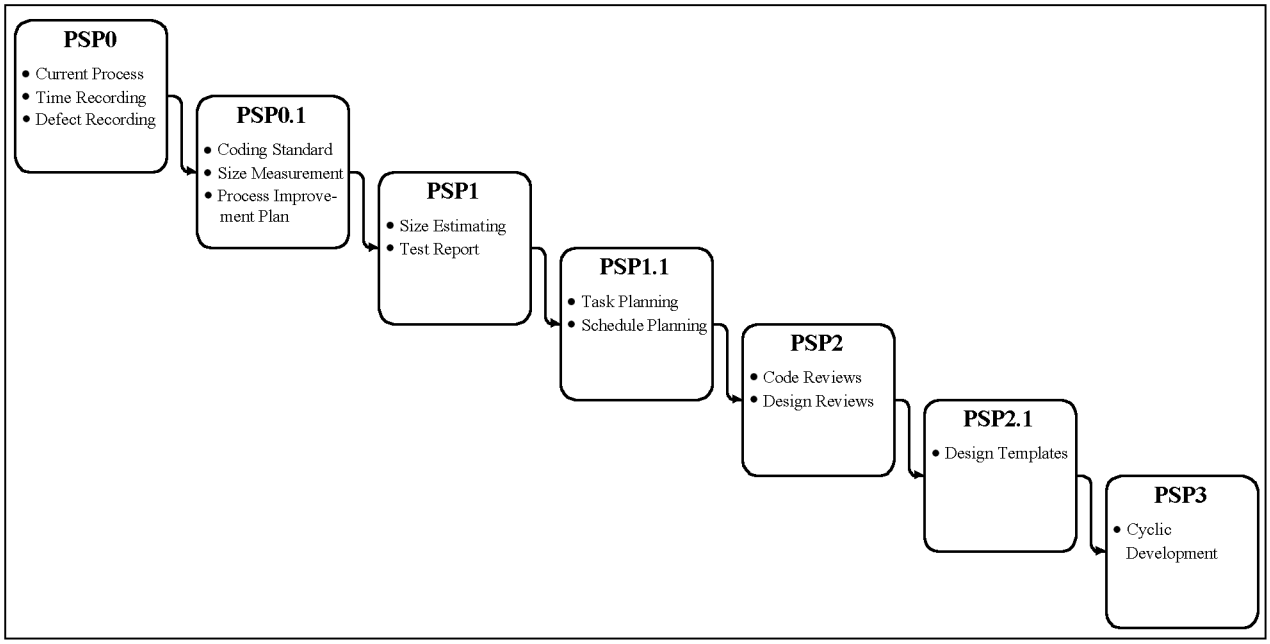

Figure 8. Family of Seven Personal Software Process (PSP) Life-Cycles

Humphrey (1995, 1996, 1997, 1998a, and 1998b), Ferguson, Humphrey, Khajenoori, Macke, and Matvya (1997), Hays and Over (1997), and Webb and Humphrey (1999) report that the Software Engineering Institute (SEI) created the Personal Software Process (PSP) as a quantitative SPI method in the late 1980s and early 1990s. Humphrey reports that the PSP is a family of seven software life cycles, PSP0 Personal Measurement, PSP0.1 Personal Measurement, PSP1 Personal Planning, PSP1.1 Personal Planning, PSP2 Personal Quality, PSP2.1 Personal Quality, and PSP3 Cyclic Development (see Figure 8).

PSP0, Personal Measurement, consists of the current process, time recording, and defect recording. PSP0.1, Personal Measurement, adds a coding standard, size measurement, and a process improvement plan. PSP1, Personal Planning, adds size estimating and test reporting. PSP1.1, Personal Planning, adds task planning and schedule planning. PSP2, Personal Quality, adds code reviews and design reviews. PSP2.1, Personal Quality, add design templates. And, PSP3, Cyclic Development, adds iteration.

PSP3, Cyclic Development consists of five phases or stages, Planning, High Level Design, High Level Design Review, Development, and Postmortem (see Figure 9).

Planning consists of program requirements, size estimate, cyclic development strategy, resource estimates, task/schedule planning, and a defect estimate. High Level Design consists of external specifications, module design, prototypes, development strategy and documentation, and an issue tracking log. High Level Design Review consists of design coverage, state machine, logic, design consistency, reuse, and development strategy verification, and defect fixes. Development consists of module design, design review, coding, code review, compile, test, and reassessment/recycling. Postmortem consists of tracking defects, size, and time.

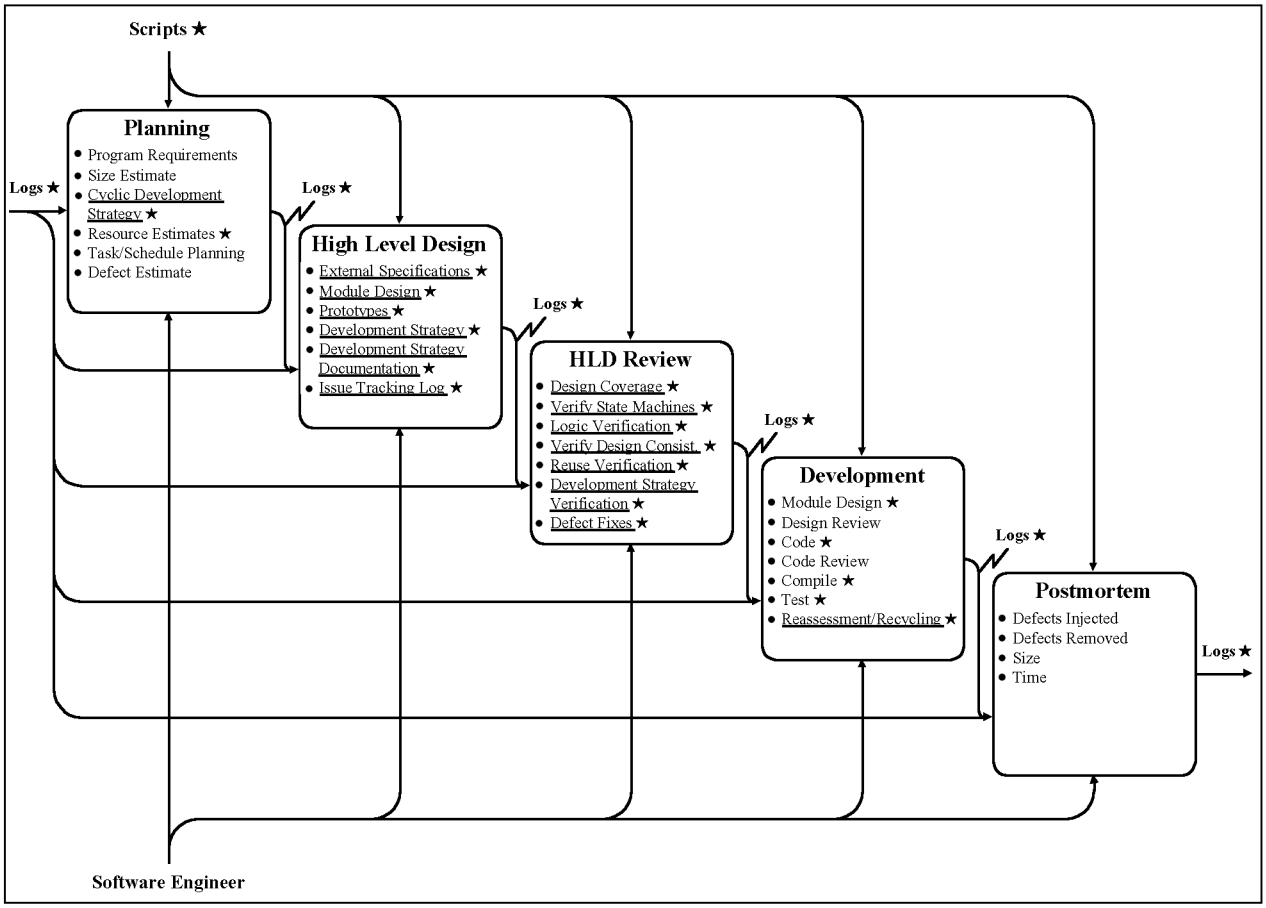

Figure 9. Personal Software Process (PSP) 3-Cycle Development Life-Cycle

Grady (1997) reports that Hewlett Packard Divisions align SPI strategies with core competencies (see Table 18). One Hewlett Packard Division identified its core competencies as quality control, process execution and predictability, and product enhancing, updates, and delivery. The quality control core competency consisted of five SPI solutions, quality planning, defect tracking, inspections, reliability modeling, and regression testing. The process execution and predictability core competency consisted of process definition, project planning, product architecture/design, defect tracking, failure analysis, the Software Inspection Process, software configuration management, and a release process. The product enhancing, updates, and delivery core competency consisted of defect tracking, software configuration management, on-line support, customer feedback capture, and installation automation.

Table 18: Hewlett Packard Divisional Software Process Improvement (SPI) Strategy

Core Competency	Strategy	Advantage/Need
Quality Control	Quality Planning	Quality prioritization
	Defect Tracking	Quality focus and prioritization
	Software Inspection Process	Inspect all specifications and designs
	Reliability Modeling	Tune model to different applications
	Regression Testing	Reduce time to do
Process Execution	Process Definition	Obtain ISO 9000 certification
	Project Planning	Create recommended model
	Product Architecture/Design	Create better design
	Defect Tracking	Quality focus and prioritization
	Failure Analysis	Assign ownership for action
	Software Inspection Process	Inspect all specifications and designs
	Configuration Management	Upgrade to supported model
	Release Process	Document and standardize
Product Enhancement	Defect Tracking	Quality focus and prioritization
	Configuration Management	Upgrade to supported model
	On-Line Support	Use full response-center resources
	Customer Feedback Capture	Create portfolio of customer surveys
	Installation Automation	Eliminate all need for hand holding

Grady (1997) goes on to report that Hewlett Packard developed a standard portfolio of SPI strategies (see Table 19). Hewlett Packard's SPI strategy portfolio consists of eleven individual SPI strategies or tactics, product definition improvement, detailed design methods, rapid prototyping, systems design improvements, the Software Inspection Process, software reuse, complexity analysis, configuration management, a certification process, software asset management, and program understanding.

Grady (1997), Barnard and Price (1994), Grady and Van Slack (1994), Weller (1993), Russell (1991), Sulack, Lindner, and Dietz (1989), and Fagan (1986 and 1976) report that Hewlett Packard, AT&T Bell Laboratories, Bull HN Information Systems, and IBM used the Software Inspection Process as a SPI strategy. Fagan reports that the Software Inspection Process is a highly structured technique for identifying and removing defects from intermediate software work products by team evaluation (see Figure 10). While technically the Software Inspection Process is a product appraisal process typically associated with late and ineffective final manufacturing inspections, the Software Inspection Process can be performed throughout a software product life cycle, including the very early stages. Fagan reports that the Software Inspection Process was invented by IBM in 1972, and is composed of six major subprocesses, Planning, Overview, Preparation, Meeting, Rework, and Follow-up. Planning is to determine whether an intermediate software work product is ready for team evaluation and to plan the team evaluation. Overview is to introduce the software work product to the team for later evaluation.

Preparation is for team members to individually review and evaluate the software work product. Meetings are to conduct the team evaluation of the software work product and identify defects. Rework is to repair defects in the software work product identified by the team inspection. Finally, Follow-ups are to determine whether the defects were repaired and certify the software work product as inspected. Fagan reports that the Software Inspection Process is a concisely defined, step-by-step, and time-constrained process with very specific objectives.

Table 19: Hewlett Packard Corporate Software Process Improvement (SPI) Strategies

Strategy	Applicability
Product Definition Improvement	Organizations that create new products
Detailed Design Methods	Systems with many interfaces
Rapid Prototyping	Complex user interface and applications
Systems Design Improvements	Chronic schedule slips due to design issues
Software Inspection Process	All projects
Software Reuse	Stable environment/configuration management
Complexity Analysis	Systems software and firmware
Configuration Management	Large and complex software product portfolio
Certification Process	All projects
Software Asset Management	Divisions with old existing code
Program Understanding	All maintenance and porting projects

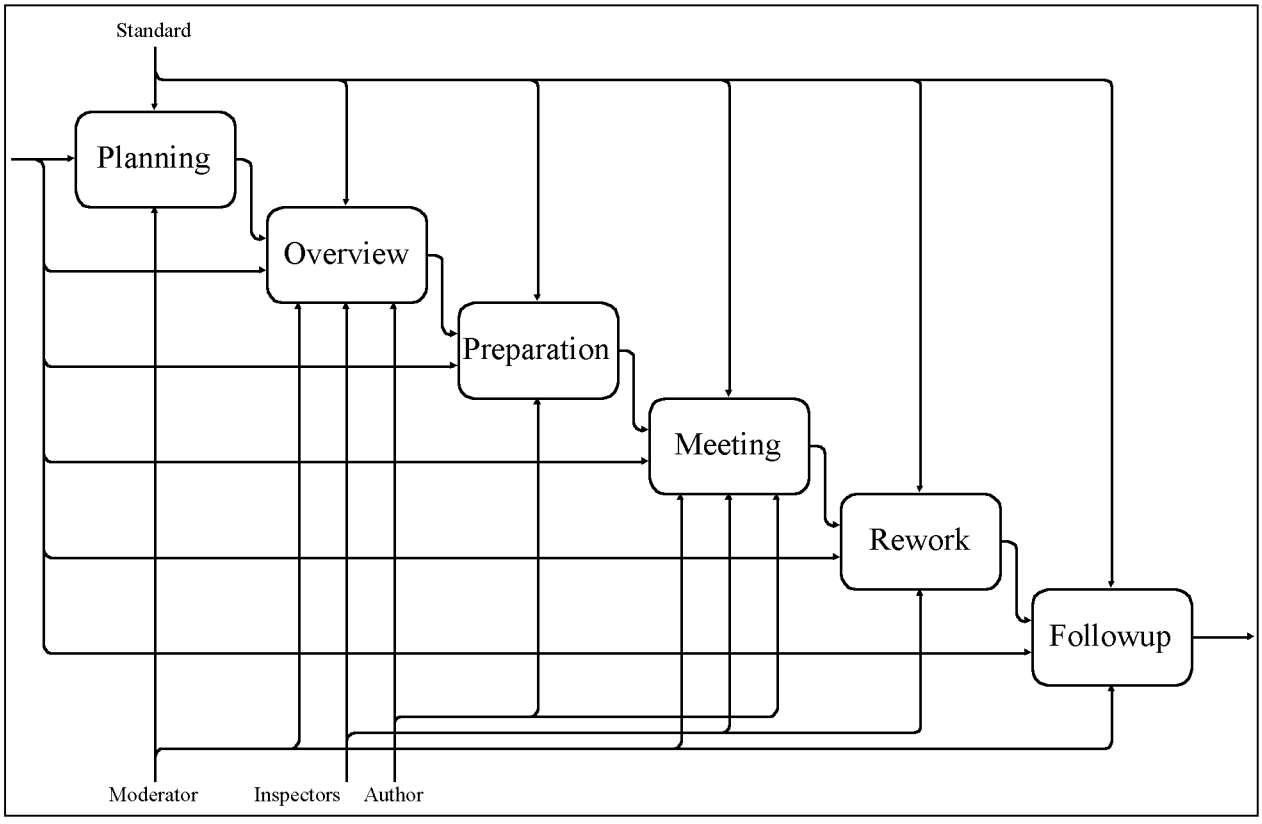

Figure 10. Software Inspection Process

Cusumano (1991) reports that the Massachusetts Institute of Technology (MIT) Sloan School of Management conducted a study of the four largest Japanese computer and software manufacturers from 1985 to 1989, yielding eleven common SPI strategies used by Fujitsu, NEC, Hitachi, and Toshiba (see Table 20). Japan's SPI strategies included, strategic management and integration, planned economies of scope, commitment to process improvement, product-process focus and segmentation, process-quality analysis and control, tailored and centralized process R&D, skills standardization and leverage, dynamic standardization, systematic reusability, computer-aided tools and integration, and incremental product/ variety improvement.

Table 20: Hitachi, Toshib,. NEC, and Fujitsu Software Process Improvement (SPI)

Time frame	Strategy	Specific Technique
Mid 1960s	Strategic Management and Integration	Establishment of process improvement agendas Facility establishment focused on single products Skill, standard, method, tool, and reuse tailoring
	Planned Economies of Scope	Developing a series of products within a facility Deliberate sharing of resources across projects Standard, method, tool, and product sharing
	Commitment to Process Improvement	Long-term process improvement commitment Serious commitment from top managers Policy, control, and incentive instituted
Early 1970s	Product-Process Focus and Segmentation	Focus on particular types of products Knowledge accumulation for applications Process segmentation and work channelization
	Skills Standardization and Leverage	Extensive training of all new recruits Training in standard process, methods and tools Capability improvement for process and quality
Late 1970s	Process-Quality Analysis and Control	Predictability in cost and scheduling Defect control Standard processes, methods, and tools
	Tailored and Centralized Process R&D	Division and facility process R&D centralization Centralized tool and methodology R&D Joint research between central laboratories
Early 1980s	Dynamic Standardization	Periodic review and change of standards Tool and technique refinement Standards for personnel performance
Mid 1980s	Systematic Reusability	Reuse tools, libraries, rewards, and controls Systematic component reuse across products Management planning, controls, and incentives
	Computer-Aided Tools and Integration	Computer-aided software engineering tools Project, data, reuse, quality, and analysis tools Extensive tool and method integration
Late 1980s	Incremental Product/Variety Improvement	Product design and performance upgrading Strong focus on design Product variety expansion in individual factories

Cusumano and Selby (1995 and 1997) report that the Massachusetts Institute of Technology (MIT) Sloan School of Management conducted a case study of software management at the Microsoft Corporation from 1993 to 1995. Cusumano and Selby, identified seven major management strategies used by Microsoft (see Table 21). The seven strategies are, find smart people who know the technology, organize small teams of overlapping functional specialists, pioneer and orchestrate evolving mass markets, focus creativity by evolving features and "fixing" resources, do everything in parallel with frequent synchronizations, improve through continuous self-critiquing, feedback, and sharing, and attack the future.

Table 21: Microsoft Software Process Improvement (SPI) Strategies

Strategy	Specific Technique
Find Smart People	Hire a CEO with a deep understanding of both the technology and the business Organize flexibly around and across product markets and business functions Hire the smartest managers you can find Hire the smartest employees you can find
Organize Small Teams	Establish functional specialties, work in small teams and overlap responsibilities Let functional experts define and hire for their technical specialties Educate new hires through learning by doing and mentoring Create career paths and "ladder levels" to retain and reward technical people
Evolve Mass Markets	Enter evolving mass markets early or stimulate new markets with good products Incrementally improve new products and make old products obsolete Push volume sales and exclusive contracts to ensure products become standards Take advantage of being the standards provider with new products Integrate, extend, and simplify products to reach new mass markets
Evolve Product Features	Divide large projects into multiple milestone cycles with no maintenance cycles Use a vision statement and outline specification of features to guide projects Base feature selection and prioritization on user activities and data Evolve a modular and horizontal design architecture with a mirror organization Control by individual commitments to small tasks and "fixed" project resources
Parallelize Activities	Work in parallel teams, but "synch up" and debug daily Always have products you can theoretically ship with versions for every market Speak a common language on a single development site Continuously test the product as you build it Use metric data to determine milestone completion and product release
Continuous Self Critique	Systematically learn from past and present projects and products Encourage feedback and improvement with quantitative metrics and benchmarks View customer support as part of the product and as data for improvement Promote linkages and sharing across product groups
Attack the Future	Create products and services for consumers instead of software developers Create up-front, per-activity, and per-transaction pricing structures Create simple unified product and service offerings on yearly cycles Blur the distinctions between applications, operating systems, and networks Blur the differences between computers, televisions and cable television systems

Cusumano and Selby identified “synch-and-stabilize” approach as a critical Microsoft software development strategy consisting of seven processes (see Table 22). Cusumano and Selby further report the existence of a critically-important, eleven step daily build process.

Table 22: Microsoft Synch-and-Stabilize Software Development Approach

Software Development Strategy
Product development and testing done in parallel
Vision statement and evolving specification
Features prioritized and built in 3 or 4 milestone subprojects
Frequent synchronizations (daily builds) and intermediate stabilizations (milestones) • Check Out: Check out private copies of the source code from a central master version of the source code • Implement Feature: Implement the feature by making changes, adding, or deleting source code • Build Private Release: Build a private version of the product using private copies of source code • Test Private Release: Test the private release of the product to make sure the new feature works • Synch Code Changes: Compare the private copies of source code to master versions for differences • Merge Code Changes: Update private copies of source code with other changes to the same source code • Build private Release: Build a private release with individual as well as group source code changes • Test Private Release: Test the private release to make sure that newly implemented features work • Execute Quick Test: Execute a highly automated “smoke test” on the private release of source code • Check In: Check in source code if the private release and quick test are successful • Generate Daily Build: “Build Master” generates complete build using central master source code version
“Fixed” release and ship dates and multiple release cycles
Customer feedback continuous in the development process
Product and process design so that large teams work like small teams

Cusumano and Yoffie (1998) report that the Massachusetts Institute of Technology (MIT) Sloan School of Management conducted a study of software management at the Netscape Corporation from 1996 to 1998. Cusumano and Yoffie identified four major software management strategies in use at Netscape (see Table 23).

The four strategies consisted of, scaling an organization on Internet time, formulating judo strategy on Internet time, designing software on Internet time, and developing software on Internet time. Scaling an organization consists of, create a compelling, living vision of products, technologies, and markets, hire and acquire managerial experience, in addition to technical expertise, build the internal resources for a big company, while organizing like a small one, and build external relationships to compensate for limited internal resources. Formulating judo strategy consists of, move rapidly to uncontested ground, be flexible and give way when attacked directly by superior force, exploit leverage that uses the weight and strategy of opponents against them, and avoid sumo competitions, unless you have the strength to overpower your opponent. Designing software consists of, design products for multiple markets (platforms) concurrently, design and redesign products to have more modular architectures, design common components that multiple product teams can share, and design new products and features for parallel development. Developing software consists of, adapt development priorities as products, markets, and customers change, allow features to evolve but with frequent synchronizations and periodic stabilizations, automate as much testing as possible, and use beta testing, internal product usage, and other measures to improve product and process quality.

Table 23: Netscape Principles for Competing on Internet Time

Strategy
Scaling an Organization on Internet Time • Create a compelling, living vision of products, technologies, and markets that is tightly linked to action • Hire and acquire managerial experience, in addition to technical expertise • Build the internal resources for big company, while organizing like a small one • Build external relationships to compensate for limited internal resources
Formulating Judo Strategy on Internet Time • Move rapidly to uncontested ground in order to avoid head-to-head combat • Be flexible and give way when attacked directly by superior force • Exploit leverage that uses the right and strategy of opponents against them • Avoid sumo competitions, unless you have the strength to overpower your opponent
Designing Software on Internet Time • Design products for multiple markets (platforms) concurrently • Design and redesign products to have more modular architectures • Design common components that multiple product teams can share • Design new products and features for parallel development
Developing Software on Internet Time • Adapt development priorities as products, markets, and customers change • Allow features to evolve but with frequent synchronizations and periodic stabilizations • Automate as much testing as possible • Use beta testing, internal product usage, and other measures to improve product and process quality

Tingey (1997) of the IBM Corporation in New York, New York conducted an analysis of three leading international quality management systems (QMS), identifying three major SPI strategies. Tingey identified the Malcolm Baldrige National Quality Award, the International Organization for Standardization (ISO) 9001, and the Software Engineering Institute's (SEI's) Capability Maturity Model (CMM) for Software (see Table 24). The Malcolm Baldrige National Quality Award is composed of seven components, Leadership, Information and Analysis, Strategic Planning, Human Resource Development and Management, Process Management, Business Results, and Customer Focus and Satisfaction. ISO 9001 is composed of twenty components, the first ten of which are Management Responsibility, Quality System, Contract Review, Design Control, Document/Data Control, Purchasing, Control of Customer-Supplied Product, Product Identification and Traceability, Process Control, and Inspection and Testing. The last ten ISO 9001 components are Control of Inspection, Measuring, and Test Equipment, Inspection and Test Status, Control of Nonconforming Product, Corrective and Preventative Action, Handling, Storage, Packaging, Preservation, and Delivery, Control of Quality Records, Internal Quality Audits, Training, Servicing, and Statistical Techniques. The SEI's CMM is composed five components or Levels, Initial, Repeatable, Defined, Managed, and Optimizing.

The last ten ISO 9001 components are Control of Inspection, Measuring, and Test Equipment, Inspection and Test Status, Control of Nonconforming Product, Corrective and Preventative Action, Handling, Storage, Packaging, Preservation, and Delivery, Control of Quality Records, Internal Quality Audits, Training, Servicing, and Statistical Techniques. The SEI's CMM is composed of five components or Levels, Initial, Repeatable, Defined, Managed, and Optimizing.

Table 24: ISO 9001, Malcolm Baldrige and Capability Model Elements

ISO 9001	Malcolm Baldrige	Capability Maturity Model
Management Responsibility	LEADERSHIP	INITIAL
Quality System	• Senior Executive Leadership	• N/A
Contract Review	• Leadership System and Organization	
Design Control	• Public/Corporate Citizenship	REPEATABLE
Document and Data Control		• Requirements Management
Purchasing	INFORMATION AND ANALYSIS	• Software Project Planning
Control of Customer-Supplied Product	• Management of Information and Data	• Software Project Tracking/Oversight
Product Identification and Traceability	• Competitive Compare/Benchmark	• Software Subcontract Management
Process Control	• Analysts and Uses of Company Data	• Software Quality Assurance
Inspection and Testing		• Software Configuration Management
Control of Inspection/Test Equipment	STRATEGIC PLANNING	
Inspection and Test Status	• Strategy Development	DEFINED
Control of Nonconforming Product	• Strategy Deployment	• Organization Process Focus
Corrective and Preventative Action		• Organization Process Definition
Handling/Storage/Packaging/Delivery	HUMAN RESOURCES	• Training Program
Control of Quality Records	• Human Resource Planning/Evaluate	• Integrated Software Management
Internal Quality Audits	• High Performance Work Systems	• Software Product Engineering
Training	• Employee Education and Training	• Intergroup Coordination
Servicing	• Employee Well-Being/Satisfaction	• Peer Reviews
Statistical Techniques		
	PROCESS MANAGEMENT	MANAGED
	• Design/introduction Product/Service	• Quantitative Process Management
	• Product/Service Production/Delivery	• Software Quality Management
	• Support Service	
	• Management of Supplier Performance	OPTIMIZING
		• Defect Prevention
	BUSINESS RESULTS	• Technology Change Management
	• Product and Service Quality Results	• Process Change Management
	• Operational/Financial Results	
	• Supplier Performance Results	
	CUSTOMER SATISFACTION	
	• Customer and Market Knowledge	
	• Customer Relationship Management	
	• Customer Satisfaction Determination	
	• Customer Satisfaction Results	
	• Customer Satisfaction Comparison	

Harrington (1995) identifies six major organizational improvement strategies, Total Cost Management, Total Productivity Management, Total Quality Management, Total Resource Management, Total Technology Management, and Total Business Management (see Table 25).

Table 25: Organizational Improvement Strategies

Strategy	Element, Component, Activity, Method, or Technique
Total Cost Management	Activity-Based Costing (ABC) Just-in-Time (JIT) Cost Accounting Process Value Analysis (PVA) Performance Management Responsibility Accounting Integrated Financial Reporting Poor-Quality Cost
Total Productivity Management	Lessening of government regulations Invest in capital equipment Invest in research and development Make all management aware of the problem Make effective use of creative problem solving Increase use of automation and robotics Increase teamwork and employee involvement Expand international markets Do the job right the first time
Total Quality Management	Start with top management involvement Educate all levels of management Understand your external customer's requirements Prevent errors from occurring Use statistical methods to solve problems and control processes Train all employees in team and problem-solving methods Focus on the process as the problem, not the people Have a few good suppliers Establish quality and customer-related measurements Focus on the internal as well as external customers Use teams at all levels to solve problems and make decisions
Total Resource Management	Aggressive employee training and empowerment Effective and efficient inventory management Optimal floor space management
Total Technology Management	Use the most advanced technology Focus on applied research Use concurrent engineering Capitalize on using information technology (IT)
Total Business Management	Product and service diversification analysis Consolidation analysis Product support analysis Technology analysis Business-line analysis Investment analysis

Total Cost Management (TCM) is composed of seven tools, Activity-Based Costing (ABC), Just-in-Time (JIT) Cost Accounting, Process Value Analysis (PVA), performance management, responsibility accounting, integrated financial reporting, and poor-quality cost. Total Productivity Management (TPM) is composed of nine steps, the first four of which are lessening of government regulations, invest in capital equipment, invest in research and development, and make all management aware of the problem. The last five Total Productivity Management (TPM) steps are, make effective use of creative problem solving, increase use of automation and robotics, increase teamwork and employee involvement, expand international markets, and do the job right the first time. Total Quality Management (TQM) is composed of eleven elements, the first five of which are, start with top management involvement, educate all levels of management, understand your external customer's requirements, prevent errors from occurring, and use statistical methods to solve problems and control processes. The last six TQM steps are, train all employees in team and problem-solving methods, focus on the process as the problem, have a few good suppliers, establish quality and customer-related measurements, focus on the internal as well as external customers, and use teams at all levels to solve problems. Total Resource Management (TRM) is comprised of three elements, aggressive employee training and empowerment, effective and efficient inventory management, and optimal floor space management. Total Technology Management (TTM) is comprised of four activities, use the most advanced technology, focus on applied research, use concurrent engineering, and capitalize on using information technology (IT). Total Business Management (TBM) consists of six elements, product and service diversification analysis, consolidation analysis, product support analysis, technology analysis, business-line analysis, and investment analysis.

McConnell (1996) conducted an analysis of software management and development best practices or SPI strategies, identifying twenty-seven individual strategies (see Table 26).

Table 26: Steve McConnell's Software Best Practices

Strategy	Specific Technique
Change Board	An approach to controlling changes to a software product
Daily Build and Smoke Test	A process in which a software product is completely built every day
Designing for Change	Designing a software product for easy maintenance programming
Evolutionary Delivery	A balance between staged delivery and evolutionary Prototyping
Evolutionary Prototyping	A life cycle model in which the system is developed in increments
Goal Setting	Establishment and commitment to a small, clear set of goals
Software Inspection Process	Product appraisal process optimized for software defect identification
Joint Application Development	A requirements-definition and user-interface design methodology
Life Cycle Model Selection	Use of a software life cycle contingency model
Measurement	The use of software metrics, models, and measurements
Miniature Milestones	A fine-grained approach to software project tracking and control
Outsourcing	Paying an outside organization to develop a software product
Principled Negotiation	Strategy for improved communications and creation of win-win options
Productivity Environments	The use of private, noise-free office space for software developers
Rapid-Development Languages	High productivity, fourth generation programming languages
Requirements Scrubbing	The elimination of complex software requirements from specifications
Reuse	The development and use of prefabricated software source code
Signing Up	Process of building individual and team esteem and belief in a project
Spiral Life Cycle Model	Life cycle model involving iteration, risk management and prototyping
Staged Delivery	A life cycle model in which software is developed in stages
Theory-W Management	Establishment of a software project in which all stakeholders benefit
Throwaway Prototyping	Production of temporary software models for requirements elicitation
Timebox Development	A construction-time practice that helps to infuse a sense of urgency
Tools Group	Organization responsible for identifying software development tools
Top-10 Risks List	Managing projects based on prioritizing critical problem areas
User-lnterface Prototyping	Use of temporary user interface models for eliciting requirements
Voluntary Overtime	Motivation of software developers to work hard for intangible rewards

The first thirteen SPI strategies are, Change Boards, Daily Builds, Designing for Change, Evolutionary Delivery, Evolutionary Prototyping, Goal Setting, Inspections, Joint Application Development, Life Cycle Model Selection, Measurement, Miniature Milestones, Outsourcing, and Principled Negotiation. The last 14 SPI strategies are, Productivity Environments, Rapid-Development Languages, Requirements Scrubbing, Reuse, Signing Up, Spiral Life Cycle, Staged Delivery, Theory-W Management, Throwaway Prototyping, Timebox Development, Tools Group, Top-10 Risks List, User-Interface Prototyping, and Voluntary Overtime.

Kaplan, Clark, and Tang (1995) report that IBM's Santa Teresa software development laboratories in Silicon Valley, California, used 40 innovations or SPI strategies from 1989 to 1995, resulting in the award of IBM's highest and most prestigious quality award, IBM's gold medal for excellence (see Table 27).

Table 27: IBM Santa Teresa Software Process Improvement (SPI) Strategies

Baldrige Stage	Leadership Category	Process Category	Technology Category
Awareness	The Excellence Council Departmental Quality Strategy Seminar Series The Leadership Institute Quality Publications	Programming Handbooks Extended Unit Testing	Satisfaction Surveys Joint Application Development Process Modeling Methods
Coping	Center for Software Excellence The Council System	ISO 9000 Software Inspection Process Early Test Involvement Combined Line Item Test	Error-Prone Module Analysis High-Risk Module Analysis Customer Survey Data Analysis
Management	Strategic Focus Empowerment Quality Week	Defect Prevention Process Process Benchmarking Analysis of the Competition	Computerized Team Workspaces Electronic Meetings On-Line Reviews LAN Library Control System Object-Oriented Design Rapid Prototyping Clean Room Methodology
Integration	Continuous Improvement Reviews Quality Exchanges WorkForce 2000	Quality Partnerships Business Partner Quality Process	Performance Mining Orthogonal Defect Classification Quality Return on Investment

The first ten SPI strategies are, The Excellence Council, Departmental Quality Strategies, Seminar Series, The Leadership Institute, Quality Publications, Programming Development Handbooks, Extended Unit Testing, Satisfaction Surveys, Joint Application Development, and Process Modeling Methods and Tools. SPI strategies eleven through twenty are, The Center for Software Excellence, The Council System, an ISO 9000 strategy, Rigorous Code Inspections, Early Test Involvement, Combined Line Item and Function Test, Error-Prone Module Analysis, High-Risk Module Analysis, Customer Survey Data Linkage Analysis, and Strategic Focus. SPI strategies twenty-one through thirty are, Empowerment, Quality Week, Defect Prevention, Process Benchmarking, Analysis of the Competition, Computer-Supported Team Work Spaces, Electronic Meetings, On-line Reviews, Local Area Network Library Control Systems, and Object-Oriented Design and Coding. The final ten SPI strategies are, Rapid Prototyping, Clean Room Techniques, Continuous Improvement Reviews, Quality Exchanges, Workforce 2000, Quality Partnerships with Customers, Business Partner Quality Process, Performance Mining, Orthogonal Defect Classification, and Quality Return-on-Investment.

Austin and Paulish (1993) of the Software Engineering Institute (SEI) at Carnegie Mellon University (CMU) conducted a survey of software process improvement in the early 1990s, identifying thirteen principle strategies (see Table 28).

Table 28: SEI-Identified Software Process Improvement (SPI) Strategies

Scope	Strategy	CMM Level	Principle Key Process Area
Environment	ISO 9000	3	Organization Process Definition
	Interdisciplinary Group Method	3	Intergroup Coordination
	Total Quality Management	3	Organization Process Focus
	Software Metrics	4	Quantitative Process Management
Product	Software Inspection Process	3	Peer Reviews
	Software Reliability Engineering	4	Quantitative Process Management
	Quality Function Deployment	4	Software Quality Management
Process	Estimation	2	Software Project Planning
	Software Process Assessment	3	Organization Process Focus
	Process Definition	3	Organization Process Definition
	Clean Room Methodology	4	Software Quality Management
	CASE Tools	5	Technology Change Management
	Defect Prevention Process	5	Defect Prevention

The thirteen SPI strategies included, estimation, ISO 9000, Software Process Assessment (SPA), process definition, Software Inspection Process, software metrics, computer-aided software engineering (CASE), Interdisciplinary Group Methods (IGMs), software reliability engineering, Quality Function Deployment (QFD), Total Quality Management (TQM), the Defect Prevention Process, and the Clean Room Methodology.

Davenport (1993) conducted a survey of organizational improvement strategies and methods at over 70 international businesses in the early 1990s, identifying two broad classes of organizational improvement strategies, Process Improvement strategies and Process Innovation strategies (see Table 29). Process Improvement strategies include, Activity-Based Costing (ABC), Process Value Analysis (PVA), Business Process Improvement (BPI), Total Quality Management (TQM), and Industrial Engineering (IE). Davenport reports that Process Innovation is an entire class unto itself that is sharply distinguished from ordinary process improvement consisting of heavy doses of automation and information technology (IT) to make broad-based sweeping organizational changes. The first fourteen of Davenport's Process Innovation strategies include, Computer Aided Software Engineering (CASE), code generation, conferencing, conventional programming, current applications, data gathering and analysis tools, decision analysis software, desktop graphics tools, Executive Information Systems (EIS), fourth-generation languages, general communications technologies, group decision-support systems, hypermedia, and idea generation tools. The second fourteen of Davenport's Process Innovation strategies include, information engineering, object-oriented programming, PC-based prototyping tools, process modeling tools, programmable databases and spreadsheets, project management tools, prototyping, rapid systems development techniques, simulation, story boarding, strategic application databases, systems reengineering products, technology trend databases, and very high-level languages.

Table 29: Process Innovation Strategies

Strategy	Technique
Process Improvement	Activity-Based Costing (ABC) Process Value Analysis (PVA) Business Process Improvement (BPI) Total Quality Management (TQM) Industrial Engineering (IE)
Process Innovation	Computer Aided Software Engineering (CASE) Code Generation Conferencing Conventional Programming Current Applications Data Gathering and Analysis Tools Decision Analysis Software Desktop Graphics Tools Executive Information Systems (EIS) Fourth-Generation Languages (4GL) General Communications Technologies Group Decision-Support Systems (GDSS) Hypermedia Idea Generation Tools Information Engineering Object-Oriented Programming (OOP) PC-Based Prototyping Tools Process Modeling Tools Programmable Databases and Spreadsheets Project Management Tools Prototyping Rapid Systems Development Techniques Simulation Story boarding Strategic Application Databases Systems Reengineering Products Technology Trend Databases Very High-Level Languages

Davenport further identifies Process Innovation strategies that accompany common organizational functions, such as, prototyping, research processes, engineering and design processes, manufacturing processes, logistics processes, marketing processes, sales and order management processes, service processes, and management processes (see Tables 30 and 31).

Table 30: Process Innovation Strategies Mapped to Organizational Functions

Organizational Function	Process Innovation Strategy
Prototyping	Fourth Generation Languages Object Oriented Languages Subroutine Libraries Databases Spreadsheets Hypermedia Story boarding Packages Code Generating CASE Tools
Research	Computer-Based Laboratory Modeling Computer-Based Field Trials Tracking and Project Management Systems Project Status Information Dissemination Systems
Engineering and Design	Computer-Aided Design and Physical Modeling Integrated Design Databases Standard Component Databases Design for Manufacturability Expert Systems Component Performance History Databases Conferencing Systems Across Design Functions Cross Functional Teams
Manufacturing	Linkages to Sales Systems for Build-to-Order Real-Time Systems for Custom Configuration Materials and Inventory Management Systems Robotics and Cell Controllers Diagnostic Systems for Maintenance Quality and Performance Information Work Teams
Logistics	Electronic Data Interchange and Payment Systems Configuration Systems Third-Party Shipment and Location Tracking Systems Close Partnerships with Customers and Suppliers Rich and Accurate Information Exchange

Process Innovation strategies for prototyping include, fourth-generation languages, object-oriented languages, subroutine libraries, databases, spreadsheets, hypermedia, story boarding packages, and code-generating CASE tools. Process Innovation strategies for research processes include, computer-based laboratory modeling, computer-based field trials, tracking and project management systems, and project status information dissemination systems. Process Innovation strategies for engineering and design processes include, computer-aided design and physical modeling, integrated design databases, standard component databases, design-for-manufacturability expert systems, component performance history databases, conferencing systems across design functions, and cross-functional teams. Process Innovation strategies for manufacturing processes include, linkages to sales systems for build-to-order, real-time

systems for custom configuration and delivery commitment, materials and inventory management systems, robotics and cell controllers, diagnostic systems for maintenance, quality and performance information, and work teams. Process Innovation strategies for logistics processes include, electronic data interchange and payment systems, configuration systems, third-party shipment and location tracking systems, close partnerships with customers and suppliers, and rich and accurate information exchange with suppliers and customers. Process Innovation strategies for marketing processes include, customer relationship databases/frequent buyer programs, point-of-sale systems tied to individual customer purchases, expert systems for data and trend analysis, statistical modeling of dynamic market environments, and close linkages to external marketing firms. Process Innovation Strategies for sales and order management processes include, prospect tracking and management systems, portable sales force automation systems, portable networking for field and customer site communications, and customer site workstations for order entry and status checking. More of Process Innovation strategies for sales and order management include, "choosing machines" that match products and services to customer needs, electronic data interchange between firms, expert systems for configuration, shipping, and pricing, and predictive modeling for continuous product replenishment.

Table 31: Process Innovation Strategies Mapped to Organizational Functions

Organizational Function	Process Innovation Strategy
Marketing	Customer Relationship Databases/Frequent Buyer Programs Point-of-Sale Systems Tied to Individual Customer Purchases Expert Systems for Data and Trend Analysis Statistical Modeling of Dynamic Market Environments Close Linkages to External Marketing Firms
Sales and Ordering	Prospect Tracking and Management Systems Portable Sales Force Automation Systems Portable Networking for Field and Customer Site Communications Customer Site Workstatioins for Order Entry and Status Checking "Choosing Machines" that Match Products and Services to Customer Needs Electronic Data Interchange Between Firms Expert Systems for Configuration, Shipping, and Pricing Predictive Modeling for Continuous Product Replenishment Composite Systems that bring Cross-Functional Information to Desktops Integration of Voice and Data Third-Party Communications and Videotext Case Management Roles or Teams Empowerment of Frontline Workers
Service	Real-Time, On-Site Service Delivery through Portable Workstations Customer Database-Supported Individual Service Approaches Service Personnel Location Monitoring Portable Communications Devices and Network-Supported Dispatching Built-In Service Diagnostics and Repair Notification Service Diagnostics Expert Systems Composite Systems-Based Service Help Desks
Management	Executive Information Systems that Provide Real-Time Information Electronic Linkages to External Partners in Strategic Processes Computer-Based Simulations that Support Learning-Oriented Planning Electronic Conferencing and Group Decision-Support Systems

The final set of Process Innovation strategies for sales and order management processes include, composite systems that bring cross-functional information to desktops, customer, product, and production databases, integration of voice and data, third-party communications and videotext, case management roles or teams, and empowerment of frontline workers. Process Innovation strategies for service processes include, real-time, on-site service delivery through portable workstations, customer database-supported individual service approaches, service personnel location monitoring, portable communications devices and network-supported dispatching, built-in service diagnostics and repair notification, service diagnostics expert systems, and composite systems-based service help desks. Process Innovation strategies for management processes include, executive information systems that provide real-time information, electronic linkages to external partners in strategic processes, computer-based simulations that support learning-oriented planning, and electronic conferencing and group decision-support systems. The final set of Process Innovation strategies for management processes include, expert systems for planning an capital allocation, standard technology infrastructure for communication and group work, standard reporting structures and information, acknowledgment and understanding of current management behavior as a process, and accountability for management process measurement and performance.

Maurer (1996), a Washington D.C.-based organization change consultant, identified two distinct organization change or process improvement approaches and strategies, conventional or default, and unconventional or resistance-embracement model (see Table 32). Conventional or default organization change or process improvement strategies include, using power, manipulate those who oppose, applying force of reason, ignore resistance, play off relationships, make deals, kill the messenger, and give in too soon. Unconventional or resistance-embracement model organization change or process improvement strategies include, maintain a clear focus, embrace resistance, respect those who resist, relax, and join with the resistance.

Table 32: Resistance Embracement Organizational Change Strategy

Strategy	Technique	Description
Conventional or Default	Use power	Threaten adversaries into conformance
	Manipulate those who oppose	Deceive adversaries with half-truths
	Apply force of reason	Overwhelm adversaries with facts
	Ignore resistance	Refuse to recognize adversarial positions
	Play off relationships	Rely on friendships to enable change
	Make deals	Make mutually beneficial trade-offs
	Kill the messenger	Fire or destroy your adversaries
	Give in too soon	Give up at the first sign of resistance
Resistance-Embracement	Maintain clear focus	Keep long and short term view/persevere
	Embrace resistance	Move toward and comprehend resistance
	Respect those who resist	Treat people with respect and dignity
	Relax	Stay calm and listen without overreacting
	Join with the resistance	Ally and befriend adversary's positions

Hammer (1996) identifies two forms of organizational process improvement strategies, Total Quality Management (TQM)—incremental process redesign, and Reengineering—radical process redesign (see Table 33). Hammer defines TQM or incremental redesign as a means of modifying processes to solve problems that prevent them from attaining the required performance level. Hammer defines Reengineering or radical redesign as a means of completely redesigning business processes for dramatic

improvement or completely replacing existing process designs with entirely new ones, in order to achieve quantum leaps. Ishikawa's seven basic tools are typically associated with Total Quality Management (TQM), checklists, pareto diagrams, histograms, run charts, scatter diagrams, control charts, and cause-and-effect diagrams. Reengineering is composed of process intensification, process extension, process augmentation, process conversion, process innovation, and process diversification.

Table 33: Reengineering and Total Quality Management (TQM) Strategies

Strategy	Impact	Technique	Description
Total Quality Management	Incremental	Checklists	Process and procedures
		Pareto Diagrams	Data categorization
		Histograms	Bar charts/charting
		Run Charts	Statistical analysis
		Scatter Diagrams	Linear regression
		Control Charts	Statistical analysis
		Cause-And-Effect Diagrams	Root cause analysis
Reengineering	Radical	Process Intensification	Better customer service
		Process Extension	Enter new markets
		Process Augmentation	Add more services
		Process Conversion	Spin-off core strengths
		Process Innovation	Add new offerings
		Process Diversification	Create new offerings

Harrington (1995) identified five international quality management and process improvement strategies by Philip B. Crosby, W. Edwards Deming, Armand V. Feigenbaum, Joseph M. Juran, and Kaoru Ishikawa (see Table 34).

Table 34: International Quality Management Strategies

Philip B. Crosby	W. Edwards Deming	Armand V. Feigenbaum	Joseph M. Juran	Kaoru Ishikawa
Management Commitment	Nature of Variation	Company-Wide Quality	Market Research	Quality First, not Profit
Quality Improvement				
Teams	Special Causes	Customer-Defined Quality	Product Development	Consumer Orientation
Measurement	Control Charts	Quality and Cost are a Sum	Design/Specification	Customer Process Focus
Cost of Quality	Interaction of Forces	Individual/Team Quality	Purchasing/Suppliers	Use Facts and Data
Quality Awareness	Losses from Decisions	Quality Management	Manufacturing Planning	Respect for Humanity
Corrective Action	Losses from Random Forces	Quality with Innovation	Production/Process Control	Cross Function
Management				
Zero Defect Planning	Losses from Competition	Quality Ethic	Inspection and Test	
Employee Education	Theory of Extreme Values	Continuous Improvement	Marketing	
Zero Defect Day	Statistical Theory of Failure	Productivity through Quality	Customer Service	
Goal Setting	Theory of Knowledge	Customer/Supplier Quality		
Error-Cause Removal	Psychology			
Recognition	Learning Theory			
Quality Councils	Transformation of Leaders			
Do It Over Again	Psychology of Change			

Crosby's strategy includes, management commitment, quality improvement teams, measurement, cost of quality, quality awareness, corrective action, zero defect planning, employee education, zero defect day, goal setting, error-cause removal, recognition, quality councils, and do it over again. Deming's strategy includes, nature of variation, losses due to tampering, minimizing the risk from variation, interaction of forces, losses from management decisions, losses from random forces, losses from competition, theory of extreme values, statistical theory of failure, theory of knowledge, psychology, learning theory, transformation of leadership, and psychology of change. Feigenbaum's strategy includes, quality is a company-wide process, is what the customer says, and cost are a sum, requires both individuality and teamwork, is a way of management, and innovation are dependent, is an ethic, requires continuous improvement, is the route to productivity, and is connected to customers and suppliers. Juran's strategy includes, market research, product development, product design/specification, purchasing/suppliers, manufacturing planning, production and process control, inspection and test, marketing, and customer service. Ishikawa's strategy includes, quality first—not short term profit, consumer orientation—not producer orientation, the next process is your customer, using facts and data to make presentations, respect for humanity as a management philosophy, and cross-function management.

Davidson (1993) conducted a study of fifty firms with the support of the IBM Advanced Business Institute in Palisades, New York. Davidson identified and developed an organizational process improvement framework composed of three major business organizational improvement strategies or phases, the Operating Excellence phase, Business Enhancement phase, and New Business Development phase, characterized by unique goals, objectives, techniques, and metrics (see Table 35). The goals of the Operating Excellence phase are cost reduction, capacity increases, organizational downsizing, yields, cost reduction, customer satisfaction, cycle time, asset turnover, response time, retention, enhancement, customer satisfaction, marketing sophistication, and flexible business systems. The objectives of the Operating Excellence phase are productivity, quality, velocity, customer service, and business precision. The techniques of the Operating Excellence phase are automation, process simplification, total quality management, statistical quality control, just-in-time, time-based competition, electronic data interchange, focus groups, market research, mass customization, microsegmentation, and activity-based costing. The metrics of the Operating Excellence phase are units per person, peak output level, cost per unit, cost per activity, revenue per employee, head count, defect rates, yields, standards and tolerances, variance, life-cycle costs, inventory and sales, and throughput.

More metrics of the Operating Excellence phase are cycle times, and time to market, response ratios, retention, revenue per customer, repeat purchase, brand loyalty, customer acquisition cost, referral rate, cost of variety, number of new products, number of product, service, and delivery configurations, and customer self-design and self-pricing flexibility. The goals of the Business Enhancement phase are retention, enhancement, customer satisfaction, marketing sophistication, flexible business systems, business augmentation, broader market scope, and new customer acquisition. The objectives of the Business Enhancement phase are customer service, business precision, enhancement, and extension. The techniques of the Business Enhancement phase are focus groups, market research, mass customization, microsegmentation, activity-based costing, embedded information technology, turbocharging, enhanced products and services, channel deployment, market expansion, and alliances. The metrics of the Business Enhancement phase are retention, revenue per customer, repeat purchase, brand loyalty, customer acquisition cost, referral rate, cost of variety, number of new products, number of product, service, and delivery configurations, and customer self-design and self-pricing flexibility. More metrics of the Business Enhancement phase are number of features, functions, and services, information flow to customer, product and service revenue ratio, customer performance, secondary revenue streams, customer diversity, number of new customers, channel diversity, new revenue sources, and broader product and

Table 35: Three Phases of Business Transformation

Phase	Objective	Technique
Operating Excellence	Productivity	Automation Process Simplification
	Quality	Total Quality Management Statistical Quality Control
	Velocity	Just-in-Time Time-Based Competition Electronic Data Interchange
	Customer Service	Focus Groups Market Research
	Business Precision	Mass Customization Microsegmentation Activity-Based Costing
Business Enhancement	Customer Service	Focus Groups Market Research
	Business Precision	Market Research Mass Customization Microsegmentation
	Enhancement	Embedded Information Technology Turbocharging Enhanced Products and Services
	Extension	Channel Development Market Expansion Alliances
New Business Development	Business Redefinition	Business Development Entrepreneurialism Spin-Off Units

market scope. The goals of the New Business Development phase are market value and start-up activity. The objective of the New Business Development phase is business redefinition. The techniques of the New Business Development phase are business development, entrepreneurialism, and spin-off units. The metrics of the New Business Development phase are market value, new lines of business, and percent of revenue from new units and services.

Reid (1997) conducted case studies of seven Internet and World-Wide-Web start-ups, Marc Andreessen's Netscape, Rob Glaser's Progressive Networks, Kim Polese's Java and Marimba, Mark Pesce's Virtual Reality Markup Language (VRML), Arial Poler's I/PRO, Jerry Yang's Yahoo, Andrew Anker's HotWired, and Halsey Minor's CNET (see Table 36). Reid concluded that the Internet is directly responsible for business, social, and cultural changes at unprecedented rates in scope, speed, and scale. The scope of Internet-enabled change includes publishing, education, entertainment, banking, industrial arts, health care, government, travel, the Olympics, employment, retailing, cellular phones, and the first amendment. The speed of Internet-enabled change is five to ten times faster than previous technological change intervals of five to ten years. The scale of Internet-enabled change includes instant market penetration to hundreds of millions of users.

Table 36: Internet Technologies for Organizational Change

Strategic Element	Tactical Element	Function
Internet Service Providers	UUNET	Business/Personal Websites/E-mail
	NETCOM	Business/Personal Websites/E-mail
	P S I n e t	Business/Personal Websites/E-mail
	BBN	Business/Personal Websites/E-mail
	Digex	Business/Personal Websites/E-mail
	@Home	Business/Personal Websites/E-mail
Equipment	Cisco	Network communication routers
	Ascend	Internet computer network equipment
	Cascade	Internet computer network equipment
	Silicon Graphics	High performance graphics computers
	Sun Microsystems	UNIX-based webservers
	US Robotics	MODEMs
Software	Netscape	Browsers/website administration/service
	Open Market	Internet commerce software
	Check Point	Secure enterprise networking solutions
	Marimba	Internet content delivery
	DimensionX	Website graphics technology
	Intervista	Website graphics technology
Enabling Services	I/PRO	Website traffic analysis software
	Yahoo!	Search engine/E-mail/business content
	CyberCash	Electronic commerce/transactions
	InfoSeek	Search engine/business content
	Lycos	Search engine/business content
	Excite	Search engine/business content
Professional Services	Organic Online	Business/e-commerce website design

Reid reports that five basic Internet technologies are responsible for these sweeping changes in business, social, and cultural change, Internet service providers, Internet equipment, Internet software, Internet enabling services, and Internet professional services. Six major Internet service providers at the time of the study included, UUNET, NETCOM, PSInet, BBN, Digex, and @Home, providing business and personal website and E-mail services. Six major Internet equipment companies at the time of the study included, Cisco, Ascend, Cascade, Silicon Graphics, Sun Microsystems, and US Robotics, providing Internet computers, networking, and communication devices and equipment. Six major Internet software companies at the time of the study included, Netscape, Open Market, Check Point, Marimba, DimensionX, and Invervista, providing website administration, browsers, intranet, content delivery, and media tools and technologies. Six major Internet enabling services at the time of the study included, I/PRO, Yahoo!, CyberCash, InfoSeek, Lycos, and Excite, providing website management, content management, and electronic commerce tools, technologies, and services. A major Internet professional services firm at the time of the study included Organic Online, providing website design and development services.

Downes and Mui (1998), directors and visiting fellows of the Diamond Exchange, an executive forum that brings together senior executives with leading strategy, technology, and learning experts, have developed a new approach to Strategic Planning for organizational performance improvement called Digital Strategy. Digital Strategy is a supercharged or hypercharged form of process improvement or reengineering, more appropriately associated with Davenport's (1993) Process Innovation strategy or Davidson's (1993) Business Transformation strategy, and is composed of three major phases, Reshaping the Landscape, Building New Connections, and Redefining the Interior (see Table 37).

Table 37: Digital Strategy for Organizational Change

Phase	Description
Reshaping the Landscape	Outsource to the customer Cannibalize your markets Treat each customer as a market segment of one Create communities of value
Building New Connections	Replace rude interfaces with learning interfaces Ensure continuity for the customer, not yourself Give away as much information as you can Structure every transaction as a joint venture
Redefining the Interior	Treat your assets as liabilities Destroy your value chain Manage innovation as a portfolio of options Hire the children

Reshaping the Landscape phase is composed of the first four of twelve principles, outsource to the customer, cannibalize your markets, treat each customer as a market segment of one, and create communities of value. Building New Connections phase is composed of the next four principles, replace rude interfaces with learning interfaces, ensure continuity for the customer, not yourself, give away as much information as you can, and structure every transaction as a joint venture. And, finally, Redefining the Interior phase is composed of the last four of twelve principles, treat your assets as liabilities, destroy your value chain, manage innovation as a portfolio of options, and hire the children. Digital Strategy fully exploits Internet economics previously outlined by Reid (1997), in order to minimize or eliminate inefficiencies in the market caused by non-value adding organizations that manage transactions, otherwise known as Coasian Economics (Coase 1994).

Slywotzky, Morrison, Moser, Mundt, and Quella (1999) founders, presidents, executives, and principals of Mercer Management Consulting analyzed more than 200 firms, identifying seven categories of thirty profit patterns which enable organizational change in order to increase market competitiveness and profitability (see Table 38).

Table 38: Profit Patterns for Organizational Performance Improvement

Category	Pattern	Technique
Mega	No Profit	Walk away or invent a new way of doing business
	Back to Profit	Build new business design for unmet customer needs
	Convergence	Identify and master new rules of competition
	Collapse of the Middle	Be the first to go to the extremes
	De Facto Standard	Create or align with emerging standards early
	Technology Shifts the Board	Go where the power will be
Value Chain	Deintegration	Dominate components of disintegrated value chain
	Value Chain Analysis	Improve performance faster than the competition
	Strengthening the Weak Link	Fix weak link with proprietary/exclusive solution
	Reintegration	Reintegrate profitable components of value chain
Customer	Profit Shift	Dynamically adjust pricing to optimize profitability
	Microsegmentation	Dominate profitably small segments of market
	Power Shift	Rebalance power or redefine customers
	Redefinition	Seek out profitable markets, beyond customer base
Channel	Multiplication	Dominate or create new business channels
	Channel Concentration	Innovate and create new model generations first
	Compression/Disintermediation	Be the first to disinvest obsolete channels
	Reintermediation	Accelerate investment in new channels
Product	Product to Brand	Build and invest in valuable brands and branding
	Product to Blockbuster	Create market-dominating products and services
	Product to Profit Multiplier	Identify top avenues for selling products/services
	Product to Pyramid	Cater to low to high end of vertical markets
	Product to Solution	Analyze and master competitor products/services
Knowledge	Product to Customer Knowledge	Analyze your customer transactions for patterns
	Operations to Knowledge	Turn proprietary processes into products/services
	Knowledge to Product	Identify, perfect, and sell core competencies
Organizational	Skill Shift	Invest in emerging skill requirements
	Pyramid to Network	Maximize external exposure and adapt organization
	Cornerstoning	Incrementally expand core products and services
	Conventional to Digital Business Design	Use changing technology to shed the industrial age

The seven categories of profit patterns or process improvement strategies included, Mega Patterns, Value Chain Patterns, Customer Patterns, Channel Patterns, Product Patterns, Knowledge Patterns, and Organizational Patterns. Mega Patterns are composed of six components, No Profit, Back to Profit, Convergence, Collapse of the Middle, De Facto Standard, and Technology Shifts the Board. Value Chain Patterns are composed of four components, Deintegration, Value Chain Squeeze, Strengthening the Weak Link, and Reintegration. Customer Patterns are composed of four components, Profit Shift, Microsegmentation, Power Shift, and Redefinition. Channel Patterns are composed of four components, Multiplication, Channel Concentration, Compression and Disintermediation, and Reintermediation. Product Patterns are composed of five components, Product to Brand, Product to Blockbuster, Product to Profit Multiplier, Product to Pyramid, and Product to Solution. Knowledge Patterns are composed of three components, Product to Customer Knowledge, Operations to Knowledge, and Knowledge to Product. Organizational Patterns are composed of four components, Skill Shift, Pyramid to Network, Cornerstoning, and Conventional to Digital Business Design.

Metrics and Models

The previous section surveyed 72 scholarly studies of software process improvement (SPI) techniques, methods, and strategies, attempting to provide the reader with a good sense of the wide-ranging approaches to SPI. This section examines 14 well known studies and expositions of metrics and models for software management and engineering, and more importantly software process improvement (SPI), identifying 74 broad metrics classes and 487 individual software metrics (see Table 39).

Table 39: Survey of Metrics for Software Process Improvements (SPI)

Author	Metric Class	Metrics
Davidson	Productivity, Quality, Velocity, Customer Service, Precision, Enhancement, Extension, Redefinition	39
Garrison	Prevention Costs, Appraisal Costs, Internal Failure Costs, External Failure Costs	36
Kan	Software Quality, Reliability, Quality Management, Structural Design, Customer Satisfaction	35
Grady	Process and Product Descriptions, High-Level Process Measurements, Defect Failure Analysis	15
Daskalantonakis	Planning, Containment, Reliability, Defect Density, Customer Service, Non-Conformance, Productivity	18
Barnard	Cost, Cycle Time, Quality, Conformity, Efficiency, Effectiveness, Productivity	21
Florac	Things Received or Used, Activities and their Elements, Things Consumed, Things Produced	80
Herbsleb	Cost, Productivity, Calendar Time, Quality, Business Value	7
McGibbon	Reuse, Clean Room, Inspections, Walk throughs, Traditional, Full	24
Hays	Personal Software Process (PSP)	35
Jones	Process Improvement, Application/System, Productivity, Cost, Quality	28
Burr	Size, Complexity, Conformity, Defectiveness, Time, Cost	32
Rosenberg	Personnel Resources, Software Analysis, Changes to Code	9
Rico	Defect Density	6
Rico	Relational Design Metrics, Object Oriented Design Metrics, Universal/Structural Design Metrics	63
Rico	Planning, Overall, Review Rate, Substage Duration, Substage Interval, Substage Efficiency	39

While Table 39 provides a quick overview of the kinds of metrics classes the 14 studies refer to, it was necessary to reexamine and reclassify the 487 individual software metrics, based on a more consistent set of criteria. The analysis identified 12 common classes of software metrics from the 74 broad classes identified by the 14 sources, based on a more consistent set of criteria (see Table 40).

It's not surprising that productivity, design, quality, and effort were the most frequently cited software metrics in the 14 studies, given that academic and industry use of these metrics, especially productivity and design, dates back nearly three decades. Size came in sixth place with only an 8% rate of occurrence, probably because function point proponents stigmatize the use of size metrics as incompetence, despite their continuing strategic importance.

The software metrics were reclassified using the following criteria, productivity—units per time, design—complexity, quality—defect density, effort—hours, cycle time—duration, size—lines of code or function points, cost—dollars, change—configuration management, customer—customer satisfaction, performance—computer utilization, ROI—return-on-investment, and reuse—percent of reused source code. The strength of this reclassification strategy is that the 487 individual software metrics fell succinctly into one of the 12 software metric classes without exception. The weakness of the reclassification is that it hides exactly what is being measured, such as productivity of a software life cycle versus software process.

Table 40: Reclassification of 487 Metrics for Software Process Improvement (SPI)

Author	Productivity	Design	Quality	Effort	Cycle Time	Size	Cost	Change	Customer	Performance	ROI	Reuse
Davidson	18		4	1	5		5		6			
Garrison				28	1		7					
Kan	5	9	14			2		4	1			
Grady	2	3	4	3	2	1						
Daskalantonakis	4		11	1	1		1					
Barnard	2 1											
Florac	15	7	14	9	4	9	7	12		3		
Herbsleb	2		1		1		2				1	
McGibbon				7	1	6	7				2	1
Hays	7		3	1	13	11						
Jones	14	2	6	3	1	2						
Burr	10	6	6		2	5			2	1		
Rosenberg	1	2		1		1		3				1
Rico	12	63	9	13	11							

While some metrics are cited as high as 22% of the time in the case of productivity, versus only 1% for ROI, there is no prioritization and importance placed on the software metrics by the software metrics classes. As mentioned before, quality is a strategic and powerful metric, though only cited 15% of the time, and size is a principle input to most cost models, though only cited 8% of the time. The importance of using customer satisfaction measurement cannot be understated though it is only cited 2% of the time. And, reuse will begin to emerge as one of the most strategic metrics of the next millennium, though it is only cited 0% of the time on average (see Figure 11).

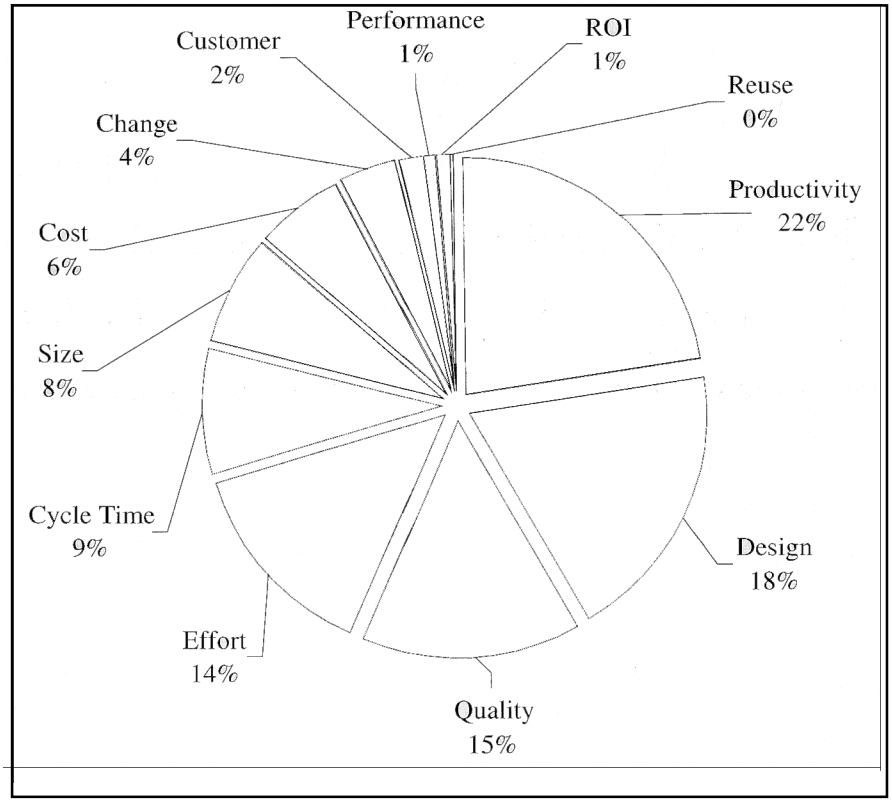

Figure 11. Citation Frequency of Metrics for Software Process Improvement (SPI)

Davidson (1993) identified eight major metric classes and 39 individual metrics of what he calls "operating performance parameters and metrics," for business transformation, an advanced form of process improvement, reengineering, and enterprise automation (see Table 41).

Table 41: Operating Parameters and Metrics for Business Transformation

Class	Metric
Productivity	Units Per Person
	Peak Output Level
	Cost Per Unit
	Cost Per Activity
	Revenue Per Employee
	Head count
Quality	Defect Rates
	Yields
	Standards and Tolerances
	Variance
	Life Cycle Costs
Velocity	Inventory and Sales
	Throughput
	Cycle Times
	Time To Market
	Response Ratios
Customer Service	Retention
	Revenue Per Customer
	Repeat Purchase
	Brand Loyalty
	Customer Acquisition Cost
	Referral Rate
Business Precision	Cost of Variety
	Number of New Products
	Number of Product, Service, and Delivery Configurations
	Customer Self-Design and Self-Pricing Flexibility
Enhancement	Number of Features, Functions, and Services
	Information Flow to Customer
	Product and Service Revenue Ratio
	Customer Performance (Industrial)
	Secondary Revenue Streams
Extension	Customer Diversity
	Number of New Customers
	Channel Diversity
	New Revenue Sources
	Broader Product and Market Scope
Business Redefinition	Market Value
	New Lines of Business
	Percent of Revenue from New Units and Services

Garrison and Noreen (1997a) identify four major metrics classes and 36 individual metrics for what they call "typical quality costs," for cost measurement, cost control, and cost minimization (see Table 42).

Table 42: Typical Costs for Measuring Quality of Conformance

Class	Metric
Prevention Costs	Systems development
	Quality engineering
	Quality training
	Quality circles
	Statistical process control activities
	Supervision of prevention activities
	Quality data gathering, analysis, and reporting
	Quality improvement projects
	Technical support provided to suppliers
	Audits of the effectiveness of the quality system
Appraisal Costs	Test and inspection of incoming materials
	Test and inspection of in-process goods
	Final product testing and inspection
	Supplies used in testing and inspection
	Supervision of testing and inspection activities
	Depreciation of test equipment
	Maintenance of test equipment
	Plant utilities in the inspection area
	Field testing and appraisal at customer site
Internal Failure Costs	Net cost of scrap
	Net cost of spoilage
	Rework labor and overhead
	Reinspection of reworked products
	Retesting of reworked products
	Downtime caused by quality problems
	Disposal of defective products
	Analysis of the cause of defects in production
	Reentering data because of keying errors
	Debugging of software errors
External Failure Costs	Cost of field servicing and handling complaints
	Warranty repairs and replacements
	Repairs and replacements beyond the warranty period
	Product recalls
	Liability arising from defective products
	Returns and allowances arising from quality problems
	Lost sales arising from a reputation for poor quality

Kan (1995) identified five major metrics classes and 35 individual metrics for what he called "metrics and models," for software quality engineering, an established, yet advanced form of measurement-based management for software development (see Table 43).

Table 43: IBM Rochester Software Process Improvement (SPI) Metrics

Class	Subclass	Metrics and Models
Software Quality	Product Quality	Defect Density Customer Problems Customer Satisfaction Function Points
	In-Process Quality	Defect Density During Machine Testing Defect Arrival Pattern During Machine Testing Detect Removal Effectiveness Phase-Based Defect Removal Model Pattern Special Case Two-Phase Model
	Maintenance	Fix Backlog and Backlog Management Index Fix Response Time Percent Delinquent Fixes Fix Quality
Reliability	Exponential	Cumulative Distribution Function (CDF) Probability Density Function (PDF) Rayleigh
	Reliability Growth	Jelinsh-Moranda Littlewood Goel-Okumoto Musa-Okumoto Logarithmic Poisson Execution Delayed S and Inflection S
Quality Management	Life Cycle	Rayleigh Life Cycle Reliability
	Testing Phase	Problem Tracking Report Reliability Growth
Structural Design	Complexity	Source Lines of Code (SLOC) Halstead's Software Science Cyclomatic Complexity Syntactic Constructs
	Structure	Invocation Complexity System Partitioning Information Flow Fan-In and Fan-Out
Customer Satisfaction	Survey	In-Person, Phone, and Mail
	Sampling	Random, Systematic, and Stratified
	Analysis	CUPRIMDA

Grady (1997) identified three major metrics classes and 15 individual metrics for what he called "baseline measurements for all software process improvement programs," as part of his plan, do, check, and act (PDCA)-based methodology—specifically the check phase—evaluate results, ensure success, and celebrate (see Table 44).

Table 44: Hewlett Packard Software Process Improvement (SPI) Metrics

Class	Metric
Process and Product Descriptions	Development Type Computer Programming Language Type of Product
High-Level Process Measurements	Product Size Effort Productivity before Changes Productivity after Changes Activity Breakdown before Changes Activity Breakdown after Changes Defects before Changes Defects after Changes Project Calendar Time before Changes Project Calendar Time after Changes
Defect Failure Analysis	Defect Failure Analysis before Changes Defect Failure Analysis after Changes

Grady and Caswell (1986) report that Hewlett Packard uses 12 other strategic software metrics. Hewlett Packard's first six software metrics include, average fixed defects per working day, average engineering hours per fixed defect, average reported defects per working day, bang, branches covered per total branches, and defects per thousands of non-commented source statements. Hewlett Packard's last six software metrics include, defects per line of documentation, defects per testing time, design weight, non-commented source statements per engineering month, percent overtime per 40 hours per week, and (phase) engineering months per total engineering months.

Daskalantonakis (1992) identified seven major metrics classes and 18 individual metrics for what he called a "practical and multidimensional view of software measurement," in support of Motorola's company-wide metrics program (see Table 45).

Table 45: Motorola Software Process Improvement (SPI) Metrics

Class	Metric
Project Planning	Schedule Estimation Accuracy Effort Estimation Accuracy
Defect Containment	Total Defect Containment Effectiveness Phase Containment Effectiveness
Software Reliability	Failure Rate
Software Defect Density	In-Process Faults In-Process Defects Total Release Defects Total Release Defects Delta Customer-Found Defects Customer-Found Defects Delta
Customer Service	New Open Problems Total Open Problems Mean Age of Open Problems Mean Age of Closed Problems
Non-Conformance Cost	Cost of Fixing Problems
Software Productivity	Software Productivity Software Productivity Delta

Diaz and Sligo (1997) report that Motorola uses three strategic metrics for measuring the effects of software process improvement (SPI), quality, cycle time, and productivity. Quality is defined as defects per million earned assembly-equivalent lines of code (a form of defect density measurement). Cycle time is defined as the amount of calendar time for the baseline project to develop a product divided by the cycle time for the new project. And, productivity is defined as the amount of work produced divided by the time to produce that work.

Barnard and Price (1994) identified seven major metrics classes and 21 individual metrics for what they called “managing code inspection information,” in support of AT&T’s efforts to ensure a more consistently effective Software Inspection Process (see Table 46).

Table 46: AT&T Software Inspection Process (SIP) Metrics

Class	Metric
Cost	Average Effort per Thousand Lines of Code Percentage of Re-Inspections
Cycle Time	Average Effort per Thousand Lines of Code Total Thousand Lines of Code Inspected
Quality	Average Faults Detected per Thousand Lines of Code Average Inspection Rate Average Preparation Rate
Conformity	Average Inspection Rate Average Preparation Rate Average Lines of Code Inspected Percentage of Re-Inspections
Efficiency	Total Thousand Lines of Code Inspected
Effectiveness Defect	Removal Efficiency Average Faults Detected per Thousand Lines of Code Average Inspection Rate Average Preparation Rate Average Lines of Code Inspected
Productivity	Average Effort per Fault Detected Average Inspection Rate Average Preparation Rate Average Lines of Code Inspected

The Software Inspection Process metric classes answer these questions: How much do inspections cost? How much calendar time do inspections take? What is the quality of the inspected software? To what degree did the staff conform to the procedures? What is the status of inspections? How effective are inspections? What is the productivity of inspections?

Florac and Carleton (1999) identified four major metrics classes, 19 metrics subclasses, and 80 individual metrics for what they call "measurable attributes of software process entities," in support of statistical process control (SPC) for software process improvement (see Table 47).

Table 47: SKI Software Process Improvement (SPI) Metrics

Things Received or Used	Activities & their Elements	Things Consumed	Things Produced
Changes	Flow Paths	Effort	Status of Work Units
Type	Processing Time	# Development Hours	# Designed
Date	Throughput Rates	# of Rework Hours	# Coded
Size	Diversions	#of Support Hours	#Tested
# Received	Delays	# of Preparation Hours	Size of Work Units
Requirements Changes	Backlogs	# of Meeting Hours	# of Requirements
Requirements Stability	Length, Size	Time	# of Function Points
# Identified	Queues	Start Time or Date	# of Lines of Code
% Traced to Design	Buffers	Ending Time or Date	# of Modules
% Traced to Code	Stacks	Duration of Process	# of Objects
Problem Reports		Wait Time	# of Bytes in Database
Type		Money	Output Quantity
Date		Cost to Date	# of Action Items
Size		Cost Variance	# of Approvals
Origin		Cost of Rework	# of Defects Found
Severity			Test Results
# Received			# of Passed Test Cases
Funds			% Test Coverage
Money			Program Architecture
Budget			Fan-In
Status			Fan-Out
People			Changes
Years of Experience			Type
Type of Education			Date
% Trained in XYZ			Size
Employment Codes			Effort Expended
Facilities & Environment			Problems & Defects
Space per Employee			# of Reports
Noise Level			Defect Density
Lighting			Type
# of Staff in Cubicles			Origin
# of Staff Sharing Offices			Distribution by Type
Investment Tools			Distributed by Origin
Computer Usage Hours			# Open
% Capacity Utilization			# Closed
			Resource Utilization
			% Memory Utilized
			% CPU Capacity Used
			% I/O Capacity Used

Herbsleb, Carleton, Rozum, Siegel, and Zubrow (1994) identified five major metrics classes and seven individual metrics for measuring the benefits of SEI Capability Maturity Model for Software (SW-CMM)-based software process improvement (see Table 48).

Table 48: SKI CMM-Based Software Process Improvement (SPI) Metrics

Class	Metric
Cost	Thousands of Dollars per Year Spent on SPI Dollars per Software Engineer per Year Spent on SPI
Productivity	Gain per Year in Productivity Gain per Year in Early Detection of Defects
Calendar Time	Reduction per Year in Calendar Time to Develop Software Systems
Quality	Reduction per Year in Post-Release Defect Reports
Business Value	Business Value Ratio of SPI Efforts

Herbsleb et al. also recommend that organizations use four more additional classes of metrics to measure Software Process Improvement (SPI), balanced score card, CMM/SEI core measures, business value, and quality metric classes. Balanced score card consists of financial, customer satisfaction, internal processes, and innovation and improvement activity metrics. CMM/SEI core measures consist of resources expended on software process improvements, resources expended to execute the software processes, amount of time (calendar time) it takes to execute the process, size of the products that result from the software process, and quality of the products produced metrics. Business value consists of increased productivity, early error detection and correction, overall reduction of errors, improved trends in maintenance and warranty work, and eliminating processes or process steps metrics. Quality consists of mean time between failures, mean time to repair, availability, and customer satisfaction metrics.

McGibbon (1996) identified three major metrics classes and 24 individual metrics for what he called “a business case for software process improvement” comparing Software Reuse, the Software Inspection Process, and the Clean Room Methodology (see Table 49).

Table 49: DACS Software Process Improvement (SPI) Metrics

Class	Metric
Without, 30% Reuse, 60% Reuse, & 90% Reuse	Estimated Source Lines of Code % Reuse Equivalent Ratio on Reuse Equivalent Code COCOMO Effort Estimate Equivalent Cost Estimated Rework (New Code) Estimated Rework (Reused Code) Estimated Rework (Total Rework) Estimated Maintenance Costs Development Effort + Maintenance Savings of Reuse Over No Reuse % Reduction
Clean Room, Inspections, & Walk throughs	Estimated Source Lines of Code Equivalent Ratio Equivalent Code Effort Estimate Equivalent Cost
Traditional, Inspections, Reuse, Clean Room, & Full	Development Costs Rework Costs Maintenance Costs Development + Maintenance Savings Software Process Improvement (SPI) Costs Return-on-Investment (ROI)

McGibbon identified another six major metric classes and 23 individual metrics for performing a detailed analysis and comparison of the Software Inspection Process and what he called “Informal Inspections,” otherwise known as Walk throughs.

Hays and Over (1997) identified 34 individual strategic software metrics in support of the Personal Software Process (PSP) pioneered by Watts S. Humphrey (see Table 50).

Table 50: Personal Software Process (PSP) Metrics

Metric	Definition
Interruption Time	Elapsed time for small interruptions from project work such as a phone call
Delta Time	Elapsed time in minutes from start to stop less interruptions
Planned Time in Phase	Estimated time to be spent in a phase for a project
Actual Time in Phase	Sum of delta times for a phase of a project
Total Time	Sum of planned or actual time for all phases of a project
Time in Phase to Date	Sum of time in actual time in phase for all completed projects
Total Time to Date	Sum of time in phase to date for all phases of all projects
Time in Phase to Date %	100 * time in phase to date for a phase divided by total time in phase to date
Compile Time	Time from the start of the first compile until the first clean compile
Test Time	Time from the start of the initial test until test completion
Defect	Any element of a program design or implementation that must be changed
Defect Type	Project defect type standard
Fix Time	Time to find and fix a defect
Lines of Code	Logical line of code as defined in the engineer's counting & coding standard
Base Lines of Code	Lines of code from a previous version
Deleted Lines of Code	Deletions from the base lines of code
Modified Lines of Code	Modifications to the base lines of code
Added Lines of Code	New objects, functions, procedures, or any other added lines of code
Reused Lines of Code	Lines of code from a previous program that is used without modification
New Lines of Code	Sum of added lines of code
Changed Lines of Code	Sum of modified lines of code
Total Lines of Code	Total program lines of code
Total New Reused	New or added lines of code that were written to be reusable
Lines of Code Type	Base, deleted, modified, added, reused, new, changed, total, total new reused
Lines of Code/Hour	Total new & changed lines of code developed divided by development hours
Estimating Accuracy	Degree to which the estimate matches the result
Test Defects/KLOC	Defects removed in the test phase per new and changed KLOC
Compile Defects/KLOC	Defects removed in compile per new and changed KLOC
Total Defects/KLOC	Total defects removed per new and change KLOC
Yield	Percent defects injected before the first compile removed before first compile
Appraisal Time	Time spent in design and code reviews
Failure Time	Time spent in compile and test
Cost of Quality	Appraisal time plus failure time
Appraisal/Failure Ratio	Appraisal time divided by failure time
Review Rate	Lines of code reviewed per hour

Various forms of defect density metrics and appraisal to failure ratio are the key metrics to focus on. Appraisal to failure ratio must reach a modest 67% in order achieve zero defects.

Jones (1997a) identified five major metrics classes and 24 individual metrics for what he called "the six stages of software excellence" for quantifying the impact of software process improvements (see Table 51).

Table 51: SPR Software Process Improvement (SPI) Metrics

Class	Metric
Process Improvement	Process Improvement Expenses per Capita Process Improvement Stages in Calendar Months Improvements in Delivered Defects Improvement in Development Productivity Improvements in Development Schedule Organization Size in Number of People Capability Maturity Model for Software Level
Application/System	Application Class Programming Language Size in Function Points Size in Lines of Code
Productivity	Work Hours per Month (Function Points) Average Monthly Salary Function Points per Month Lines of Code per Month Cost per Function Point Cost per Line of Code
Cost	Work Hours per Function Point per Activity Staff (Number of People) per Activity Effort (Months) per Activity Schedule (Months) per Activity Costs per Activity Percent of Costs per Activity
Quality	Potential Defects (Estimated) Defect Removal Efficiency Delivered Detects Defects per Function Point Defects per Thousand Lines of Code

Burr and Owen (1996) identified seven major metrics classes and 32 individual metrics for what they called “commonly available metrics” with which to perform Statistical Process Control (SPC) for Software Process Improvement (SPI) (see Table 52).

Table 52: Software Process Improvement (SPI) Metrics for SPC

Class	Subclass	Subclass
Product	Size	Lines of Code per Module Modules per Function Functions per System Data Types per Area Variables
	Complexity	McCabe’s Path Count Call Count Data Types
	Conformity	Completeness Functional Differences Supplier Confidence Customer Confidence
	Defectiveness	Defect Count Function Failures Data Faults Machine or System Failures Reliability
Process	Time	Lines of Code per Day Lines of Code per Hour Modules per Month Review Time Stage Time Preventative per Total Time Corrective per Total Time
	Cost	Systems Utilization Cost per Line of Code Cost per Line of Module Cost of Correction Cost of Failure
	Defectiveness	Error Count Error Rate per Module

Rosenberg, Sheppard, and Butler (1994) identified three broad metrics classes, three metrics subclasses, and nine individual metrics for what they called "Software Process Assessment (SPA) metrics" in support of Software Process Improvement (SPI) (see Table 53).

Table 53: NASA GSFC Software Process Improvement (SPI) Metrics

Class	Subclass	Metric
Process	Personnel Resources Form	Effort by Phase
Product	Software Analysis	Complexity Readability Size
	Changes to Code	Component Origination (% Complete) Component Origination (Amount Reused) Change Report (Type) Change Report (Date) Change Report (Effort)

Rico (1998) identified five forms of defect density metrics for what he called "Quality Metrics" in direct support of Software Process Improvement (SPI) measurement (see Table 54).

Table 54: Defect Density Metrics for Software Process Improvement (SPI)

Source	Metric Name	Metric Algorithm
IEEE	Defect Density	$\frac{\text{Defects}}{\text{KSLOC}}$
IBM (Michael Fagan)	Defect Removal Effectiveness	$\frac{\text{Inspection Defects}}{\text{Inserted Defects}} \times 100\ \%$
IBM (NASA Space Shuttle)	Early Detection Percentage	$\frac{\text{Major Inspection Defects}}{\text{Inserted Defects}} \times 100\ \%$
Dunn	Effectiveness	$\frac{\text{Defects}}{\text{Current Phase + Post Phase}} \times 100\ \%$
Motorola	Total Defect Containment Effectiveness	$\frac{\text{Pre-Release Defects}}{\text{Pre-Release + Post-Release Detects}}$
Motorola	Phase Containment Effectiveness	$\frac{\text{Phase Errors}}{\text{Phase Errors + Phase Defects}}$

Rico (1998) identified three metric classes and 63 individual metrics for what he called "software product metrics" in support of Software Process Improvement (SPI), relational design metrics, object oriented design metrics, and universal/structural design metrics (see Table 55).

Table 55: Universal/Structural Design Metrics for Software Process Improvement (SPI)

Relational Design Metrics	Object Oriented Design Metrics	Universal/Structural Design Metrics
Attribute Consistency	System Size in Classes	Cyclomatic Complexity
Use of Domains	Number of Hierarchies	Fan In
Unnecessary Keys	Number of Independent Classes	Fan Out
Foreign Key Indexes	Number of Single Inheritance	Dependencies
Keys on Similar Attributes	Number of Multiple Inheritance	Design Changes
Relationships (Multiple Paths)	Number of Internal Classes	Historical Defectiveness
Relationships (Infinite Loops)	Number of Abstract Classes	Current Defectiveness
Relationships (Implied)	Number of Leaf Classes	Software Science
Unnecessary Denormalization	Average Depth of Inheritance	Static Graph Theoretic Complexity
Index Consistency	Average Width of Inheritance	Generalized Graph Theoretic Complexity
Missing Indexes (Defined Relationships)	Average Number of Ancestors	Dynamic Graph Theoretic Complexity
Missing Indexes (Implied Relationships)	Measure of Functional Abstraction	Unit Test Case Determination
Excessive Indexes	Measure of Attribute Abstraction	Design Structure
Unnecessary Indexes	Data Access Metric	Data Flow Complexity
No Unique Identifier	Operation Access Metric	
Unique Constraint	Number of Methods	
Use of Surrogate Keys	Class Interface Size	
Redundant Attributes	Number of Inline Methods	
Repeating Groups	Number of Polymorphic Methods	
Homonym Attributes	Number of Attributes	
Missing Tables	Number of Abstract Data Types	
Inconsistent Attribute Definition	Class Size in Bytes	
Inconsistent Constraint Definition	Direct Class Coupling	
Incorrect Relationship Definition	Direct Attribute Based Coupling	
Disabled Constraints		

Rico (1996) identified six metric classes and 39 individual metrics for what he called "Software Inspection Process metrics" in support of Software Process Improvement (SPI), publishing a comprehensive set of software inspection process cost models (see Table 56).

Table 56: Software Inspection Process Metrics for Software Process Improvement (SPI)

Metric Class	Metric	Model
Planning	Rico	SLOC / (Rate * 2) * (Team Size * 4 + 1)
	Hewlett Packard	SLOC / (Rate * 2) * 25
	AT&T	50 * KSLOC
	Bell Northern Research	3 * KSLOC * 4 * 8
	Tom Gilb	SLOC / (Rate * 2) * (5.76 * Team Size)
Overall	Total Defects	
	Detects per Hour	
	Major Defects	
	Major Defects per Hour	
	Minor Defects	
	Minor Defects per Hour	
	Defect Removal Efficiency	
	Total Hours	
	Duration	
	People	
Review Rate	Overview Rate	
	Preparation Rate	
	Inspection Rate	
	Rework Rate	
Substage Duration	Planning Hours	
	Overview Hours	
	Preparation Hours	
	Inspection Hours	
	Rework Hours	
	Follow up Hours	
Substage Interval	Planning/Overview Interval	
	Overview/Preparation Interval	
	Preparation/Inspection Interval	
	Inspection/Rework Interval	
	Rework/Follow up Interval	
	Planning/Preparation Interval	
	Planning/Inspection Interval	
	Planning/Rework Interval	
	Planning/Follow-up Interval	
	Inspection/Follow up Interval	
Substage Efficiency	Preparation Efficiency	
	Inspection Efficiency	
	Inspection Gain Rate	
	Inspection Suppression	

Costs and Benefits

Table 1, Figure 2, and Table 39 demonstrate that a uniform, industry standard definition of Software Process Improvement (SPI) doesn't yet exist as of this writing. This section identifies the costs and benefits of SPI as reported by 24 of the most quantitative, authoritative, and complete descriptions of SPI efforts and their results known. Nevertheless, the survey and identification of SPI costs and benefits revealed a lack of uniform, industry standard metrics for measuring and reporting the costs and benefits of SPI.

Of the 24 quantitative studies, 78% reported quality, 28% reported cycle time reduction, 28% reported productivity increase, 17% reported cost reduction, 11% report cost estimation accuracy, 6% reported size estimation accuracy, 6% reported employee satisfaction, and 6% reported product availability improvements. Of the studies reporting measurements on traversing SEI CMM Levels, 11% reported Level 1 to 2, 11% reported Level 2 to 3, 6% reported Level 3 to 4, 6% reported Level 4 to 5, and 33% reported Level 1 to 5 time measurements. Of those reporting major accomplishments, 6% reported to be ISO 9000, 6% reported to have won the U.S. Malcolm Baldrige National Quality Award, and 28% reported to have achieved CMM Level 5.

Table 57: Survey of Software Process Improvement (SPI) Costs and Benefits

Source of SPI Costs and benefits													
Improvement	Arthur	Oldham	Wigle	Grady	Ferguson	Hays	Jones	Diaz	Haley	Kan	Herbsleb	Kajihara	Mays
Quality	50%	10X	98%	10X	67X	137:1	95%	86%	77%	67%	39%	100X	
Cost	50%												99%
Cycle Time	50%	83%					75%	8X			19%		
Productivity							365%	3X	190%		35%	100%	
Total DREa			100%		99.8%	99.9%							
Precision										99 9%			
Costing						100:1			93%				
Sizing						250:1							
ROI Ratio		19:1	8:1	1.35:1							5:1		482:1
ROI Dollars		$100M		$450M									
Cost/Person					$15K	$15K	$21K						$483
Years	8	6	15	10	.05	.05	3.5	6.5	7	4	3.5	9	2
People	400							350	1,200		1,375	15,032	414
SKI Level 5		✔	✔					✔					
ISO 9000										✔			
Baldrige										✔			

Represents defect removal efficiency of product appraisal activities such as inspection and test (not an improvement percentage).

In addition, 28% reported return-on-investment (ROI) data, 28% reported the amount of money spent per person on SPI, 28% reported the number of software managers and developers, 11% reported the amount of money saved by SPI, and 6% reported shareholder value increase. And, finally, 33% reported defect removal efficiency measurements, 11% reported rework cost reductions, 11% reported defect insertion rate reductions, 6% reported quality estimation accuracy, and 6% reported product failure reductions.

Of the 26 individual measurement data points reported by the 24 studies, 50% of them were directly related to software quality. Only 6% of the reported metrics and 11% of the reported measurements were related to cost reduction. This doesn't necessarily show a positive correlation between cost and quality. ROI measurements actually show a negative correlation; that is, the higher the quality, the lower the cost. Table 57 summarizes some of the most important metrics and measurement values for the cost and benefits of SPI found in the 24 principle references.

Arthur (1997) reports that U.S. West Technologies experienced 50% or greater reductions in cycle time, defects, and cost. Arthur reports that in six months of SPI efforts to examine computer system reliability issues, U.S. West reduced system outage by 79% and increased system availability to 99.85%. U.S. West also examined other areas of their business such as service order errors, long distance errors, billing cycle time, billing errors, billing strategy, postage costs, and new product development time. Manual operations were automated reducing costs by 88%. Postage costs were reduced from $60 million to $30 million, resulting in savings of 50%. Cash flow was improved by 50%, and service order errors were decreased by over 50%.

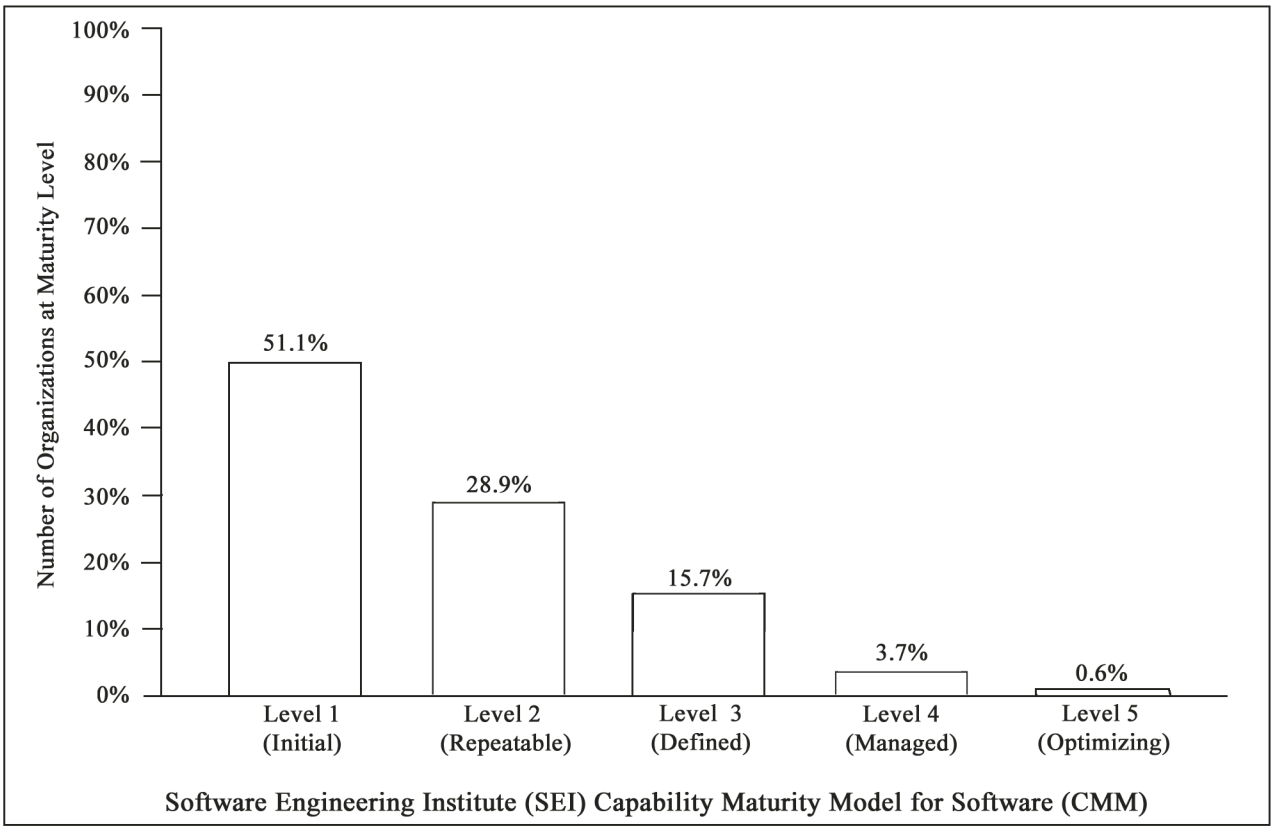

Figure 12. SEI CMM Maturity Profile (domestic)

The CMM is the Software Engineering Institute's Capability Maturity Model for Software pioneered in its current form by Humphrey (1989). The CMM is a framework for evaluating software management and development sophistication, one being the worst and five being the best. The Software Engineering Institute (1999) reports that one-half of one percent of software development organizations worldwide are at CMM Level 5, and 80% are at or below CMM Level 2, as in Figure 12. Achieving CMM Level 5 is the rough equivalent of winning the Malcolm Baldrige National Quality Award, a rare and prestigious state of organizational quality.

Cosgriff (1999a) reports that the Ogden Air Logistic Center Software Engineering Division of Hill Air Force Base (AFB) in Utah went from CMM 1 to CMM Level 5 in six years. Cosgriff reports that Hill's Software Engineering Division took two and a half years to progress from CMM Level 1 to 2, six months to go from Level 2 to 3, and about 2 years to go from Level 3 to 4. Finally Cosgriff reports Hill took about a year to go from Level 4 to 5.

Oldham, Putman, Peterson, Rudd, and Tjoland (1999) report that Hill AFB's SPI efforts yielded an order of magnitude improvement in software quality (10X), an 83% reduction in software development and maintenance cycle times, and a 19:1 return-on-investment ratio for Hill's SPI efforts, equating to $100 million.

Fowler (1997) reports an 86% improvement in software quality for Boeing Defense and Space Group of Seattle, Washington, also an elite member of the CMM Level 5 club. Yamamura and Wigle (1997) also of Boeing's CMM Level 5 outfit, show a 98% improvement in software quality, an improvement in defect removal efficiency of nearly 100%, and report earning 100% of possible incentive fees from their clients. Yamamura and Wigle also report that employee satisfaction has increased from 26% to 96%. Finally, Yamamura and Wigle report that Boeing yields a 7.75:1 return-on-investment for using highly effective product appraisal activities.

Grady (1997) reports that Hewlett-Packard (HP) has determined the return-on-investment costs for 11 different SPI strategies. Grady reports return-on-investments of 9% for product definition, 12% for detailed design method, 12% for rapid prototyping, 12% for system design, and 20% for inspection software process improvements. Grady also reports returns of 35% for reuse, 5% for complexity analysis, 10% for configuration management, 6% for process certification, 6% for software asset management, and 7% for program understanding software process improvements. Grady goes on to report that HP achieved a 58X improvement in product failures, a 10X improvement in product defects, and savings of over $450 million from the use of inspections between 1987 and 1999, nearly $77 million in 1999 alone, as shown in Figure 13.

Ferguson, Humphrey, Khajenoori, Macke, and Matvya (1997) report a 67X increase in software quality for Advanced Information Services' SPI efforts. Ferguson et al. report an appraisal to failure ratio of 3.22:1, a review efficiency of 76.2%, a 99.3% test efficiency, a 99.8% total defect removal efficiency, and only one fielded defect in 18 software product releases for Motorola's SPI efforts, as described in Table 58.

Hays and Over (1997) report a 250:1 improvement in software size estimation and a 100:1 improvement in effort estimation accuracy as shown in Figure 14. Hays and Over reported a 7:1 improvement in SPI efforts using specific software quality methodologies for achieving SPI. Hays and Over also report a 120:1 improvement in software quality during software compilation and a 150:1 improvement in software quality during testing. Hays and Over also report a 75% defect removal efficiency before software compilation in the best case and an average programming productivity of 25 sources lines of code per hour, while still achieving near zero defect delivery.

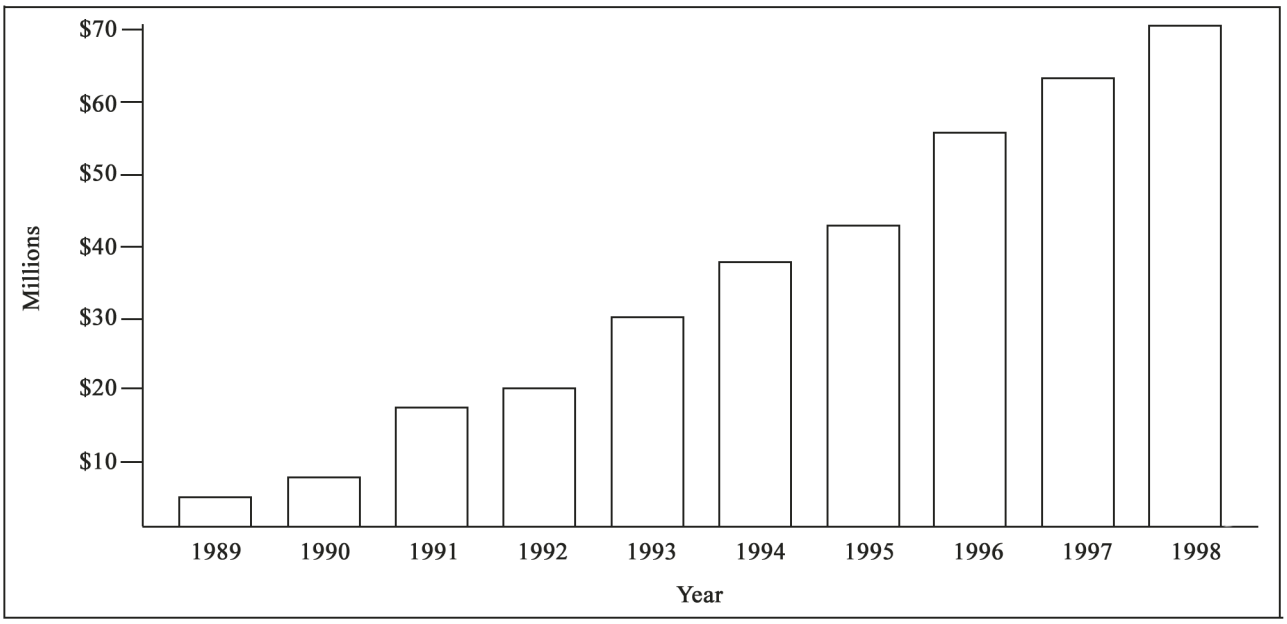

Figure 13. Hewlett Packard Annual Software Inspection Process Savings

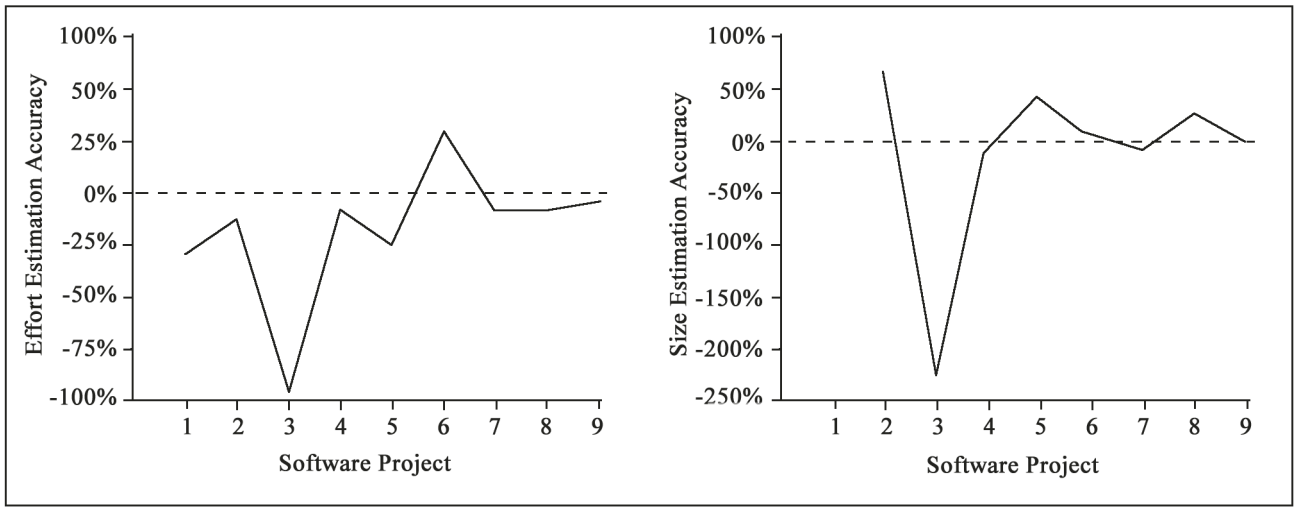

Figure 14. SEI Personal Software Process (PSP) Results

Jones (1997a) reports to have measurements, costs, and benefits for SPI involving 7,000 software projects, 600 software development organizations, and six industries. Jones reports that 200 of the 600 organizations in his database are actively pursuing SPI efforts. Jones reports that it takes an average of $21,281 per person to conduct assessments, improve management and technical processes, institute software tools and reuse, and ultimately achieve industry leadership. Jones reports that it takes 34 months in the best case and 52 months in the worst case to achieve industry leadership using a concerted SPI effort, resulting in a 95% reduction in defects, 365% increase in productivity, and 75% reduction in cycle time.

Table 58: Motorola Personal Software Process (PSP) Benefits

Defect Containment Analysis								
Project	Size	Defects	Insertion	Review	Efficiency	Test	Efficiency	Fielded
1	463	13	3%	8	62%	5	100%	0
2	4,565	69	2%	59	86%	10	100%	0
3	1,571	47	3%	39	83%	8	100%	0
4	3,381	69	2%	47	68%	22	100%	0
5	5	0	0%	0	0%	0	0%	0
6	22	2	9%	2	100%	0	0%	0
7	1	1	100%	1	100%	0	0%	0
8	2.081	.34	2%	33	‘),’,	()	(l’,	1
9	114	15	13%	13	87%	2	100%	0
10	364	29	8%	27	93%	2	100%	0
11	7	0	0%	0	0%	0	0%	0
12	620	12	2%	10	83%	2	100%	0
13	720	9	1 %	7	78%	2	100%	0
14	3,894	20	1%	18	90%	2	100%	0
15	2,075	79	4%	52	66%	27	100%	0
16	1,270	20	2%	19	95%	1	100%	0
17	467	17	4%	14	82%	3	100%	0
18	3,494	139	4%	89	64%	50	100%	0
Total	25,114	575	2%	438	76%	136	99%	1

Diaz and Sligo (1997) report SPI data from Motorola’s Government Electronics Division (GED) in Scottsdale, Arizona, involving a 1,500 engineer enterprise, 350 of whom are involved in software management and development, and 34 major programs or products. Diaz and Sligo report that the GED is currently at SEI CMM Level 5. Diaz and Sligo report that three GED programs are at CMM Level 1, nine at Level 2, five at Level 3, eight at Level 4, and nine GED programs are at SEI CMM Level 5. Diaz and Sligo report a 54% defect removal efficiency increase from CMM Level 2 to 3, a 77% defect removal efficiency increase from Level 2 to 4, and an 86% defect removal efficiency increase from Level 2 to 5. Diaz and Sligo report a cycle time improvement of nearly 8X and a productivity improvement of nearly 3X from CMM Level 1 to 5. Diaz and Sligo report that it took Motorola GED approximately 6 to 7 years to journey from SEI CMM Level 1 to Level 5 (see Figure 15).

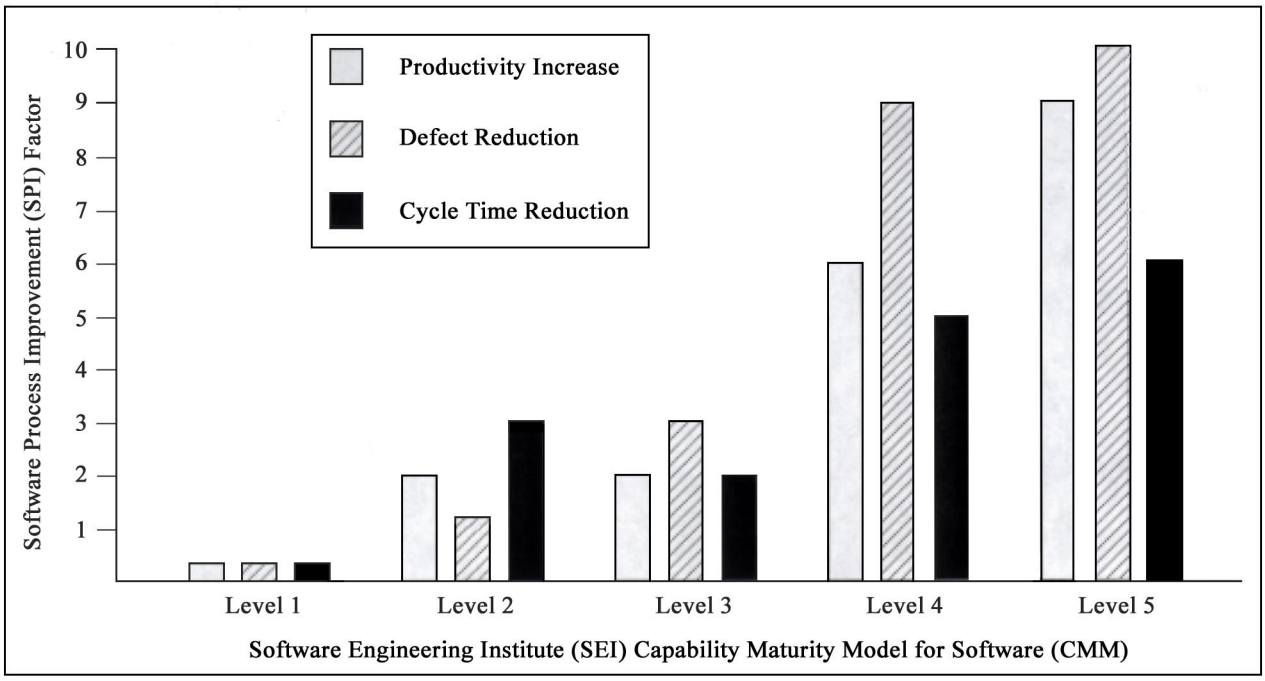

Figure 15. Motorola CMM-Based Software Process Improvement (SPI)

Haley (1996) reports SPI data from Raytheon Electronic Systems' Equipment Division in Marlborough, Massachusetts, involving 1,200 software engineers and a diverse variety of programs. Haley reports some of the programs as air traffic control, vessel traffic management, transportation, digital communications, ground-based and shipboard radar, satellite communications, undersea warfare, command and control, combat training, and missiles. Haley reports as a result of Raytheon's extensive SPI efforts, rework was reduced by over 50%, defects found in testing dropped by 80%, productivity increased by 190%, software cost estimation accuracy increased by 93%, and software quality increased by 77%. Haley reports that these SPI results were in conjunction with transitioning from SEI CMM Level 1 to Level 3, over a seven year period from 1988 to 1995, as shown in Figure 16.

McGibbon (1996), Director of the Data and Analysis Center for Software (DACS) at Rome Laboratory in Rome, New York conducted a quantitative analysis of SPI costs, benefits, and methods. McGibbon found an 82% decrease in software development costs, a 93% decrease in software rework costs, a 95% decrease in software maintenance costs, and a 99% reduction in software defects using SPI versus traditional software management and development methods (see Figure 17).

Kan (1995) reported that the IBM Federal Systems Division, in Gaithersburg, Maryland, developed a quality estimation technique used on nine software projects consisting of 4,000,000 source lines of code, that predicted the accuracy of final software quality within 6 one-hundredths of a percent of accuracy (see Figure 18).

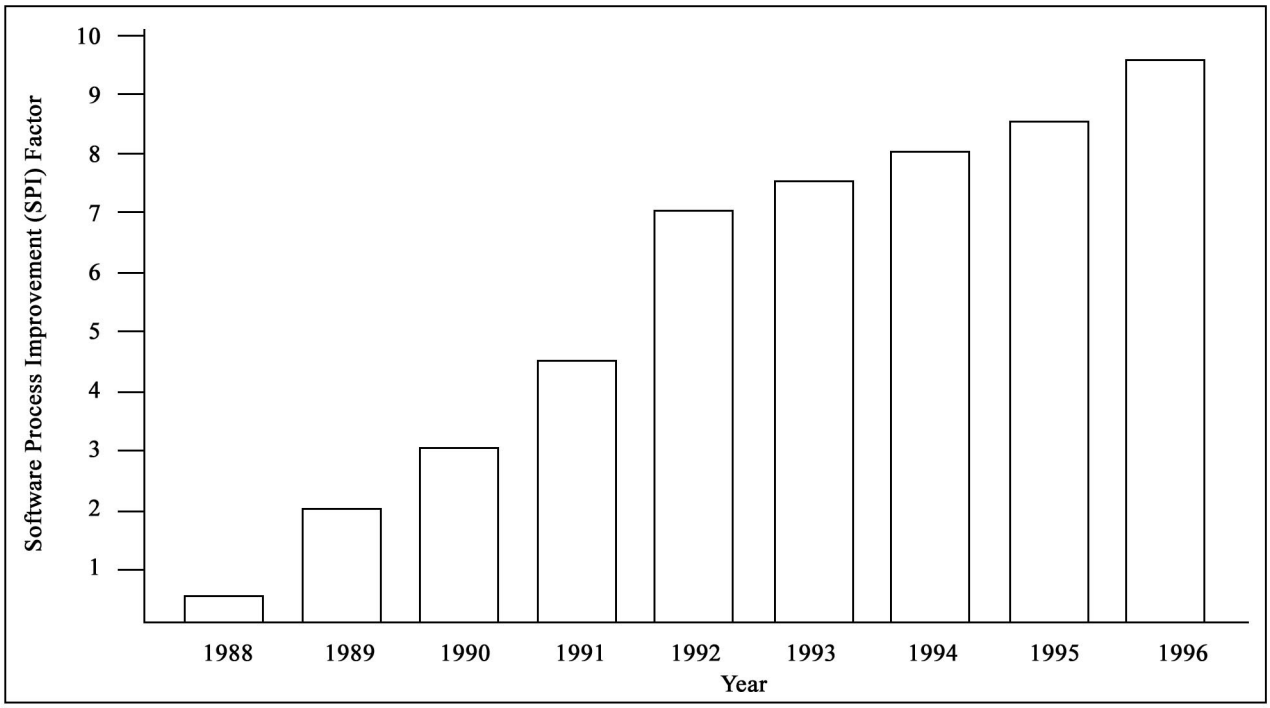

Figure 16. Raytheon CMM-Based Software Productivity Improvements

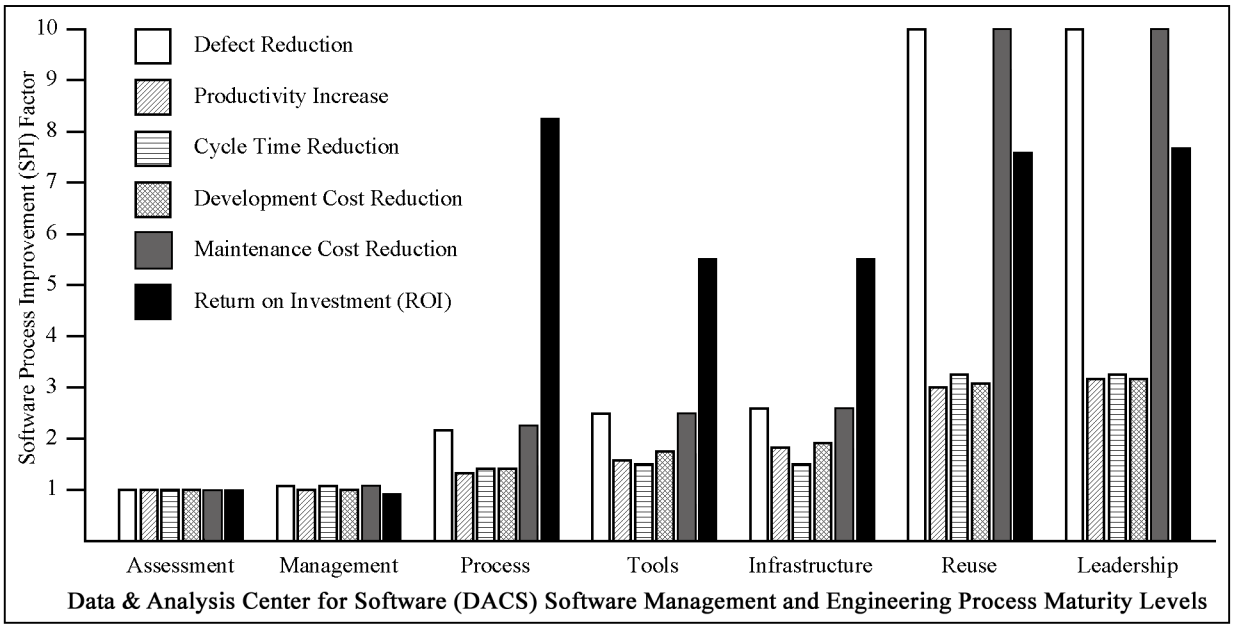

Figure 17. DACS Software Process Improvement (SPI) Model

Note that defect and maintenance cost reductions are off the scale and are approximately 18 times better than the assessment level (*not* 10 times as shown).

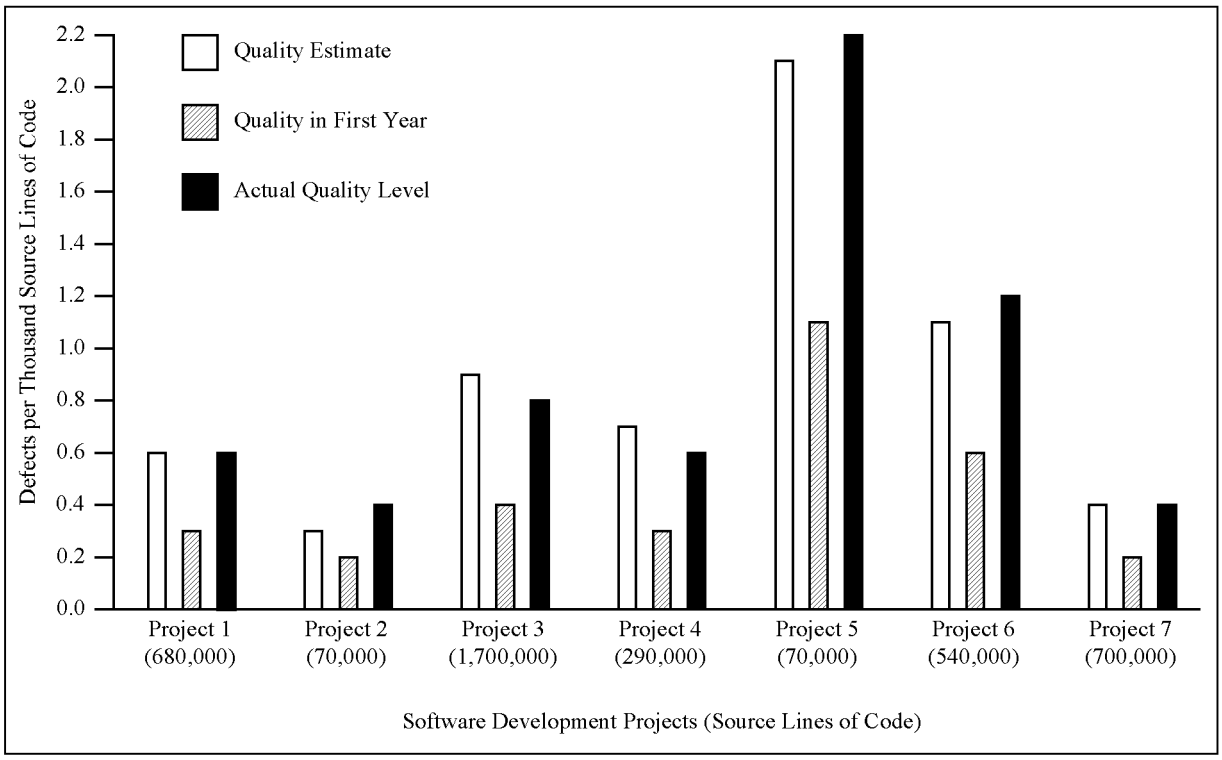

Figure 18. IBM Rayleigh Life-Cycle Reliability Model Accuracy

Kan (1991) reported software quality estimation accuracy of more than 97%, overall problem reporting estimation accuracy of over 95%, defect insertion rate and defect population reductions of over 50%, and asymptotic defect populations by system test and delivery for IBM's SPI efforts, in Rochester, Minnesota.

Kan, Dull, Amundson, Lindner, and Hedger (1994) reported 33% better customer satisfaction than the competition, software quality improvements of 67%, defect insertion reductions of 38%, testing defect reductions of 86%, implementation of 2,000 defect prevention actions, and an asymptotic defect population by testing, for their SPI efforts (see Figure 19). Kan et al. reports that IBM in Rochester, Minnesota, won the Malcolm Baldrige National Quality Award in 1990, and obtained ISO 9000 registration for the IBM Rochester site in 1992.

Sulack, Linder, and Dietz (1989) reported that IBM Rochester's SPI efforts supported the development of eight software products, five compilers, five system utilities, 11,000,000 lines of online help information, 32,000 pages of manuals, a 500,000 line automated help utility, and 1,100 lines of questions and answers. Sulack, Lindner, and Dietz also reported that IBM's SPI efforts resulted in the development of native support for 25 international languages. Sulack, Lindner, and Dietz reported that in total, IBM Rochester's SPI efforts supported the development of 5,500,000 new source lines of code and the conversion of more than 32,000,000,000 source lines of code for a new mid range computer system. Finally, Sulack, Lindner, and Dietz reported a 38% cycle time reduction for not only introducing SPI efforts at IBM Rochester, but achieving the aforementioned results as well.

Herbsleb, Carleton, Rozum, Siegel, and Zubrow (1994) of the SEI conducted a cost-benefit analysis of CMM-based SPI involving 13 software management and development organizations (see Figure 20). Herbsleb's et al. study involved Bull HN, GTE Government Systems, Hewlett Packard, Hughes Aircraft Co., Loral Federal Systems, Lockheed Sanders, Motorola, Northrop, Schlumberger, Siemens Stromberg-Carlson, Texas Instruments, the United States Air Force Oklahoma City Air Logistics Center, and the United States Navy Fleet Combat Direction Systems Support Activity. Herbsleb's et al. study surveyed organizational characteristics such as organizational environment and business characteristics and SPI efforts such as SPI effort descriptions, process maturity information, measures and techniques in use, and description of data collection activities.

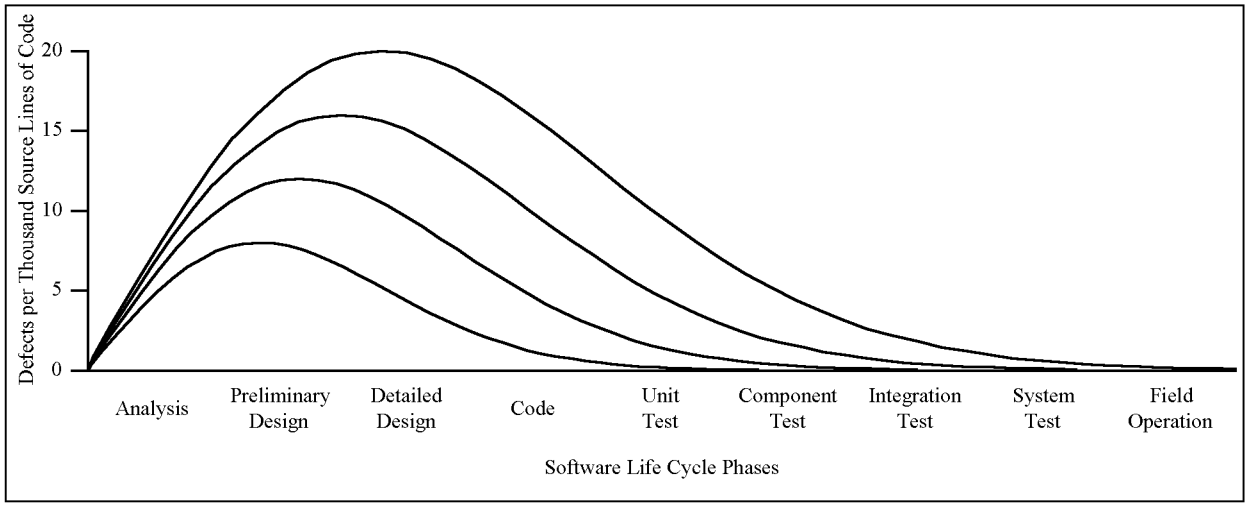

Figure 19. IBM Rayleigh Life-Cycle Reliability Model

Herbsleb's et al. study also surveyed results such as impact of SPI on business objectives, impact of SPI on social factors, and actual performance versus projections. Herbsleb et al. reported costs and lengths of SPI efforts for five of thirteen organizations. Herbsleb et al. reported one organization spent $1,203,000 per year for six years, one spent $245,000 in two years, one spent $155,000 in six years, one spent $49,000 dollars in four years, and one spent $516,000 in two years. Herbsleb et al. reports that yearly costs per software developer for the same five organizations were, $2,004, $490, $858, $1,619, and $1,375 respectively. Herbsleb et al. reported that yearly productivity increases for four of the thirteen organizations were 9% for three years, 67% for one year, 58% for four years, and 12% for five years. Herbsleb et al. reported defect removal efficiency improvements of 25%, cycle time reductions of 23%, software quality improvements of 94%, and return-on-investments of nearly 9:1. Herbsleb et al. reported that the median SPI performance for all thirteen organizations included $245,000 yearly costs, 3.5 years of SPI, $1,375 per software developer, 35% productivity increase, 22% defect removal efficiency increase, 19% cycle time reduction, 39% software product quality increase, and a 5:1 return-on-investment.

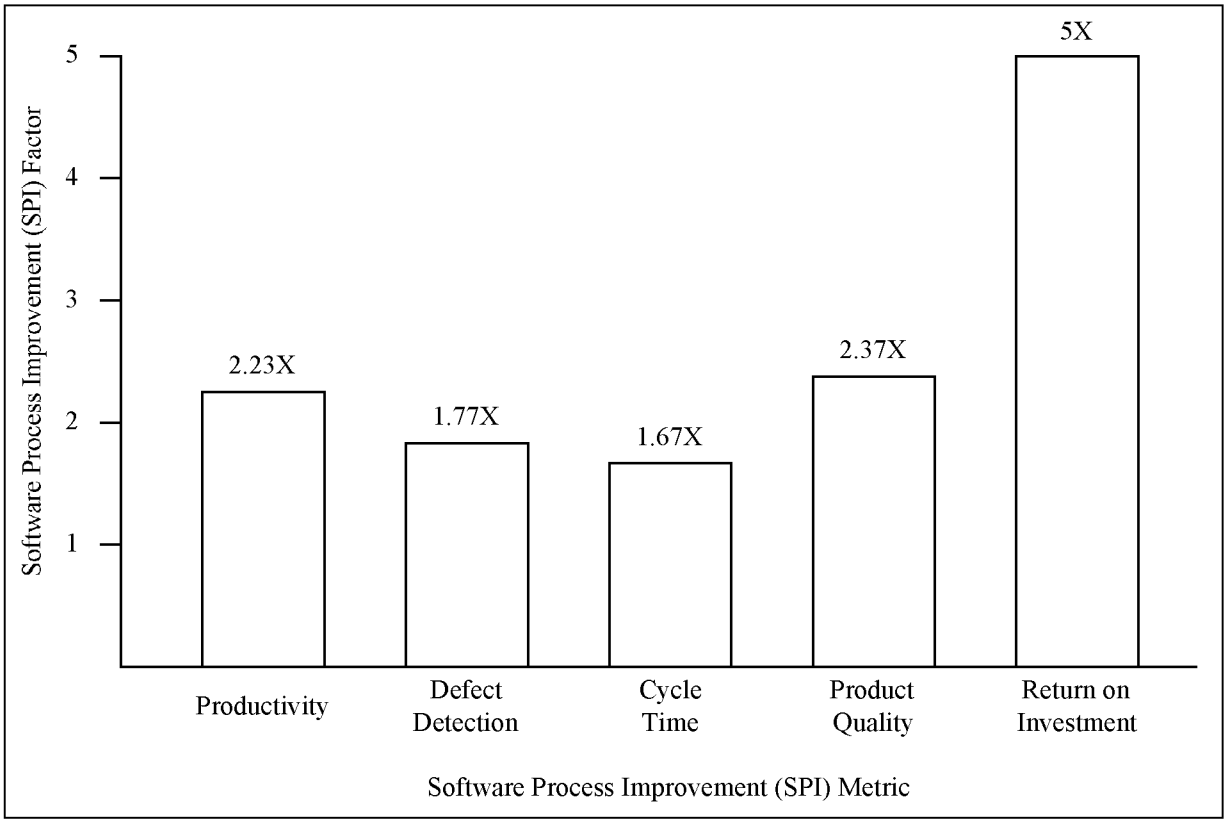

Figure 20. SEI Software Process Improvement (SPI) Survey (of 13 Organizations)

Kajihara, Amamiya, and Saya (1993) report a 100% increase in productivity from 1989 to 1993 and a 10:1 decrease in the number of software defects from 1984 to 1993, both as a result of NEC's SPI efforts in Tokyo, Japan (see Figure 21). Kajihara, Amamiya, and Saya go on to report that the number of defect analysis reports associated with NEC Tokyo's SPI efforts increased by 33X, from 50 in 1981 to 1,667 at their peak in 1990. Kajihara, Amamiya, and Saya report that the number of groups and people involved in NEC Tokyo's SPI efforts grew from 328 groups and 2,162 people in 1981 to 2,502 groups and 15,032 people in 1990.

Weller (1993) reported that Bull HN Information System's Major Systems Division performed over 6,000 Software Inspections as part of their SPI-related efforts between 1990 and 1991 on mainframe computer operating systems. Weller reported that Bull HN Information Systems managed 11,000,000 source lines of code, adding up to 600,000 source lines of code every year. Weller reported that the number of software defects removed were 2,205, 3,703, and 5,649 in 1990, 1991, and 1992, respectively. Weller reported a 76% increase in defect removal efficiency, 33% increase in software quality, and a 98.7% defect removal efficiency before testing in the best case.

Mays, Jones, Holloway, and Studinski (1990) reported that IBM Communications Systems at Research Triangle Park, North Carolina, achieved a 50% defect insertion rate reduction for their SPI related efforts, involving 414 software developers (see Figure 22). Mays et al. reported that the total cost was less than half a percent of the total organizational resources, in order to achieve the 50% defect insertion rate reduction. The 50% reduction in defects resulted in four staff years of saved Software Inspection time, 41 staff years of saved testing time without Software Inspections, and 410 staff years of saved post release defect removal time without Software Inspections and testing. The total return-on-investment for IBM's SPI related efforts was over 482:1 in the best case.

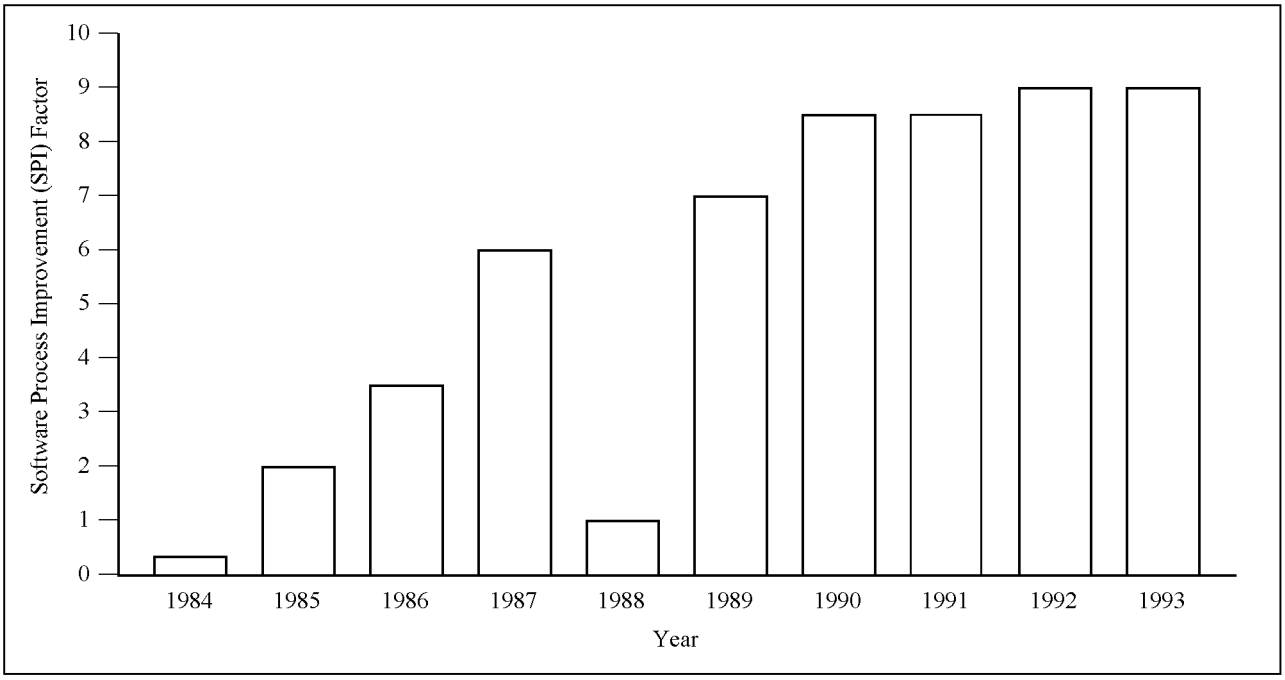

Figure 21. NEC (Tokyo, Japan) **Defect Prevention Results**

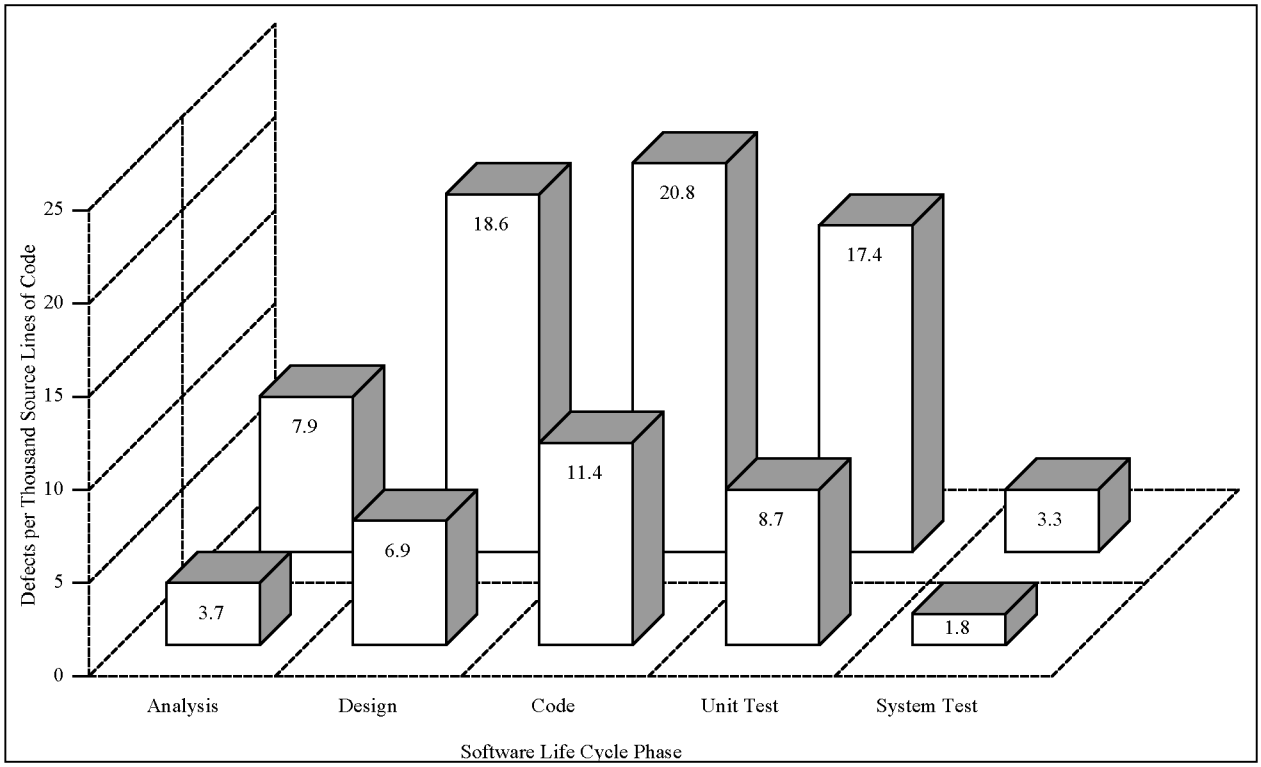

Figure 22. Defect Prevention Results

Lim (1998) conducted an extensive survey of the costs and benefits of using Software Reuse as a SPI strategy throughout international industry, as well as comprehensive Software Reuse cost-benefit analyses at Hewlett Packard's (HP's) Manufacturing Productivity Section and San Diego Technical Graphics Division from 1983 to 1994 (see Table 59). Lim reports 100% quality increases at HP, 50% decreases in time-to-market at AT&T, $1.5M in savings at Raytheon, a 20X increase in productivity at SofTech, and a 25% increase in productivity at DEC as a result of using Software Reuse. Lim also reports a 57% increase in productivity at HP, 461% increase in productivity in an HP firmware division, 500% cycle time reduction in HP, and a 310% return-on-investment (ROI) at HP (in the best case) as a result of using Software Reuse. Poulin (1997) cites similar benefits for Software Reuse from 10 software companies world-wide. Poulin reports that NEC achieved a 6.7X productivity increase, GTE saved $14M, Toshiba reduced defects 30%, DEC reduced cycle times 80%, CAP-Netron achieved 90% reuse levels, Raytheon increased productivity 50%, and Software Architecture and Engineering reached 90% reuse levels.

Table 59: Hewlett Packard Software Reuse Costs and Benefits

	Division	
Cost Category	Manufacturing	Graphics
Timespan	1983- 1992	1987- 1994
Years	10	8
Initial Effort	26 Staff Months	107 Staff Months
Initial Cost	$0.3M	$1.3M
Sustaining Effort	54 Staff Months	99 Staff Months
Sustaining Cost	$0.7M	$ 1.3M
Total Effort	80 Staff Months	206 Staff Months
Total Cost	$1.0M	$2.6M
Effort Saved	328 Staff Months	446 Staff Months
Cost Saved	$4.1M	$5.6M
Return-on-Investment	310%	115%
Net Present Value Effort	125 Staff Months	75 Staff Months
Net Present Value Dollars	$1.6M	$0.9M
Break-Even Point	Second Year	Sixth Year

Kaplan, Clark, and Tang (1995) of IBM Santa Teresa conducted a survey of 40 SPI strategies, briefly describing them, identifying the process steps where possible, and enumerating the costs and benefits as well. Kaplan, Clark, and Tang identified the Clean Room Methodology as a strategically important SPI strategy (see Table 60). Kaplan, Clark, and Tang identified resulting quality levels for 15 software projects at 2.3, 3.4, 4.5, 3.0, 0, 0, 2.6, 2.1, 0.9, 5.1, 3.5, 4.2, 1.8, 1.8, and 0.8 defects per thousand software source lines of code, for an average defect density of 2.4.

Slywotzky, Morrison, Moser, Mundt, and Quella (1999) conducted in-depth case studies of nine firms and examined more that 200 firms and the impact that management strategy, Business Process Reengineering (BPR), and process improvement had on shareholder value (see Figure 23). While Slywotsky's et al. work isn't about SPI per se, his book does study a form of process improvement called value chain analysis, or Process Value Analysis (PVA), as mentioned previously, among other BPR or process improvement techniques. Slywotzky et al. reported that Microsoft achieved a 220:1, Coca Cola achieved a 20:1, Cisco achieved a 15:1, GE achieved a 12:1, Nike achieved an 11:1, Yahoo achieved a 12:1, Mattel achieved a 3:1, and The Gap achieved a 4:1 shareholder value advantage over their competitors.

Table 60:Clean Room Methodology Benefits

Year	Organization	Product	Software Size	Defect Density
1987	IBM	Flight control	33,000	2.3
1988	IBM	Software tool	85,000	3.4
1989	NASA	Satellite control	40,000	4.5
1990	University	Software tool	12,000	3.0
1990	Martin Marietta	Word processor	1,800	0.0
1991	IBM	Operating system	600	0.0
1991	IBM	Operating system	10,000	2.6
1991	IBM	Compiler	21,900	2.1
1991	IBM	Imaging product	3,500	0.9
1992	IBM	Printer driver	6,700	5.1
1992	IBM	Expert system	17,800	3.5
1992	NASA	Satellite control	170,000	4.2
1993	IBM	Device driver	39,900	1.8
1993	IBM	Database	8,500	1.8
1993	IBM	Network software	4,800	0.8

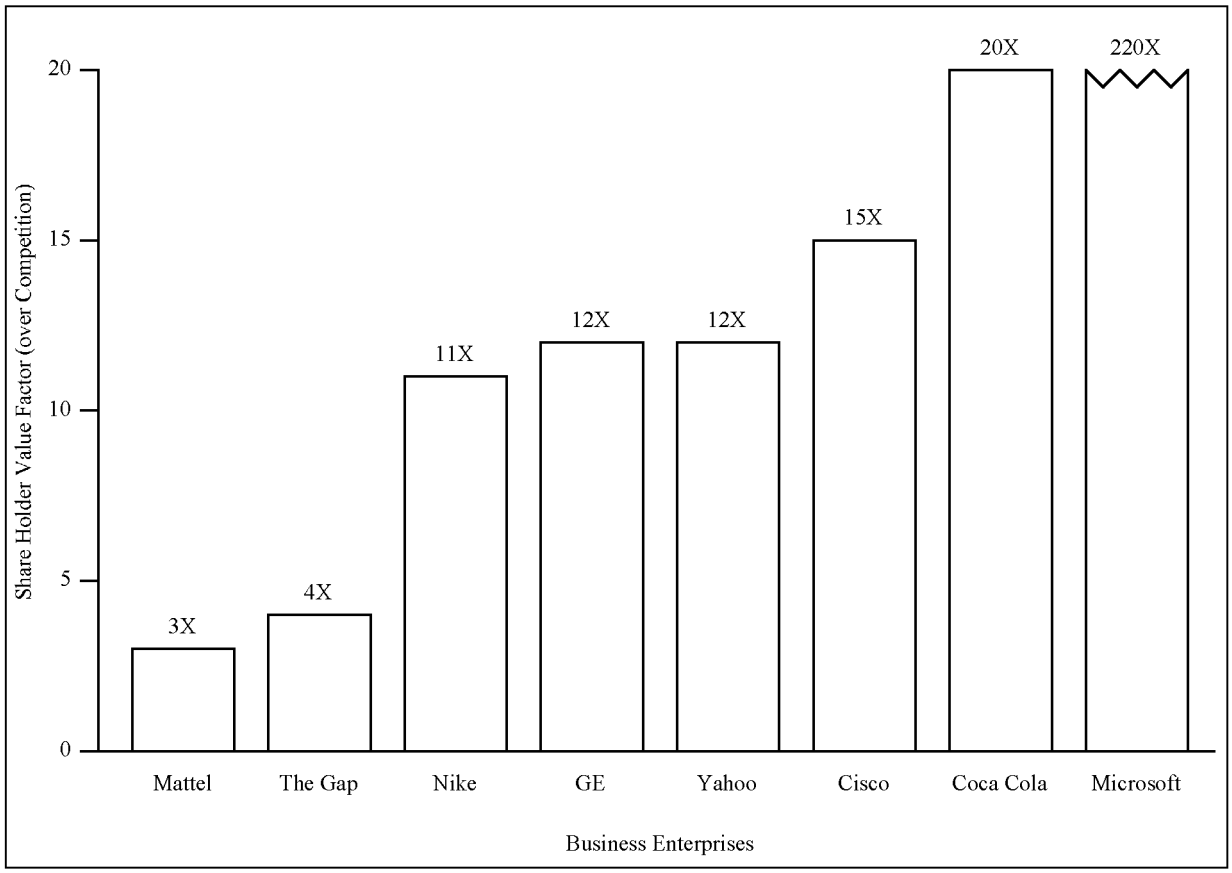

Figure 23. Share Holder Value (as a result of SPI)

Comparative Analyses

So far this study, specifically the literature review, has examined the definition of SPI, the quantitative costs and benefits of SPI, and a broad-based examination of SPI techniques, methods, methodologies, approaches, and strategies. This section attempts to examine the best SPI strategies based on existing analytical comparative analyses of the various SPI approaches. The reason previous sections have examined such a broad base of SPI methods, rather than rushing right into to this section's analyses, was to expose the reader to an authoritatively wide variety of SPI techniques that are available for later individual analysis.

This section examines 18 quantitative and qualitative SPI models, comparative analyses, and decision analysis models to introduce candidate and foundational approaches for identifying and selecting from multiple SPI strategies based on individual costs and benefits (see Table 61).

Table 61: Survey of Software Process Improvement (SPI) Comparative Analyses

Author	Model	Quantitative	Costs	Benefits	Criteria	Techniques, Methods, Strategies	Best SPI Method
Humphrey	SKI SW-CMM	No	No	No	n/a	18 Key Process Areas (KPAs)	Requirements Analysis
Austin	Decision Matrix	No	No	Yes	2	13 Various	Cost Estimation
McConnell	Decision Matrix	No	No	Yes	5	29 Various	Evolutionary Life Cycle
Grady	Decision Matrix	Yes	Yes	Yes	4	11 Various	Program Understanding
McGibbon	Decision Matrix	Yes	Yes	Yes	6	Clean Room, Inspection, Reuse	Software Inspections
Rico	Defect Removal	Yes	Yes	Yes	14	PSP, Inspection, Test	PSP
McGibbon	Defect Removal	Yes	Yes	Yes	29	Clean Room, Inspection, Walkthrough	Clean Room
n/a	Decision Matrix	No	No	Yes	11	Reviews, Inspection, Walkthrough	Software Inspections
Kettinger	Decision Analysis	No	No	No	11	72 Various	n/a
Tingey	Decision Matrix	No	No	No	12	Baldrige, ISO 9001, SKI SW-CMM	Baldrige
Harrington	Decision Matrix	No	No	Yes	16	6 Various Quality Mgmt Systems	TQM
Rico	Decision Matrix	Yes	Yes	Yes	12	Vertical Process, Vertical Life Cycle	PSP
Jones	Decision Matrix	No	No	No	3	49 Various	Quality Metrics
Haskell	Decision Matrix	Yes	Yes	Yes	6	SKI SW-CMM, ISO 9001	ISO 9001
Wang	Decision Matrix	Yes	No	No	444	SPRM, SPICE, CMM, BOOTSTRAP, ISO9000	SPRM
Wang	Decision Matrix	Yes	No	No	444	SPICE, CMM, BOOTSTRAP, ISO 9000	SPICE
Wang	Decision Matrix	Yes	No	No	5	50 Various	Software Architecture
McConnell	Decision Matrix	No	No	Yes	11	10 Various	Spiral Life Cycle

Humphrey (1987 and 1989) and Paulk, Weber, Curtis, and Chrissis (1995) created the Capability Maturity Model for Software (CMM) as a prescriptive framework for Software Process Improvement (SPI) - note that the CMM is prescriptive for Software Process Improvement (SPI), not necessarily software management, engineering, or process definition. The CMM is designed to identify key or strategic processes, group and arrange them according to importance and priority, and direct the order of Software Process Improvement (SPI) priorities, activities, and implementation (see Figure 24).

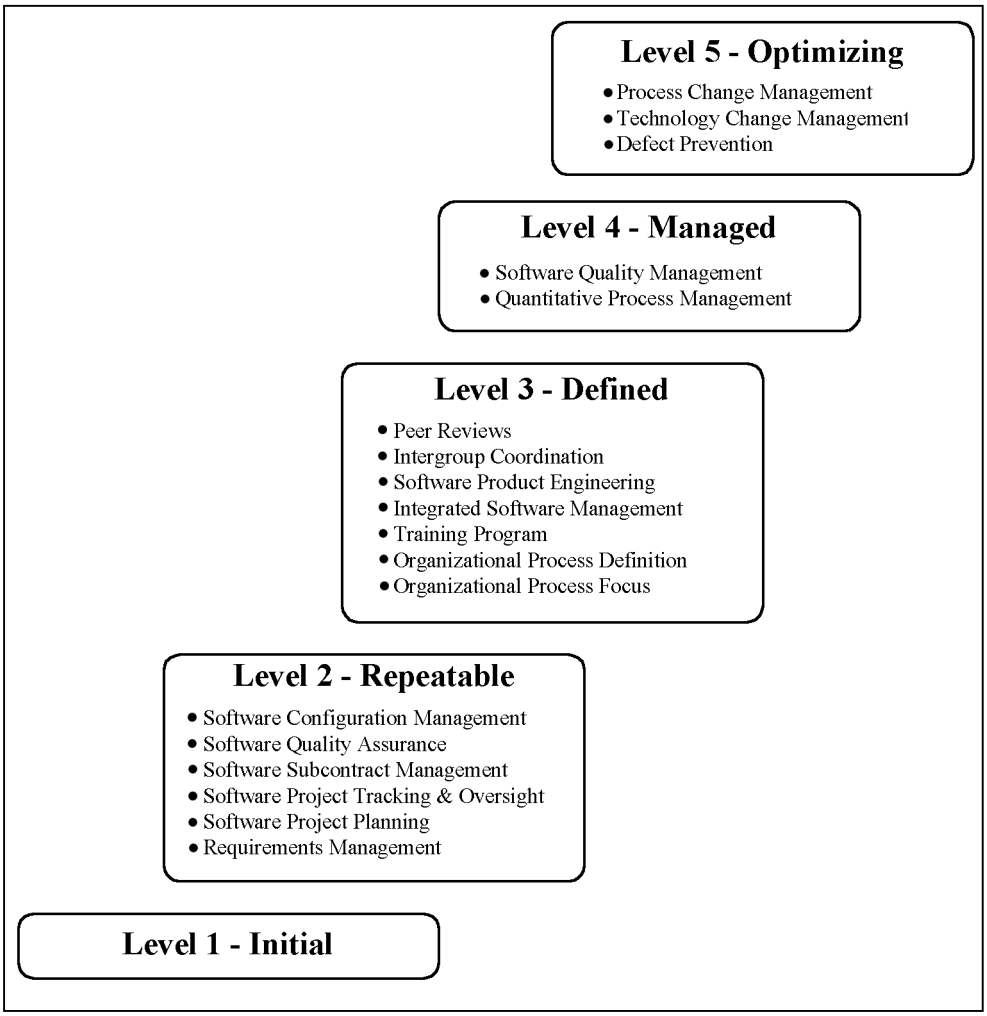

Figure 24. SEI Capability Model for Software (CMM)

According to the CMM, organizations should first focus on the six Level 2 (Repeatable) Key Process Areas (KPAs), Requirements Management, Software Project Planning, Software Project Tracking and Oversight, Software Subcontract Management, Software Quality Assurance, and then Software Configuration Management. Then software organizations should focus on the seven Level 3 (Defined) Key Process Areas (KPAs), Organizational Process Focus, Organizational Process Definition, Training Program, Integrated Software Management, Software Product Engineering, Intergroup Coordination, and then Peer Reviews. Then software organizations should focus on the Level 4 (Managed) Key Process Areas (KPAs), Quantitative Process Management and then Software Quality Management. Finally, software organizations should focus on the Level 5 (Optimizing) Key Process Areas (KPAs), Defect Prevention, Technology Change Management, and Process Change Management.

The CMM seems to be consistent with W. Edwards Deming's first three of fourteen points, nature of variation, losses due to tampering (making changes without knowledge of special and common causes of variation), and minimizing the risk from the above two (through the use of control charts). In other words, W. Edwards Deming believed that minimizing variation is the key to organizational performance improvement (but, only if the techniques to minimize variation are based on measurable decisions). Likewise, the CMM asks that processes be stabilized, defined, and measured before software process changes are implemented. Unfortunately, it takes many years to reach CMM Level 5 and less than 1% of

worldwide organizations are at CMM Level 5. Therefore, the CMM would have virtually no worldwide organizations attempt process improvement. On the contrary, W. Edwards Deming meant that organizations should take measurements on day one and then make process changes based on measurement data (not wait many years to perform process improvements).

Austin and Paulish (1993), then of the Software Engineering Institute (SEI), conducted a qualitative analysis and comparison of 13 "tactical" Software Process Improvement (SPI) methods beyond the strategic organizational nature of the CMM (see Table 62).

Table 62: SKI Comparison of Software Process Improvement (SPI) Methods

CMM Level	Strategy	Pros	Cons
1	Estimation	Fundamental to project planning	Requires historical data
I	ISO 9000	Required for many markets	Emphasis on evidence only
1 - 2	Software Process Assessment	Good first step to improvement	Provides findings only
I - 2	Process Definition	Provides improvement baseline	Lack of skills with tools
1 - 2	Software Inspection Process	Easy to begin	Commonly used for code
1 - 2	Software Metrics	Used with other methods	Must be tailored to goals
I - 2	CASE Tools	Automates process	High investment costs
1 - 2	Interdisciplinary Group Method	Promotes better teamwork	Communication overhead
2 - 3	Software Reliability Engineering	Provides field defect predictions	Lack of training and skills
2 - 3	Quality Function Deployment	Helps build the "right" products	Difficult to manage
2 - 3	Total Quality Management	Builds a "quality culture"	Requires organization buy-in
3 - 4	Defect Prevention Process	Makes classes of errors extinct	Only for mature organizations
3 - 4	Clean Room Methodology	Can result in high product quality	Radically different approach

Austin and Paulish identified qualitative pros and cons of the 13 Software Process Improvement (SPI) methods, as well as a mapping them to the CMM (as shown in Table 28). Only SEI CMM Level 4 organizations should attempt the Clean Room Methodology and the Defect Prevention Process. Only SEI CMM Level 3 organizations should attempt Total Quality Management, Quality Function Deployment, and Software Reliability Engineering. Only SEI CMM Level 2 organization should attempt Interdisciplinary Group Methods, CASE Tools, Software Metrics, the Software Inspection Process, Process Definition, and Software Process Assessment. Finally, SEI CMM Level 1 organizations may attempt to use ISO 9000 and estimation. Since many worldwide software organizations aren't at SEI CMM Levels 3, 4, and 5, Austin and Paulish recommend that organizations shouldn't use many powerful SPI methods.

McConnell (1996) identified, defined, and compared 29 software process improvement (SPI) methods in terms of potential reduction from nominal schedule (cycle-time reduction), improvement in progress visibility, effect on schedule risk, chance of first-time success, and chance of long-term success (see Table 63).

Evolutionary prototyping, outsourcing, reuse, and timebox development are excellent for potential reduction from nominal schedule (cycle-time reduction). Evolutionary delivery, evolutionary prototyping, and goal setting (for maximum visibility) are excellent for improvement in progress visibility. Most Software Process Improvement (SPI) methods are reported to have a positive effect on schedule risk. Theory-W management, throwaway prototyping, top-10 risk lists, and user-interface prototyping have a good chance of first-time success. Finally, many of the software process improvement (SPI) methods are reported to result in a good chance of long-term success.

Grady (1997) identified, defined, and compared 11 Software Process Improvement (SPI) methods in use throughout Hewlett Packard in terms of difficulty of change, cost of change, break-even time of change, and percent expected cost improvement (see Table 64).

Grady reports that software reuse is the most difficult, most expensive, and has the longest breakeven point, but has the greatest payoff. Grady reports that complexity analysis and program understanding are the simplest, least expensive, and have short breakeven points, with the smallest payoffs. Rapid prototyping and the Software Inspection Process are also attractive.

McConnell (1996) identified, defined, and compared 29 software process improvement (SPI) methods in terms of potential reduction from nominal schedule (cycle-time reduction), improvement in progress visibility, effect on schedule risk, chance of first-time success, and chance of long-term success (see Table 63).

Table 63: Construx Comparison of Software Process Improvement (SPI) Methods

SPI Method	Cycle-Time Reduction	Progress Visibility	Schedule Risk	First-Time Success	Long-Term Success
Change Board	Fair	Fair	Decreased	Very Good	Excellent
Daily Build and Smoke Test	Good	Good	Decreased	Very Good	Excellent
Designing for Change	Fair	None	Decreased	Good	Excellent
Evolutionary Delivery	Good	Excellent	Decreased	Very Good	Excellent
Evolutionary Prototyping	Excellent	Excellent	Increased	Very Good	Excellent
Goal Setting (shortest schedule)	Very Good	None	Increased	Good	Very Good
Goal Setting (least risk)	None	Good	Decreased	Good	Very Good
Goal Setting (max visibility)	None	Excellent	Decreased	Good	Very Good
Software Inspection Process	Very Good	Fair	Decreased	Good	Excellent
Joint Application Development	Good	Fair	Decreased	Good	Excellent
Life Cycle Model Selection	Fair	Fair	Decreased	Very Good	Excellent
Measurement	Very Good	Good	Decreased	Good	Excellent
Miniature Milestones	Fair	Very Good	Decreased	Good	Excellent
Outsourcing	Excellent	None	Increased	Good	Very Good
Principled Negotiation	None	Very Good	Decreased	Very Good	Excellent
Productivity Environments	Good	None	No Effect	Good	Very Good
Rapid-Development Languages	Good	None	Increased	Good	Very Good
Requirements Scrubbing	Very Good	None	Decreased	Very Good	Excellent
Reuse	Excellent	None	Decreased	Poor	Very Good
Signing Up	Very Good	None	Increased	Fair	Good
Spiral Life Cycle Model	Fair	Very Good	Decreased	Good	Excellent
Staged Delivery	None	Good	Decreased	Very Good	Excellent
Theory-W Management	None	Very Good	Decreased	Excellent	Excellent
Throwaway Prototyping	Fair	None	Decreased	Excellent	Excellent
Timebox Development	Excellent	None	Decreased	Good	Excellent
Tools Group	Good	None	Decreased	Good	Very Good
Top-10 Risks List	None	Very Good	Decreased	Excellent	Excellent
User-lnterface Prototyping	Good	Fair	Decreased	Excellent	Excellent
Voluntary Overtime	Good	None	Increased	Fair	Very Good

Evolutionary prototyping, outsourcing, reuse, and timebox development are excellent for potential reduction from nominal schedule (cycle-time reduction). Evolutionary delivery, evolutionary prototyping, and goal setting (for maximum visibility) are excellent for improvement in progress visibility. Most software process improvement (SPI) methods are reported to have a positive effect on schedule risk. Theory-W management, throwaway prototyping, top-10 risk lists, and user-interface prototyping have a good chance of first-time success. Finally, many of the software process improvement (SPI) methods are reported to result in a good chance of long-term success.

Grady (1997) identified, defined, and compared 11 software process improvement (SPI) methods in use throughout Hewlett Packard in terms of difficulty of change, cost of change, break-even time of change, and percent expected cost improvement (see Table 64).

Table 64: HP Comparison of Software Process Improvement (SPI) Methods

Strategy	Difficulty	Cost	Breakeven	Savings
Product Definition Improvement	Low	Medium	Medium	3 - 9%
Detailed Design Methods	High	Medium	Long	3 - 12%
Rapid Prototyping	Low	Low	Medium	5 - 12%
Systems Design Improvements	Medium	Medium	Long	5 -12%
Software Inspection Process	Low	Medium	Short	8 - 20%
Software Reuse	High	High	Long	10 - 35%
Complexity Analysis	Low	Low	Short	2 - 5%
Configuration Management	High	High	Long	3 -10%
Certification Process	Medium	Medium	Medium	3 - 6%
Software Asset Management	High	Medium	Long	3 - 6%
Program Understanding	Low	Low	Short	3 - 7%

Grady reports that software reuse is the most difficult, most expensive, and has the longest breakeven point, but has the greatest payoff. Grady reports that complexity analysis and program understanding are the simplest, least expensive, and have short breakeven points, with the smallest payoffs. Rapid prototyping and the Software Inspection Process are also attractive.

McGibbon (1996) conducted a cost-benefit or return-on-investment analysis of three major vertical Software Process Improvement (SPI) strategies or approaches, the Software Inspection Process, Software Reuse, and the Clean Room Methodology, based on existing empirical data and analyses (see Figure 25).

Development costs were $1,861,821, rework costs were $206,882, maintenance costs were $136,362, savings were $946,382, and SPI costs were $13,212 for the Software Inspection Process (with a return-on-investment 71.63:1). Development costs were $815,197, rework costs were $47,287, maintenance costs were $31,168, savings were $2,152,600, and SPI costs were $599,139 for Software Reuse (with a return-on-investment of 3.59:1). Development costs were $447,175, rework costs were $39,537, maintenance costs were $19,480, savings were $2,528,372, and SPI costs were $77,361 for Clean Room (with a return-on-investment of 33:1).

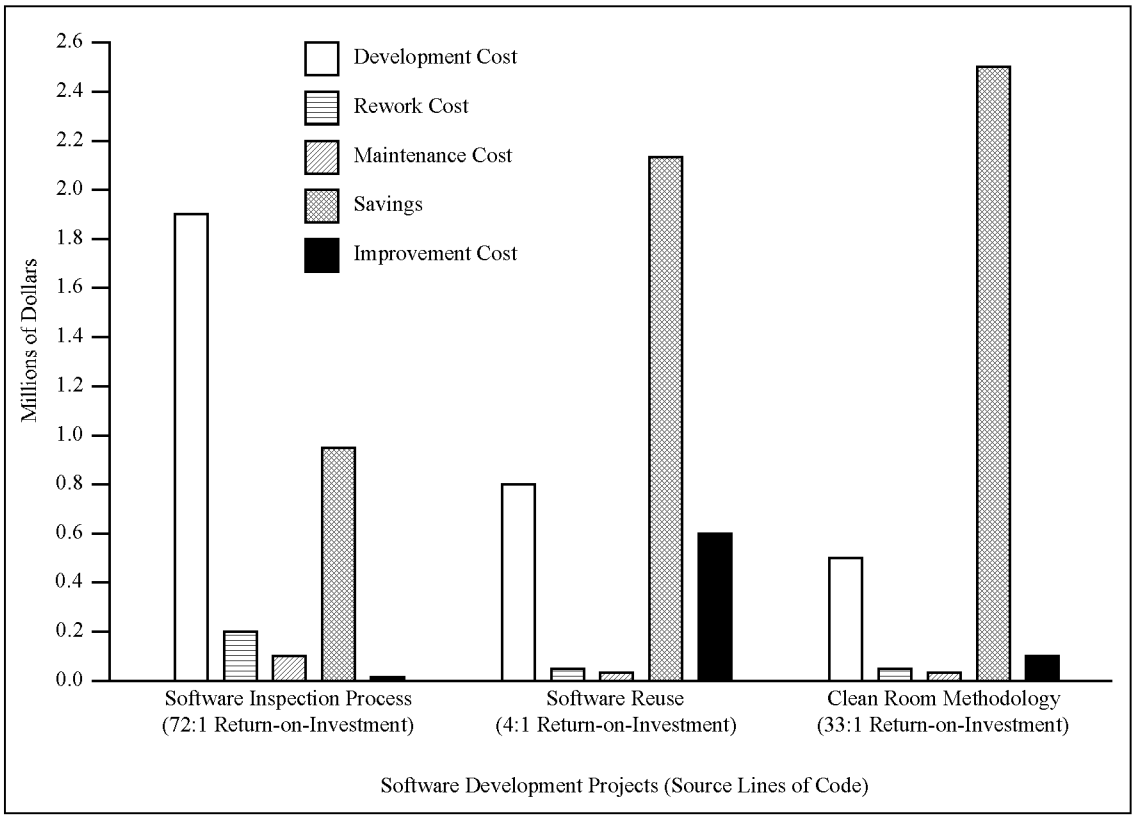

Figure 25. DACS Software Process Improvement (SPI) Study Results

Rico (1999) conducted a cost-benefit or return-on-investment analysis of three major vertical software process improvement (SPI) strategies or approaches, the Personal Software Process (PSP), the Software Inspection Process, and Testing, based on existing empirical data and analyses (see Table 65).

Table 65: PSP, Software Inspection Process, and Testing Comparison

Cost/Benefits	PSP	Inspection	Test
Program Size	10 KSLOC	10 KSLOC	10 KSLOC
Start Defects	1,000	1,000	1,000
Review Hours	97.24	708	n/a
Review Defects	666	900	n/a
Detects per Hour	6.85	1.27	n/a
Start Defects	333	100	1,000
Test Hours	60.92	1,144	11,439
Test Defects	333	90	900
Defects per Hour	5.47	12.71	12.71
Total Hours	400 *	1,852	11,439
Total Defects	1,000	990	900
Quality Benefit	100X	10X	n/a
Delivered Detects	0	10	100
Cost Benefit	29X	6X	n/a

* PSP hours include development time—others only validation time

Review hours were 97.24, review efficiency was 67%, test hours were 60.92, total hours were 400, and delivered defects were zero, for a quality benefit of 100X and a cost benefit of 29X over testing, using the Personal Software Process (PSP). Review hours were 708, review efficiency was 90%, test hours were 1,144, total hours were 1,852, and delivered defects were 10, for a quality benefit of 10X and a cost benefit of 6X over testing, using the Software Inspection Process. Test hours were 11,439, test efficiency was 90%, and delivered defects were 100, using Testing. PSP hours included both development and test, while the others did not.

McGibbon (1996) conducted a detailed cost-benefit analysis of the Clean Room Methodology, the Software Inspection Process, and Walkthroughs, for a later comparison to traditional, Software Reuse, and "full" software process improvement (see Table 66).

Table 66: Clean Room, Software Inspection Process, and Walkthrough Comparison

Cost/Benefits	Clean Room	Formal Inspection	Informal Inspection
Lines of Code	39,967	39,967	39,967
Defects per KSLOC	5	7	7
Total Defects Expected	200	280	280
Design			
% Defects Introduced	35%	35%	35%
Total Defects Introduced	70	98	98
% Defects Detected	80%	65%	40%
Defects Detected	56	64	39
Rework Hours/Defect	2.5	2.5	2.5
Total Design Rework	140	:159	98
Coding			
% Defects Introduced	65%	65%	65%
Total Defects Introduced	130	182	182
% Defects Detected	98%	70%	35%
Defects Detected	141	151	84
Rework Hours/Defect	2.5	2.5	2.5
Total Design Rework	353	378	211
Test			
Defects Found in Test	1	51	114
Rework Hours/Defect	25	25	25
Total Test Rework	22	1,271	2,861
% of Defects Removed	99%	95%	85%
Maintenance			
Defects Left for Customer	2	14	42
Post Release Defects/KSLOC	0.05	0.35	1.05
Rework Hours/Defect	250	250	250
Total Maintenance Rework	500	3,497	1O,491
Maintenance $	$19,484	$136,386	$409,159
Totals			
Total Rework Hours	1,014	5,306	13,660
Total Rework Costs	$39,544	$206,918	$532,752
Effort $ + Maintenance $	$466,659	$2,618,814	$2,891,586
Clean Room $ Improvement		$2,152,155	$2,424,927
Clean Room % Improvement		82%	84%

Total development defect removal efficiencies for the Clean Room Methodology and Formal and Informal Inspections were 99%, 95%, and 85%, respectively. Total development rework hours for the Clean Room Methodology and Formal and Informal Inspections were 515, 1,808, and 3,170, respectively. Total Maintenance Rework for the Clean Room Methodology, Formal and Informal Inspections were 500, 3,497, and 10,491, respectively. Total maintenance costs for the Clean Room Methodology and Formal and Informal Inspections were $19,484, $136,386, and $409,159, respectively. Total development and maintenance costs for the Clean Room Methodology and Formal and Informal Inspections were $466,659, $2,618,814, and $2,891,586, respectively.

The IEEE Standard for Software Reviews and Audits (IEEE Std 1028-1988) compares four types of reviews for software management and engineering, Management Review, Technical Review, the Software Inspection Process, and Walkthroughs (see Table 67). The objective of Management Reviews is to ensure progress, recommend corrective action, and ensure proper allocation of resources. The objective of Technical Reviews is to evaluate conformance to specifications and plans and ensure change integrity. The objective of the Software Inspection Process is to detect and identify defects and verify resolution. And, the objective of Walkthroughs is to detect defects, examine alternatives, and act as a forum for learning. Management Reviews, Technical Reviews, and Walkthroughs are informal gatherings of usually large numbers of people for the purpose of status reporting, information gathering, team building, and information presentation and brainstorming. The Software Inspection Process is a highly structured gathering of experts to identify defects in software work products ranging from requirement specifications to the software source code. The Software Inspection Process has concise objectives, steps, time limits, and lends itself to measurement and analysis.

Kettinger, Teng, and Guha, (1996) conducted a survey of 72 Business Process Reengineering (BPR) methods and 102 automated BPR tools, designing an empirically derived contingency model for devising organizational-specific BPR strategies by selecting from multiple BPR methods and tools. The model works by first assessing individual organizational BPR requirements and propensity for change (see Table 68).

Kettinger's, Teng's, and Guha's BPR methodology is composed of three steps, Assessing Project Radicalness (project radicalness planning worksheet), Customizing the Stage-Activity (SA) Methodology (a separate model for selecting appropriate BPR stages and activities), and Selecting Reengineering Techniques (based on a categorization of BPR techniques). The project radicalness planning worksheet (Table 68) is used to determine if a specific organization is best suited by low-impact process improvement techniques, or whether the organization needs to be redesigned from the ground-up. The stage-activity framework is applied by answering these four questions: How radical is the project? How structured is the process? Does the process have high customer focus? Does the process require high levels of IT enablement? Selecting reengineering techniques is accomplished by selecting from 11 technique groupings, project management, problem solving and diagnosis, customer requirement analysis, process capture and modeling, process measurement, process prototyping and simulation, IS systems analysis and design, business planning, creative thinking, organizational analysis and design, and change management.

Tingey (1997) conducted a comparison of the Malcolm Baldrige National Quality Award, ISO 9001, and the SEI's Capability Maturity Model for Software (CMM), in order to help organizations choose the best quality management system (see Table 69). According to Tingey, the Malcolm Baldrige National Quality Award is the best quality management system. Malcolm Baldrige is 2.5X better than CMM for Leadership, 44X better than ISO 9001 for Human Resources, 1.4X better than ISO 9001 for implementing, 9.4X better than ISO 9001 for managing, 1.8X better than ISO 9001 for improving, and 3.6X better than CMM for motivating.

Table 67: Comparison of Reviews, Software Inspection Process. and Walkthroughs

Characteristics	Management Review	Technical Review	Software Inspection	Walkthrough
Objective	Ensure progress. Recommend corrective action. Ensure proper allocation of resources.	Evaluate conformance to specifications and plans. Ensure change integrity.	Detect and identify defects. Verify resolution.	Detect defects. Examine alternatives. Forum for learning.
Delegated Controls				
Decision Making	Management team charts course of action. Decisions are made at the meeting or as a result of recommendations.	Evaluate conformance to specifications and Ensure change integrity.	Detect and identify defects. Verify resolution.	Detect defects. Examine alternatives. Forum for learning.
Change Verification	Change verification left to other project controls.	Leader verifies as part of review report.	Moderator verifies rework.	Change verification left to other project controls.
Group Dynamics				
Recommended Size	Two or more persons.	Three or more persons.	Three to six persons.	Two to seven persons.
Attendance	Management, technical leadership, and peer mix.	Technical leadership and peer mix.	College of peers meet with documented attendance.	Technical leadership peer mix.
Leadership	Usually the responsible manager.	Usually the lead engineer.	Trained moderator.	Usually producer.
Procedures				
Material Volume	Moderate to high, depending on the specific statement of objectives for the meeting.	Moderate to high, depending on the specific statement of objectives for the meeting.	Relatively low.	Relatively low.
Presenter	Usually the responsible manager.	Usually the lead engineer.	Trained moderator.	Usually producer.
Data Collection	As required by applicable policies, standards, or plans.	Not a formal project requirement. May be done locally.	Formally required.	Not a formal project requirement. May be done locally.
Outputs				
Reports	Management review report.	Technical review reports.	Defect list and summary. Inspection report.	Walkthrough report.
Data Base Entries	Any schedule changes must be entered into the project tracking database.	No formal data base required.	Defect counts, characteristics, severity, and meeting attributes are kept.	No formal database requirement.

Harrington (1995) conducted an analysis and comparison of six major organizational improvement approaches, Total Business Management (TBM), Total Cost Management (TCM), Total Productivity Management (TPM), Total Quality Management (TQM), Total Resource Management (TRM), and Total Technology Management (TTM) frameworks or models (see Table 70).

Total Quality Management (TQM) seems to be the best organizational improvement model, scoring affirmatively in 12 of 16 (75%) of the categories. Total Resource Management (TRM) comes in a close second place, scoring affirmatively in 11 of 16 (69%) of the categories. Total Business Management (TBM), Total Cost Management (TCM), and Total Technology Management (TTM) tied for third place, scoring affirmatively in 10 of 16 (63%) of the categories. All six of the organizational improvement frameworks seemed to be about the same on Harrington's evaluation (demonstrating a good overall effect of using all approaches).

Table 68: Business Process Reengineering (BPR) Contingency Model

Factor	Question	Process Improvement	Process Redesign	Radical Reengineering
Strategic Centrality	Is the targeted process merely tangential (1) or integral (5) to the firm's strategic goals and objectives?	1 ---- 2 Tangential	---- 3 ----	4 ---- 5 Integral
Feasibility of IT to change process	Does IT enable only incidental change (1) or fundamental process change (5)?	1 ---- 2 Incidental	---- 3 ----	4 ---- 5 Integral
Process breadth	Is the scope of the process intra-functional (1) interorganizational (5)?	1 ---- 2 Intra-functional	---- 3 ----	4 ---- 5 Interorganizational
Senior management	Is the senior management visibly removed (1) or actively involved commitment (5) in the BPR efforts?	1 ---- 2 Removed	---- 3 ----	4 ---- 5 Involved
Performance measurement	Are the preferred performance measurement criteria efficiency criteria based (1) or effectiveness based (5)?	1 ---- 2 Efficiency	---- 3 ----	4 ---- 5 Effectiveness
Process functionality	Is the process functioning marginally (1) or is the process not functioning well at all (5)?	1 ---- 2 Marginally	---- 3 ----	4 ---- 5 Not Well
Project resource	Are only minimal resources (1) available to support the process availability change or are resources abundant (5)?	1 ---- 2 Scarce	---- 3 ----	4 ---- 5 Abundant
Structural flexibility	Is the organizational structure rigid (1) or is it flexibly conducive (5) to change and learning?	1 ---- 2 Rigid	---- 3 ----	4 ---- 5 Flexible
Cultural capacity for	Does the culture support the status quo (1) or actively seek change participatory change (5)?	1 ---- 2 Status quo	---- 3 ----	4 ---- 5 Adaptable
Management's willingess	Are only modest impacts on people tolerable (1) or is management to impact people willing to deal with the consequences of distruptive impacts (5)?	1 ---- 2 Modest	---- 3 ----	4 ---- 5 Disruptive
Value chain target	Is the BPR effort targeted at an internal support process (1) or a core process (5)?	1 ---- 2 Support	---- 3 ----	4 ---- 5 Core

Table 69: Malcolm Baldrige, ISO 9001, and SKI CMM Comparison

Criteria	Malcolm Baldrige	ISO 9001	SKI CMM
Malcolm Baldrige			
Leadership	23.5 ✓	15.7	9.7
Information and Analysis	19.9	32.2	38.4 ✓
Strategic Planning	17.6	44.5 ✓	26.9
Human Resources	30.9 ✓	0.7	8.5
Process Management	1.5	5.5 ✓	5.2
Business Results	2.2	1.4	11.3 ✓
Customer Satisfaction	4.4 ✓	0	0
Total Quality Management			
Planning	10.3	7.5	16.3 ✓
Implementing	13.2 ✓	9.6	11.4 ✓
Managing	6.6 ✓	0.7	0
Improving	12.5 ✓	6.9	9.5
Communicating	29.4 ✓	66.4 ✓	56.3
Training	4.4 ✓	0	0
Motivating	23.6 ✓	8.9	6.5

Table 70: Comparison of Enterprise Ouality Management Models

Criteria	TBM	TCM	TPM	TQM	TRM	TTM
Increases Market Share	Yes	Yes	Yes	Yes	Yes	Yes
Increases Return-on-lnvestment	Yes	Yes	Yes	Yes	Yes	Yes
Increases Value Added per Employee	Yes	Yes	Yes	No	Yes	No
Increases Stock Prices	Yes	Yes	Yes	Yes	Yes	Yes
Improves Morale	No	No	No	Yes	No	No
Improves Customer Satisfaction	No	No	No	Yes	No	Yes
Improves Competitive Position	Yes	Yes	Yes	Yes	No	Yes
Improves Reliability	No	No	No	Yes	No	Yes
Improves Maintainability	No	No	No	No	No	Yes
Improves Safety	No	No	No	No	Yes	No
Decreases Waste	No	Yes	Yes	Yes	Yes	No
Decreases Overhead	Yes	Yes	Yes	Yes	Yes	No
Decreases Inventory	Yes	Yes	No	No	Yes	No
Causes Layoffs	Sometimes	Yes	Yes	Sometimes	Sometimes	Sometimes
Increases the Number of Employees	Sometimes	No	No	Sometimes	Sometimes	Sometimes
Increases Profit	Yes	Yes	Yes	Yes	Yes	Yes

Rico (1998) conducted a cost-benefit or return-on-investment analysis of Software Process Improvement (SPI) strategies, identifying three major classes of SPI strategies, Indefinite, Vertical Process, and Vertical Life Cycle, creating a highly structured, empirically-derived analytical model to classify, evaluate, and select SPI strategies (see Figure 26).

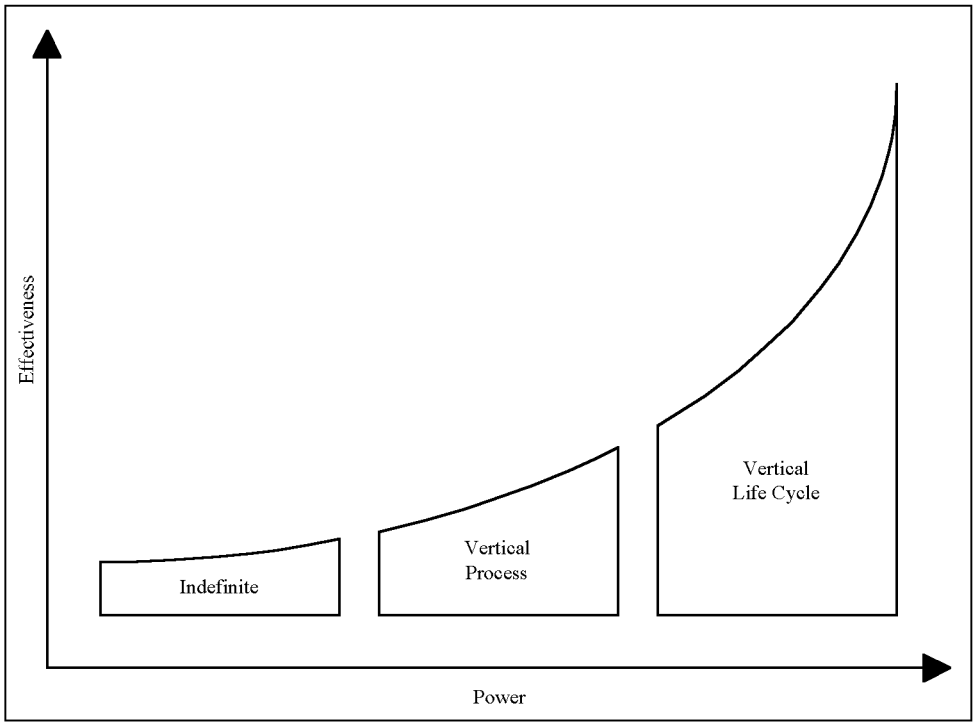

Figure 26. SPI strategy Empirical Analytical Model

Indefinite SPI strategies include, Kaizen, ISO 9000, Experience Factory, Goal Question Metric, Total Quality Management, Capability Maturity Model, and Business Process Reengineering. Vertical Process SPI strategies include, Configuration Management, Test, Inspection, Quality Estimation, Statistical Process Control (SPC), Defect Classification, and Defect Prevention. Vertical Life Cycle SPI strategies include, Personal Software Process, Defect Removal Model, and Product Line Management. Indefinite SPI strategies involve inventing software processes by non-experts, Vertical Process Strategies involve using proven software processes, and Vertical Life Cycle SPI strategies involve using proven software life cycles.

Jones (1997b) conducted an analysis and comparison of ten major Software Process Improvement (SPI) strategy classes their applicability based on organization size (see Table 71).

Table 71: SPR Comparison of Software Process Improvement (SPI) Methods

SPI Class	SPI Technique	Organization Size		
		Large	Medium	Small
Enterprise Quality Programs	Baldrige Awards	Maybe	Maybe	No
	Quality Assurance Departments	Yes	Maybe	No
	Executive Quality Goals	Yes	Yes	Maybe
	Management Quality Goals	Yes	Yes	Yes
	SKI CMM Level 3, 4, or 5	Yes	Maybe	No
Quality Awareness and training	In-House Seminars	Yes	Maybe	No
	Public Seminars	Yes	Yes	Yes
	Online Quality Forums	Yes	Yes	Yes
	Risk-Analysis Training	Yes	Maybe	No
Quality Standards and Guidelines	In-House Standards	Yes	Maybe	No
	IEEE Standards	Maybe	Maybe	Maybe
	ISO Standards	Yes	Yes	Maybe
Quality Analysis Methods	Assessments	Yes	Yes	Maybe
	Baseline Studies	Yes	Yes	Maybe
	Benchmark Comparisons	Yes	Yes	Maybe
	Risk Analysis	Yes	Yes	Maybe
Quality Measurement Methods	Function Point Normalization	Yes	Yes	Yes
	Defect Aging Measures	Yes	Yes	Yes
	Defect Distribution Measures	Yes	Yes	Yes
	Defect Severity Measures	Yes	Yes	Yes
	Root Cause Analysis	Yes	Maybe	Maybe
Defect Prevention Methods	Configuration Control Tools	Yes	Yes	Yes
	Change Control Boards	Yes	Maybe	No
	Design Inspections	Yes	Maybe	Yes
	Code Inspections	Yes	Yes	Yes
	Graphical Specification Methods	Yes	Yes	Yes
	Prototyping	Yes	Yes	Yes
	Risk Analysis	Yes	Maybe	Maybe
	Quality Function Deployment	Maybe	Maybe	No
	Certified Reusable Materials	Yes	Maybe	Maybe
Non-Test Defect Removal Methods	Design Inspections	Yes	Yes	Yes
	Code Inspections	Yes	Yes	Yes
	Usability Reviews	Yes	Maybe	Maybe
Testing Methods	Unit Test by Programmers	Yes	Yes	Yes
	Complexity Analysis	Yes	Yes	Maybe
	Regression Test by Specialists	Yes	Maybe	No
	Performance Test by Specialists	Yes	Maybe	No
	System Test by Specialists	Yes	Maybe	No
	Field Test by Clients or Customers	Yes	Yes	Yes
	Test Coverage Analysis	Yes	Yes	Yes
	Test Library Control Tools	Yes	Yes	Yes
	Test Case Reviews	Maybe	Maybe	Maybe
	Test Script Automation	Yes	Yes	Yes
User Satisfaction Methods	Usability Laboratories	Yes	No	No
	User Focus Groups	Yes	Maybe	Maybe
	User Satisfaction Surveys	Yes	Maybe	Maybe
Post-Release Quality Methods	Automated Defect Tracking	Yes	Yes	Yes
	Customer Support Specialists	Yes	Yes	Maybe
	Online Defect Reporting	Yes	Yes	Yes

The ten SPI strategy classes included, enterprise quality programs, quality awareness and training, quality standards and guidelines, quality analysis methods, quality measurement methods, defect prevention methods, non-test defect removal methods, testing methods, user satisfaction methods, and post-release quality methods. Jones' analysis merely indicates that most SPI strategies apply to organizations of all sizes, without any sharply discriminating factors.

Haskell, Decker, and McGarry (1997) conducted an economic analysis and comparison of Software Engineering Institute (SEI) Capability Maturity Model for Software (CMM) Software Capability Evaluations (SCEs) and ISO 9001 Registration Audits at the Computer Sciences Corporation (CSC), between 1991 and 1997 (see Table 72). CSC required seven years of elapsed calendar time and 4,837 staff hours or 2.33 staff years of actual effort to achieve SEI CMM Level 3 compliance, while requiring one year of elapsed calendar time and 5,480 staff hours or 2.63 staff years of actual effort to achieve ISO 9001 Registration. Some of the major differences include a 7:1 advantage in elapsed calendar time to become ISO 9001 Registered in one attempt, versus multiple SEI SCE attempts over a seven-year period.

Table 72: Software Capability Evaluations (SCEs) and ISO 9001 Registration Audits

Factors	SCE	SCE	ISO 9001	SCE	ISO 9001
Date	10/91	2/96	5/97	11/97 to 1/98	11/97
Staff Months	2	4	12	2	6
Staff Hours	850	1,800	3,400	800	500
External Consultants	• Minimal	• None	• 200 Hours • Consultant • Internal Auditor • Pre-Registration Assessment	• None	• None
Preparation Strategy	• Internal Assessments	• Gap Analysis • Lessons Leamed • Deployment Focus	• Implement Plan • External Experts • Train Staff • Deployment Focus	• Action Items • Awareness Seminars • Internal Assessments	• Process Improvements • Management Reviews • Internal Audits • Corrective Actions
Result	Few KPAs Satisfied	13 KPAs Satisfied	ISO 9001 Registration	SKI CMM Level 3	ISO 9001 Registration

Wang, Court, Ross, Staples, King, and Dorling (1997a) conducted a technical analysis and comparison of international Software Process Improvement (SPI) strategies, identifying five leading models, Software Process Reference Model (SPRM), Software Process Improvement and Capability Determination (SPICE), Capability Maturity Model for Software (CMM), BOOTSTRAP, and ISO 9000 (see Table 73).

Table 73: Comparison of SPRM, SPICE, CMM, BOOTSTRAP, and ISO 9000

SPRM Subsystem	SPRM Process Category	SPRM	SPICE	CMM	BOOTSTRAP	ISO 9000
Organization	Organizational Structure	13	10	0	7	5
	Organization	26	21	20	8	2
	Customer Service	42	30	I	8	18
Software Engineering	Software Engineering Methodology	23	7	8	10	0
	Software Development	60	29	12	43	30
	Software Development Environment	32	11	0	11	14
Management	Software Quality Assurance (SQA)	78	22	18	45	52
	Project Planning	45	24	22	18	16
	Project Management	55	11	42	25	12
	Contract & Requirement Management	42	27	16	14	18
	Document Management	17	5	5	8	6
	Human Management	11	4	6	4	4
		444	201	150	201	177

According to Wang et al. the Software Engineering Institute's (SEI's) Capability Maturity Model for Software (CMM) is the weakest SPI model by far, accounting for only 33.7% of the necessary software management and engineering requirements suggested by the SPRM SPI model. SPICE and BOOTSTRAP are reported to account for 45% of SPRM's requirements, while IS0 9000 helps bring up the rear, meeting 40% of SPRM's requirements. SPRM is reported to be a super SPI model composed of all of SPICE's 201, BOOTSTRAP's 201, ISO 9000's 177, and the SEI CMM's 150 requirements. After redundancy elimination, SPRM is left with 407 common requirements plus 37 new ones for a total of 444.

Wang, Court, Ross, Staples, King, and Dorling (1997b) conducted a technical analysis and comparison of international Software Process Improvement (SPI) strategies, identifying four leading models, BOOTSTRAP, ISO 9000, Capability Maturity Model for Software (CMM), and Software Process Improvement and Capability Determination (SPICE) (see Table 74).

Table 74: Comparison of BOOTSTRAP, ISO 9000, CMM, and SPICE

SPRM Subsystem	SPRM Process Category	BOOTSTRAP	ISO 9000	CMM	SPICE
Organization	Organizational Structure	8%	4%	1%	8%
	Organization	7%	3%	12%	20%
	Customer Service	7%	12%	1%	30%
Software Engineering	Software Engineering Methodology	7%	1%	7%	7%
	Software Development	24%	20%	11%	24%
	Software Development Environment	9%	7%	1%	12%
Management	Software Quality Assurance (SQA)	35%	39%	15%	23%
	Project Planning	18%	14%	16%	24%
	Project Management	25%	9%	31%	11%
	Contract & Requirement Management	8%	14%	12%	28%
	Document Management	6%	5%	3%	5%
	Human Management	7%	3%	5%	4%
		13%	11%	10%	16%

After aggregating the individual requirements for each of the four SPI models, BOOTSTRAP, ISO 9000, CMM, and SPICE, Wang et al. divided each model's requirements by the aggregate number of requirements for each of the 12 SPRM Process Categories. While individual models performed widely for individual SPRM Process Categories, the average of all of the SPRM Process Categories for each of the four SPI models was surprisingly similar. SPICE led the way meeting an average of 16% of the total aggregate requirements for the four models. BOOTSTRAP came in second place with 13%, ISO 9000 with 11%, and the CMM trailing with an average of 10% of the overall aggregate requirements. This analysis and comparison differs from Wang et al. (1997a) in that each of the four SPI models were only compared to each other.

Wang, King, Dorling, Patel, Court, Staples, and Ross (1998) conducted a survey of worldwide software engineering practices, identifying six major process classes (see Table 75).

Table 75. Worldwide Survey Software Best Practices

Business Process Class	Business Process Activity	Weight	Priority	In-Use	Effect
Development Process Definition	Evaluate Software Development Methodologies	3.9	93.8	87.5	78.6
	Model Software Process	3.8	94.1	81.3	100
	Describe Activities and Responsibilities	4.3	100	87.5	100
	Establish Task Sequences	3.8	81.3	93.3	93.3
	Identify Process Relationships	3.7	93.3	92.9	92.9
	Document Process Activities	3.9	87.5	92.9	86.7
	Identify Control Point of Project	3.8	93.8	71.4	84.6
	Maintain Consistency across all Processes	3.6	80.0	57.1	76.9
	Develop Software according to Defined Process	4.3	100	78.6	92.9
	Derive Project Process from Organization Standard	4.3	100	72.7	92.9
	Approval Processes and Equipment	3.5	85.7	71.4	76.9
	Identify Special Requirements for Special Systems	4.3	100	85.7	93.3
Requirements Analysis	Analyze Requirement according to Defined Process	4.1	100	84.6	83.3
	Specify Formal Requirements	3.0	73.3	53.3	79.6
	Define Requirements Feasibility/Testability	3.8	93.3	76.9	75.0
	Prevent Ambiguities in Specification	3.9	93.3	78.6	84.6
	Interpret/Clarify Requirements	3.7	94.1	68.8	84.6
	Specify Acceptance Criteria	3.8	87.5	100	86.7
	Allocate Requirements for Processes	3.1	90.9	44.4	87.5
	Adopt Requirements Acquisition Tools	2.1	28.6	7.7	80.0
Design	Design System according to Defined Process	3.9	93.8	78.6	84.6
	Design Software Architecture	4.2	100	100	100
	Design Module Interfaces	4.1	100	81.3	87.5
	Develop Detailed Design	3.6	88.2	93.8	76.5
	Establish Document Traceability	3.9	88.9	63.6	78.6
	Specify Final Design	3.8	86.7	64.3	78.6
	Define Design Change Procedure	4.0	100	53.3	91.7
	Adopt Architectural Design Tools	2.9	56.3	43.8	80.0
	Adopt Module Design Tools	2.9	62.5	73.3	76.9
Coding	Code according to Defined Process	3.8	87.5	68.8	85.7
	Choose proper Programming Language(s)	3.8	93.8	81.3	92.9
	Develop Software Modules	4.0	93.3	100	92.3
	Develop Unit Verification Procedures	3.8	93.8	68.8	86.7
	Verify Software Modules	4.1	100	80.0	92.9
	Document Coding Standards	4.1	88.2	82.4	93.3
	Define Coding Styles	3.6	82.4	56.3	66.7
	Adopt Coding-Support/Auto-Generation Tools	2.9	60.0	28.6	50.0
Module Testing	Testing according to a Defined Process	4.5	100	82.4	93.8
	Determine Test Strategy	4.4	100	76.5	93.8
	Specify Test Methods	4.1	94.1	76.5	92.9
	Generate Test	3.8	93.8	75.0	84.6
	Conduct Testing	4.3	100	86.7	85.7
	Adopt Module Testing Tools	3.1	71.4	57.1	69.2
Integration and System Testing	Integrations Test according to Defined Process	4.3	100	80.0	92.9
	Acceptance Test according to Defined Process	4.1	100	80.0	92.9
	System Tests Generation	3.8	92.3	69.2	83.3
	Test Integrated System	4.1	100	84.6	91.7
	Adopt Integration Tools	2.8	53.8	16.7	63.6
	Adopt Module Cross-Reference Tools	3.1	76.9	16.7	81.8
	Adopt System Acceptance Testing Tools	3.1	76.9	25.0	90.9

The worldwide opinion survey results for each of the 49 individual Business Process Activities (BPAs) look surprisingly similar. The median weight appears to be about four, on a scale of one to five, for all 49 BPAs. The median weight for Priority (percentage of organizations rating the BPA highly significant), In-Use (percentage of organizations that used the BPA), and Effect (percentage rating the BPA effective) appears to be homogeneously in the 80s. The Design Software Architecture BPA scored 100s for Priority, In-Use, and Effective, and some testing BPAs had a surprising abundance of 100s. According to Rico (1999), testing is one of the least effective verification and validation activities from a quantitative standpoint.

McConnell (1996) performed a qualitative analysis of ten software life cycle models, pure waterfall, code-and-fix, spiral, modified waterfall, evolutionary prototyping, staged delivery, evolutionary delivery, design-to-schedule, design-to-tools, and commercial-off-the-shelf (see Table 76). Works with poorly understood requirements, works with unprecedented systems, produces highly reliable system, produces system with large growth envelope, manages risks, can be constrained to a predefined schedule, has low overhead, allows for midcourse corrections, provides customer with process visibility, provides management with progress visibility, and requires little manager or developer sophistication, were 11 criteria used.

Table 76: Construx Comparison of Software Development Life Cvcles

Software Life-Cycle	Ambiguity	Innovation	Reliability	Growth	High Risk	Schedule	Overhead	Change	Oversight	Manage	Difficulty
Pure Waterfall	Poor	Poor	Excellent	Excellent	Poor	Fair	Poor	Poor	Poor	Fair	Fair
Code and Fix	Poor	Poor	Poor	Poor-Fair	Poor	Poor	Excellent	Poor-Excel	Fair	Poor	Excellent
Spiral Excellent	Excellent	Excellent	Excellent	Excellent	Fair	Fair	Fair	Excellent	Excellent	Poor	
Modified Waterfall	Fair Excel	Fair-Excel	Excellent	Excellent	Fair	Fair	Excellent	Fair	Fair	Fair Excel	Poor-Fair
Evolutionary Prototyping	Excellent	Poor-Fair	Fair	Excellent	Fair	Poor	Fair	Excellent	Excellent	Fair	Poor
Staged Delivery	Poor	Poor	Excellent	Excellent	Fair	Fair	Fair	Poor	Fair	Excellent	Fair
Evolutionary Delivery	Fair-Excel	Poor	Fair-Excel	Excellent	Fair	Fair	Fair	Fair-Excel	Excellent	Excellent	Fair
Design-to-Schedule	Poor-Fair	Poor	Fair	Fair-Excel	Fair-Excel	Excellent	Fair	Poor-Fair	Fair	Excellent	Poor
Design-to-Tools	Fair	Poor-Excel	Poor-Excel	Poor	Poor-Fair	Excellent	Fair-Excel	Excellent	Excellent	Excellent	N/A
Cornmercial-Off-The-Shelf	Excellent	Poor-Excel	Poor-Excel	N/A	N/A	Excellent	Excellent	Poor	N/A	N/A	Fair

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Methodology

As stated, the objective of this study involves "Using Cost Benefit Analyses to Develop a Pluralistic Methodology for Selecting from Multiple Prescriptive Software Process Improvement (SPI) Strategies." This chapter satisfies these objectives by designing, constructing, and exercising a multi-part methodology consisting of a Defect Removal Model, Cost and Benefit Data, Return-on-Investment Model, Break Even Point Model, and Costs and Benefits of Alternatives, which all lead up to a Cost and Benefit Model (as shown in Figure 27).

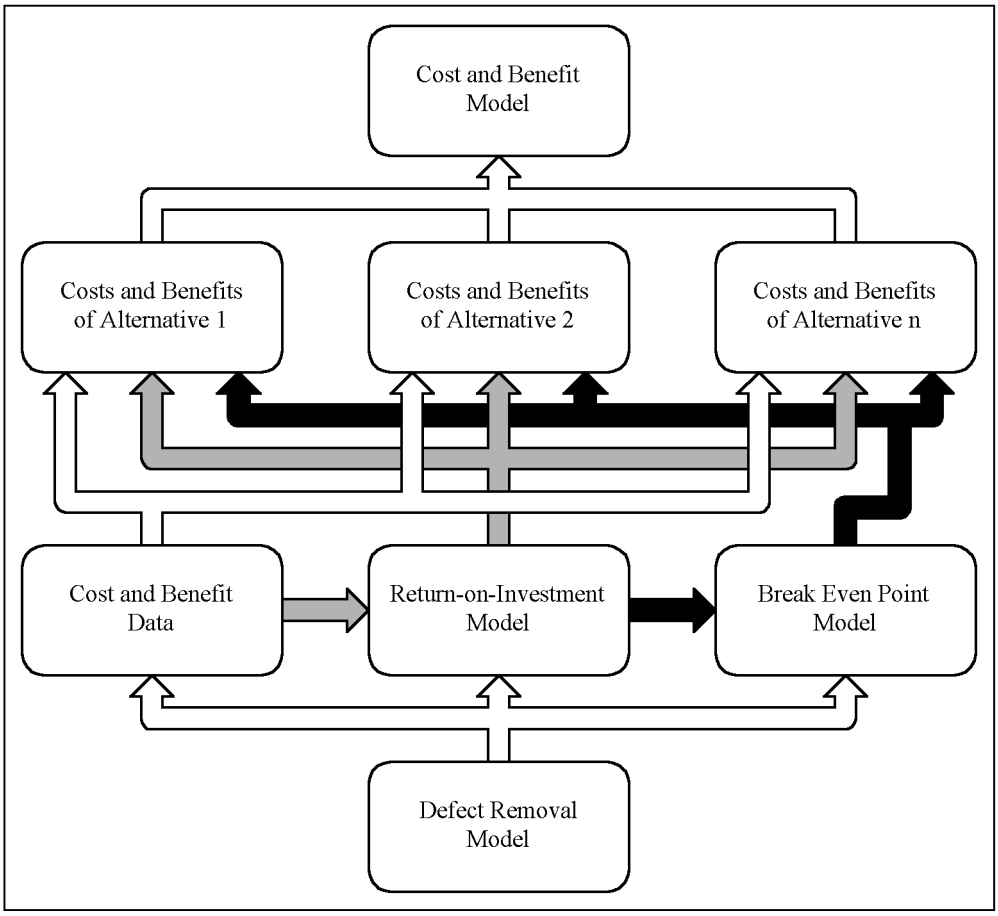


Figure 27. Methodology for Evaluating and Selecting Costs and Benefits

Costs and benefits of SPI strategies will be evaluated by a variety of interrelated techniques, starting with the Defect Removal Model. The Defect Removal Model, as explained later, is a technique for evaluating SPI method effectiveness, and once economic models are factored in, provides an empirically valid approach for comparing the costs and benefits of SPI methods. Obviously, existing cost and benefit data for SPI methods selected from the Literature Survey will be judiciously factored into, and drive, each of the individual analytical models. A Return-on-Investment (ROI) Model will be designed, based on the Defect Removal Model and populated by empirical cost and benefit data, in order to arrive at quality, productivity, cost, break even, and of course, ROI estimates. Eventually, a SPI strategy Cost and Benefit Model will be constructed from Cost and Benefit Criteria, SPI Strategy Alternatives, and Cost and Benefits of Alternatives.

The design of the Methodology was significantly influenced by McGibbon's (1996), Jones' (1996 and 1997a), Grady's (1994 and 1997), and Rico's (1999) Defect Removal Model-based comparisons of SPI costs and benefits. An analysis of SPI costs and benefits by Herbsleb, Carleton, Rozum, Siegel, and Zubrow (1994), perhaps the most common SPI method cost and benefit study in existence, also served as primary influence for the design of the Methodology.

McGibbon's (1996) study, however, was the primary influence for two reasons, it is comprehensive in nature, and it exhibits a uniquely broad range of comparative economic analyses between SPI methods. In addition, McGibbon's study stands alone in unlocking economic analyses associated with the Clean Room Methodology, Software Reuse, and even the Software Inspection Process. McGibbon's study goes even further than that, in creating and establishing a valid empirically-based methodology for using existing cost and benefit data and analyses, for evaluating and selecting SPI methods. Furthermore, McGibbon's study implicitly, perhaps incidentally or accidentally, focuses on "prescriptive" SPI methods, which is the principal objective of this study.

Grady's (1997) text on SPI strategies also influenced the design and direction of the Methodology, explicitly identifying the Software Inspection Process as having an overwhelming impact on bottom line organizational performance (as shown in Figure 13). Thus, Grady's works helped justify the creation and significance of the ROI Model, which will be explained in greater detail later.

Rico's (1999) Defect Removal Model-based SPI method comparison, however, was the final influence in selecting and fully designing the Methodology, highlighting the vast economic advantages that one SPI strategy may have over another. In fact, Rico's study was the starting point for implementing the Methodology, which quickly picked up a lot of momentum and took on an entire life of its own. After only a few minutes of briefly extending Rico's analyses, the results proved mesmerizingly phenomenal, and thus the Methodology was conceived. In fact, the results of the Methodology, and later the data analyses, exceeded all expectations. And, just to imagine that the final results were preliminarily yielded after only a few moments of additional permutations involving Rico's study is truly amazing.

Herbsleb's, Carleton's, Rozum's, Siegel's, and Zubrow's (1994) study also helped justify the use of existing empirical data for analyzing and evaluating SPI methods and strategies. In fact, their study significantly influenced the selection of the Cost and Benefit Criteria. Herbsleb's, Carleton's, Rozum's, Siegel's, and Zubrow's study involved averaging of reported cost and benefits, much like McGibbon's (1996), helping justify the use of this technique here.

Kan's (1995) seminal masterpiece created the final justification, validation, and foundation of this Defect Removal Model-based Methodology. Kan's (1991 and 1995) in vivo (industrial) experiments and applications of the Defect Removal Model were invaluable to justifying the basis for this Methodology, and providing the confidence to advance this study.

Cost and Benefit Criteria

Three cost criteria and five benefit criteria for a total of eight criteria were chosen with which to evaluate, assess, and analyze SPI alternatives: Training Hours, Training Cost, Effort, Cycle Time, Productivity, Quality, Return-on-Investment, and Break Even Hours. These criteria were chosen because of their commonality and availability as exhibited by Table 40, Reclassification of 487 Metrics for Software Process Improvement (SPI), Figure 11, Citation Frequency of Metrics for Software Process Improvement (SPI), and Table 57, Survey of Software Process Improvement (SPI) Costs and Benefits (see Table 77).

Table 77: Criteria for Evaluating Software Process Improvement (SPI) Alternatives

Criterion	Definition
Training Hours	Training hours refer to the number of person-hours of formal classroom instruction applied for teaching a software process
Training Cost	Training cost refers to the number of training hours plus training fees and travel expenses such as air fare, meals, hotels, car rental, and other applicable training costs
Effort	Effort refers to development effort—the effort required to design, code, unit test, and system test, measured in person-months (Come, Dunsmore, and Shen, 1986)
Cycle Time	Cycle time or duration is defined as the elapsed time in hours or months during which development effort proceeds without interruption (Come, Dunsmore, and Shen, 1986)
Productivity	Productivity is the number of lines of source code produced per programmer-month (person-month) of effort (Come, Dunsmore, and Shen, 1986)
Quality	Quality or defect density is the number of software defects committed per thousand lines of software source code (Come, Dunsmore, and Shen, 1986)
Return-on-lnvestment	Return-on-investment metrics are collected for the purpose of measuring the magnitude of the benefits relative to the costs (Lim, 1998)
Break Even Hours	Break even hours are defined as the level of activity at which an organization neither earns a profit nor incurs a loss (Garrison and Noreen, 1997)

Table 39, Survey of Metrics for Software Process Improvement (SPI), showed 74 broad metric classes and 487 individual software metrics. However, Figure 11, Citation Frequency of Metrics for Software Process Improvement (SPI), reclassified the 74 classes of 487 metrics into 11 classes: Productivity (22%), Design (18%), Quality (15%), Effort (14%), Cycle Time (9%), Size (8%), Cost (6%), Change (4%), Customer (2%), Performance (1%), and Reuse (1%). This helped influence the selection of the eight criteria for SPI cost/benefit analysis, since later quantitative analyses will be based on the existence and abundance of software metrics and measurement data available in published sources.

But, availability is not the only reason these eight criteria were chosen. These eight criteria were chosen because it is believed that these are the most meaningful indicators of both Software Process and Software Process Improvement (SPI) performance, especially, Effort, Cycle Time, Productivity, Quality, Return-on-Investment (ROI), and Break Even Hours. Effort simply refers to cost, Cycle Time refers to duration, Productivity refers to number of units produced, Quality refers to number of defects removed, ROI refers

to cost saved, and Break Even refers to length of time to achieve ROI. So, "face validity" is an overriding factor for choosing these criteria, organizations have chosen these software metrics to collect and report upon, doing exactly that over the years. Thus, this is the reason these data are so abundantly available.

Quality software measurement data will prove to be a central part of this analysis (and this thesis, as reported earlier), and the direct basis for a Return-on-Investment (ROI) model that will act as the foundation for computing ROI itself. Thus, the Quality criterion is an instrumental factor, and it is fortunate that SPI literature has so abundantly and clearly reported Quality metric and measurement data, despite Quality's controversial and uncommon usage in management and measurement practice. The SEI reports that approximately 95.7% of software organizations are below CMM Level 4. CMM Level 4 is where software quality measurement is required. It is safe to assert that 95.7% of software organizations do not use or collect software quality measures.

Training Hours

Training Hours refers to the number of direct classroom hours of formal training required to instruct and teach software managers and engineers to use a particular SPI method. Some authors, most notably McGibbon (1996), assert that Training Hours are a significant factor when considering the choice of SPI methods. For instance, the Personal Software Process (PSP) requires 80 hours of formal classroom instruction per person, in order to teach the PSP's software engineering principles. While, some methods, such as the Software Inspection Process, are reported to use as little as 12 hours of formal classroom instruction. So, one might assert that PSP training takes nearly seven times as many resources as the Software Inspection Process, these numbers will prove to be far less significant. For instance, due to the efficiency and productivity of using the PSP, the PSP will exhibit an ROI of 143:1 over the Software Inspection Process. However, while Training Hours were initially thought to be a significant discriminating factor in choosing SPI methods that doesn't seem to play out, Training Hours are no less important. For both small and large organizations on a tight schedule and budget, Training Hours may still be considered an important issue. This is a fruitful area for future research, optimal Training Hours for both teaching a SPI method and achieving optimal process efficiency and effectiveness. One and half days for any SPI method seems too short, while it has to be questioned whether 80 hours is too much for the fundamental precepts of a method such as the PSP. Another topic of controversy is whether Training Hours should be charged to organizational overhead (that is, profits) or to project time. Conventional wisdom holds that Training Hours would negatively impact schedule. Later analysis will challenge these notions indicating that it is possible to directly incur Training Hours and still show a significant ROI over the absence of the SPI method. This is also a fruitful area for future research.

Training Cost

Training Cost is the conversion of Training Hours into monetary units, principally fully-burdened person-hours (base rate of pay plus benefits and corporate profits), in addition to ancillary costs such as air fare, transportation, hotels, meals, per diem, training charges, materials, consultant costs, and other fees. This becomes especially significant when the SPI method is of a uniquely proprietary nature, such as SEI CMM, Authorized Lead Evaluator (Software Capability Evaluation—SCE), Authorized Lead Assessor (CMM-Based Assessment for Internal Process Improvement—CBA-IPI), Authorized PSP Instructor, and even basic PSP Training. Each of the training courses mentioned are closely guarded trademarked SPI methods of the SEI (of which Training Cost over Training Hours comes at a high price). McGibbon (1996) didn't mention Training Cost as defined here, in his SPI cost/benefit analysis of Software Reuse, Clean Room Methodology, and the Software Inspection Process. Again, later analysis will show that Training Costs are seemingly dwarfed by the ROI of using particular SPI methods. However, PSP, SCE,

and CBA-IPI costs of 15 to 25 thousand dollars per person (not including labor costs) appears daunting at first and may cause many not to consider the use of these seemingly premium-priced SPI methods. However, as mentioned earlier, carefully planned and managed Training Costs, may still prove to have a positive ROI, even when directly charged to a project.

Effort

Effort refers to the number of person-hours required in order to use a SPI method when constructing (planning, managing, analyzing, designing, coding, and testing) a software-based product. Effort translates directly into cost, which is by far the single most influential factor when choosing a SPI method (or at least it should be). Effort establishes a basis for measuring cost, time, effectiveness, efficiency, ROI, and acts as a basis for comparative analyses. Unfortunately, Effort is a software metric, and software organizations don't usually apply software metrics (less than 95.7% according to the SEI). What this means is that organizations don't usually track the costs of individual activities, and rarely track macro-level costs, such as overall project cost. It's not unusual for organizations to spend large amounts of overhead before projects begin, engage in projects without firmly defined beginning and end-points, and then continue spending money on projects well after their formal termination. In other words, it is quite rare for an organization to firmly assert the cost of even a single project, much less a single process, activity, or SPI method. Once again, it's not unusual for organizations to spend hundreds or even thousands of uncounted person-hours, and then re-plan or redirect without the slightest concern for person-hours spent-to-date. (These numbers may range into the hundreds of thousands or even millions untracked and unaccounted-for person-hours in monolithic programs and projects, especially in defense and aerospace.) For the purposes of this study and analysis, relatively concise effort is asserted, used, and analyzed, especially for the PSP, Software Inspection Process, Clean Room Methodology, and Software Test. Very authoritative studies were used to quantify the costs of Software Reuse and the Defect Prevention Process. The costs associated with ISO 9000 were also confidently authoritative, while the SEI's CMM costs were the least rigorously understood, yet very well analyzed by Herbsleb, Carleton, Rozum, Siegel, and Zubrow (1994). In other industries, such as microprocessor design and development, process improvement costs are primarily in the form of research and development and in capital investments, overseas expansion, real estate, facilities, state-of-the-art equipment, and long-term process calibration (Garrison and Noreen, 1997). While, each of the SPI methods examined in this study were 100% human intensive (not involving expenditures in capital investments).

Cycle Time

According to Garrison and Noreen (1997), Cycle Time is "the time required to make a completed unit of product starting with raw materials." In simple terms, Cycle Time is the length or duration of a software project constrained by a finite beginning and ending date, measured in person-hours, person-days, or person-months. Cycle Time answers the question, "How long does it take?" Cycle Time and Effort are not the same. For instance, whether a software product takes eight person-hours or twelve person-hours over the course of a single 24-hour period such as a business day, the Cycle Time is still a single day. For example, eight people can work eight hours each on a Monday jointly producing a software product. While, 64 person-hours or eight person-days were consumed, the Cycle Time is a single day. When time-to-market is a concern, or just plainly meeting a software project schedule, Cycle Time is an extremely important factor in addition to Effort. Measuring Cycle Time, or Cycle Time reduction, becomes an important aspect of measuring the use of a particular SPI method. Cycle Time is especially important in producing software products before competitors, or fully realizing the revenue potential of existing products. For instance, being the first-to-market and extending market presence as long as possible before

competitive market entrance allows for maximization of revenue. In addition, releasing a new product before existing products reach full revenue potential prematurely interrupts the revenue potential of existing products. Most organizations rarely have the maturity to concisely control revenue potential and would be satisfied to manage Cycle Time predictability. Only extremely rare organizations have the management discipline and maturity to plan and manage a continuous stream of products over extended periods of time based on Cycle Time measurements.

Productivity

According to Conte, Dunsmore, and Shen (1986), "Productivity is the number of lines of source code produced per programmer-month (person-month) of effort." Humphrey (1995) similarly states, "Productivity is generally measured as the labor hours required to do a unit of work." Humphrey goes on to state, "When calculating Productivity, you divide the amount of product produced by the hours you spent." Therefore, Productivity is a measure of how many products and services are rendered (per unit of time). Productivity is a useful measure of the efficiency or inefficiency of a software process. So, Productivity is a naturally useful measure for SPI. Productivity can be a measure of the number of final or intermediate products. For instance, Productivity may be measured as the number of final software products such as word processors per unit of time (typically every one or two years). Or, Productivity may be measured as the number of intermediate software work products. Software Productivity has historically taken on this latter form of measurement, intermediate software work products. The intermediate software work product most commonly measured is source lines of code (SLOC) per person month. Thus, this is the most commonly available software productivity data measured, collected, and available in published literature. Unfortunately, SLOC isn't the only intermediate software work product available for software Productivity measurement. Other common intermediate software work products available for counting are requirements, specifications, design elements, designs, tests, and software management artifacts such as project plans, schedules, estimates, and work breakdown structures. Software Productivity measurement is a highly controversial and much maligned discipline. First, is a misunderstanding of what is being represented by typical software Productivity measurements, SLOC per person-month. This metric can typically be measured in the following way, divide the total number of SLOC produced as part of a final software product by total Effort (previously discussed). This yields normalized productivity for a given software product. This is the source of common confusion surrounding software Productivity measurement. Many consider this measurement (SLOC/Effort) to be useful only for measuring the programming phase of development, and a grossly insufficient measure of overall software life cycle Productivity measurement (arguing that SLOC/Effort is not applicable to measuring analysis, design, or testing Productivity). Nothing could be further from the truth. SLOC/Effort is a simple but powerful measure of overall software life cycle Productivity measurement in its normalized form. This doesn't mean that measuring productivity in other terms isn't as equally useful or powerful. For example, number of requirements produced per analysis phase hour would be an exemplary software Productivity measure. This however, doesn't discount the usefulness of SLOC/Effort as a powerful software Productivity measure in any way, shape, or form. While, software life cycle-normalized software Productivity measurements using SLOC are commonly misunderstood, there's another controversy surrounding software Productivity measurement associated with SLOC. Jones (1998) argues that SLOC is a poor measure to be used as a basis for software Productivity measurements because of the difficulty in generalizing organizational software Productivity measurements using SLOC. There are many programming languages of varying levels of power, usability, abstraction, and difficulty. What might take one SLOC in Structured Query Language (SQL) may take 27 SLOCs of Assembly. This may lead some to believe that SQL is low-productivity language because it results in fewer SLOC, while in fact is it may

actually result in higher Productivity. There are two basic problems with Jones' arguments. The first is that it doesn't take the same Effort and cost to analyze, design, code, test, and maintain one line of SQL as it does 27 lines of Assembly. If it did (and it doesn't), it would be 27 times more productive to program in Assembly than SQL. In fact, we know this to be the exact opposite. According to Jones' own data, it is 27 times more productive to program in SQL than Assembly. An ancillary problem, but nevertheless more important, is Jones' insistence on generalizing software Productivity measurement data across organizations. Statistical Process Control (SPC) theory (Burr and Owen, 1996) asserts that even if two organizations used the same programming language or even the identical software Productivity measurement strategy (even Jones' non-SLOC based software Productivity measurement methodology—Function Points), mixing software Productivity data between disparate organizations is not a useful strategy. In other words, SPC tells us that software Productivity of one organization does not imply software Productivity of another because of the differences in process capability (even with extremely stable and automated-intensive processes). This fails to even mention the gross structural inadequacy of the Function Points method itself (Humphrey, 1995).

Quality

Quality, as defined and measured here, will take the common form of Defect Density. According to Conte, Dunsmore, and Shen (1986), "Defect Density is the number of software defects committed per thousand lines of software source code." Once again, Defect Density is a simple but extremely powerful method, for not only measuring Quality, but also efficiently managing software projects themselves. Defect Density, like Productivity, commonly takes the software life cycle-normalized form of total number of defects found in all life cycle artifacts divided by the total number of SLOC. Like Productivity, many consider Defect Density metrics to be of overall limited usefulness to the software life cycle, being only applicable to programming phases of software product development (ignoring planning, analysis, design, test, and maintenance). However, Kan (1995) and Humphrey (1995) have convincingly demonstrated that Defect Density, in its software life cycle-normalized form, is a highly strategic, single point metric upon which to focus all software life cycle activity for both software development and SPI. While, Kan's seminal masterpiece gives a much greater scholarly portrait of sophisticated metrics and models for software quality engineering, Humphrey breaks Defect Density down into its most practical terms, Appraisal to Failure Ratio. Humphrey has demonstrated that an optimal Appraisal to Failure Ratio of 2:1 must be achieved in order to manage software development to the peak of efficiency. While, Kan encourages the use of Rayleigh equations to model defect removal curves, Humphrey presents us with the practical saw-tooth form, two parts defects removed before test and one part during test, resulting in very near zero defect levels in finished software products. Since, defects found in test cost 10 times more than defects found before test, and 100 times more after release to customers, Humphrey has found that finding 67% of defects before test leads to optimal process performance, minimal process cost, and optimal final software product quality. The other common argument against the use of Defect Density metrics is that they seem to be rather limited in scope, ignoring other more encompassing software life cycle measurements. Again, Humphrey's Defect Density Metrics Appraisal to Failure Ratio-based methodology has proven that metrics need not be inundating, overwhelming, all encompassing, and sophisticated. People seem to insist on needless sophistication in lieu of powerful simplicity. Probably the more prevalent objection to the use of Defect Density Metrics seems to be an intuitive objection to the notion that Quality cannot be adequately represented by Defect Density. Quality, rather intuitively, takes the form market success, popularity, usefulness, good appearance, price, market share, good reputation, good reviews, and more importantly innovation. Defect Density doesn't capture any of the aforementioned characteristics. In fact, defect-prone products have been known to exhibit the intuitive characteristics of

high product quality, and software Products with exemplary Defect Densities have been considered of utterly low quality. This is merely a common confusion between product desirability and Quality. Customer satisfaction and market share measurement is a better form of measuring product desirability while Defect Density is an excellent form of measuring software Quality. Kan gives an excellent exposition of over 35 software metrics for measuring many aspects of software Quality, including customer satisfaction measurement, while reinforcing the strategic nature of Defect Density metrics for measuring software quality associated with SPI.

Return-on-Investment

According to Lim (1998), "Return-on-Investment metrics are collected for the purpose of measuring the magnitude of the benefits relative to the costs." According to Herbsleb, Carleton, Rozum, Siegel, and Zubrow (1994) and Garrison and Noreen (1997), there seems to be wide disparity in the definition, meaning, application, and usefulness of Return-on-Investment (ROI). Herbsleb, Carleton, Rozum, Siegel, and Zubrow claim that Business Value (value returned on each dollar invested) is actually measured, and not ROI itself. Garrison and Noreen define ROI as Margin (Net Operating Income/Sales) multiplied by Turnover (Sales/Average Operating Assets)—or rather a ratio of sales (or revenue) to operating expenses (or process costs). All three definitions have more commonality than differences, primarily, a ratio of revenue to expenses. If the revenue of employing a particular SPI method exceeds the cost of implementing the SPI method, then a positive ROI has been yielded. For example, if a 10,000 SLOC software product requires 83.84 person years (174,378 staff hours) using conventional methods, but only 400 person hours of Effort using the Personal Software Process (PSP), then PSP's ROI is determined to be (174, 378 – 400) divided by 400, or a whopping 435:1. ROI is not all that difficult, convoluted, or meaningless as Herbsleb, Carleton, Rozum, Siegel, and Zubrow, and Garrison and Noreen seem to assert. The next question becomes "at what point will the ROI be achieved?"

Break Even Hours. According to Garrison and Noreen (1997), break even point is defined as "the level of activity at which an organization neither earns a profit nor incurs a loss." Reinertsen (1997) similarly defines break even point as "the time from the first dollar spent until the development investment has been recovered." Garrison and Noreen present the equation of total fixed expenses divided by selling price per unit, less variable expenses per unit, resulting in the number of break even units. So, the break even point is when the total sales intersect the total expenses, according to Garrison and Noreen. Garrison's and Noreen's rendition of break even point is time-independent. In other words, Garrison's and Noreen's formulas indicate at what sales volume a break even point will be achieved, but make no assertion as to what point in "time" the sales volume will be achieved (since sales volume is determined by unpredictable market forces). However, for the purposes of this study, the break even point will be referred to as Break Even Hours and fully tied to time. Break Even Hours in software development may be computed a number of ways. Break Even Hours may be computed as the total cost of implementing a new SPI method. Break even point analysis in this study yielded some interesting results. Because, SPI method investment costs in Training Hours and Training Costs represent such small fractions of total life cycle costs, and sometimes large gains in Productivity, SPI break even points are surprisingly measured in hours or programming a few SLOC. On the other hand, break even analysis in traditional manufacturing industries usually involves the cost-justification of large capital investments in real estate, building construction, and equipment modernization (Garrison and Noreen, 1997). Therefore, process improvement in traditional industries generally involves capital investments measured in thousands and even millions of dollars. Break even analysis is imperative when large economies of scale are traditionally involved. However, SPI methods are typically measured in dozens and sometimes a few hundred hours, compared to total life cycle costs measuring in the hundreds of thousands of hours. So for a good SPI

method, break even points must be searched for in micro-scales involving hours, versus months, years, and even decades. SPI method break even analysis surprisingly challenges many conventional myths, holding that SPI takes years and decades to yield beneficial results.

Alternative Strategies

Eight SPI alternatives were chosen with which to evaluate, assess, and analyze cost and benefit data, the Personal Software Process (PSP), Clean Room Methodology, Software Reuse, Defect Prevention Process, Software Inspection Process, Software Test Process, Capability Maturity Model, and ISO 9000 (see Table 78).

Table 78: Alternatives for Evaluating and Benefits

Alternative	Class	Type	Typically Reported Data
Personal Software Process	Vertical Life Cycle	Product Appraisal	Cost, Productivity, Quality
Clean Room Methodology	Vertical Life Cycle	Formal Method	Cost, Quality, R01
Software Reuse	Vertical Process	Design Method	Cost, Productivity, Quality
Defect Prevention Process	Vertical Process	Preventative	Cost, Quality, R01
Software Inspection Process	Vertical Process	Product Appraisal	Cost, Productivity, Quality, R01
Software Test Process	Vertical Process	Product Appraisal	Cost, Quality
Capability Maturity Model	Indefinite	SPI Model	Cycle Time, Productivity, Quality
ISO 9000	Indefinite	Quality Standard	Cost, Productivity, Quality

Six of the SPI alternatives are vertical or prescriptive SPI methods offering relatively concise step-by-step guidance, Personal Software Process (PSP), Clean Room Methodology, Software Reuse, Defect Prevention Process, Software Inspection Process, and Software Test Process. Two of the SPI alternatives are indefinite or descriptive SPI methods that offer high-level strategic and non-prescriptive guidance, Capability Maturity Model (CMM) and ISO 9000. Three of the SPI alternatives are vertical life cycle methods offering complete, end-to-end processes or methodologies for building software products, Personal Software Process (PSP), Clean Room Methodology, and Software Reuse. Three of the SPI alternatives are verfical process methods offering only partial software life cycle support (usually product appraisal or validation), Defect Prevention Process, Software Inspection Process, and Software Test Process. All eight of the SPI alternatives were chosen for a number of reasons, maturity, completeness, acceptability, and most especially an abundance of quantitative cost and benefit data. However, it wasn't just the availability of abundant cost and benefit data that drove their selection, but also the magnitude of the cost and benefit data (e.g., low implementation cost and high quality benefit). The reason that the Capability Maturity Model (CMM) and ISO 9000 were chosen is because one is a de facto international standard and the other a certified international standard for SPI and SPI-related activity (e.g., software quality management). The Literature Survey proved instrumental in the identification and selection of these eight SPI alternatives for cost and benefit analyses, particularly in the case of the Clean Room Methodology and Software Reuse, because of their reportedly impressive costs and benefits. The Literature Survey also surfaced other SPI alternatives, but failed to justify their continued analyses because of the lack of reported cost and benefit data, most notably, Orthogonal Defect Classification

(ODC), Product Line Management (PLM), and Software Process Improvement and Capability dEtermination (SPICE). Ironically, each of the eight SPI alternatives are principally aimed at improving quality, and may rightly be classified as software quality methodologies, with the one possible exception of Software Reuse, which is principally a design or a compositional method. Orthogonal Defect Classification (ODC) is a very promising software quality methodology that should not be overlooked in future analyses, nor should Product Line Management (PLM), which is a software design management methodology. It is reasonably safe to assert that no other SPI method exists with reported costs and benefits as impressive as the ones selected and examined here. While, broad and impressive studies do exist (McConnell, 1996), very little cost and benefit data is available to justify them.

Personal Software Process (PSP)

The PSP is a relatively new software development life cycle, and software quality methodology (Humphrey, 1995). The PSP consists of five main software life cycle phases, Planning, High-Level Design, High-Level Design Review, Development, and Postmortem. The PSP is characterized by deliberate project planning and management, quantitative resource estimation and tracking, quality planning and management, highly structured individual reviews of software work products, and frequent software process and product measurements. Johnson and Disney (1998) report that the PSP requires at least "12 separate paper forms, including a project plan summary, time recording log, process improvement proposal, size estimation template, time estimation template, object categories worksheet, test report template, task planning template, schedule planning template, design checklist, and code checklist." Johnson and Disney go on to state that a single PSP project results in 500 individual software measurements, and that a small group of PSP projects easily results in tens of thousands of software measurements. The PSP is a highly prescriptive, step-by-step, measurement-intensive software process for developing software with the explicit goal of improving software process performance, achieving SPI, and resulting in measurably high quality software products. The PSP has emerged in an age and backdrop of qualitative, ambiguous, and highly undefined software development standards, life cycles, processes, and methodologies. The PSP is small, efficient, tangibly examinable, and yields an abundance of data for SPI research and analysis. Despite the newness of the PSP, and its popular but incorrect reputation as an academic classroom software methodology, the PSP has yielded a phenomenally large amount of examinable data for research and analysis. And, surprisingly still, despite the PSP's growing reputation as an overly bureaucratic software methodology (Johnson and Disney, 1998), the PSP is the smallest and most efficient SPI method ever recorded, yielding the highest recorded ROI and productivity for any SPI method known to the industry. Since the PSP was primarily conceived as a SPI method, the PSP is very inexpensive to operate, the PSP results in measurably high quality and productivity, and the PSP produces an abundance of measurement data, the PSP becomes a natural candidate for analysis and comparison in this study. Ironically, despite the PSP's newness, there was more PSP data available for examination and analysis than from any other SPI method examined by this study.

Clean Room Methodology

The Clean Room Methodology, like the PSP, is a software development life cycle and software quality methodology (Pressman, 1997; Kaplan, Clark, and Tang, 1995). Clean Room consists of seven main software life cycle phases, Function Specification, Usage Specification, Incremental Development Plan, Formal Design and Correctness Specification, Random Test Case Generation, Statistical Testing, and Reliability Certification Model, according to Kaplan, Clark, and Tang. Another variation presented by Kaplan, Clark, and Tang, defines Clean Room software life cycle phases as, Define Box Structures, Define Stimuli and Responses, Define State Boxes, Define Clear Boxes, Plan Statistical Reliability

Certification, Define Usage Specification, Create Incremental Development Plan, and Develop Verifiable Designs. Pressman defines Clean Room as an eight phase software life cycle consisting of, Requirements Gathering, Statistical Test Planning, Box Structure Specification, Formal Design, Correctness Verification, Code Generation, Inspection, and Verification, Statistical Usage Testing, and Certification. Clean Room is characterized by rigorous requirements analysis, incremental development, formal specification and design, deliberate test planning, formal verification, rigorous testing, and testing-based reliability growth modeling. Clean Room is also somewhat prescriptive, with the explicit goal of improving software quality and resulting in measurably high quality software products. Unlike the PSP, however, Clean Room wasn't targeted at SPI and places little emphasis on process definition, performance, and measurement. The bottom line is that Clean Room is a formal methods-based methodology making use of basic mathematical proofs and verification. Clean Room has the explicit goal of reducing the number of software defects committed, reducing reliance on the Software Inspection Process and Testing, and measurably increasing software quality levels beyond those achievable by the Software Inspection Process. Clean Room was chosen because of an abundance of software quality measurement data available as a result of using this methodology. Clean Room was also chosen for examination because of a recent study of this methodology by McGibbon (1996), exhibiting the costs and benefits of using Clean Room, and comparing it to other candidate SPI methods chosen for examination in this study, most notably, the Software Inspection Process and Software Reuse. Ironically, other than McGibbon's study, very little is known about the mechanics of Clean Room, despite the existence of several books devoted exclusively to Clean Room. In addition, these books tend to vaguely define Clean Room, don't seem to provide a coherent project planning and management framework, such as that explicitly provided by the PSP, and provide very little cost and benefit data, being woefully short of reported Clean Room measurements. Perhaps, that's because Clean Room is more of a technical, versus management, based methodology that relies on introducing the use of basic formal specification and verification techniques, and a loosely associated post-process measurement framework only reporting one measurement, software quality (in terms of Defect Density). Clean Room suffers from an unshakable reputation as being overly difficult, because it employs formal methods, and vaguely applicable to modern information technologies and application domains (particularly business, database, and data warehousing domains). In addition to the high cost of implementation and perception as being overly difficult to apply, Clean Room offers little evidence that it results in quality levels beyond those of much maligned product appraisal techniques, such as the Software Inspection Process. However, one surprising element of Clean Room revealed by McGibbon, was that Clean Room (as a formal method), results in smaller software source code sizes. Smaller software sizes naturally imply fewer opportunities to commit software defects, and subsequently, longer-term efficiencies in software maintenance productivity. As mentioned before, this study views McGibbon's analysis as the Rosetta stone or key to unlocking the secrets of Clean Room for examination and comparative analysis as a candidate SPI method.

Software Reuse

According to Poulin (1997), Software Reuse is defined as "the use of existing components of source code to develop a new software program, or application." Lim (1998) states that, "reuse is the use of existing assets in the development of other software with the goal of improving productivity, quality, and other factors (e.g., usability)." Both, Poulin and Lim explain that Software Reuse exploits an allegedly simple axiom, build and pay for software source code once, and reuse it many times. Software Reuse attempts to do for the software industry what the industrial revolution, interchangeable parts, and integrated circuits have done for 20th century manufacturing and even the more recent phenomenon of the high technology electronics industry. The fundamental notion behind Software Reuse is to reduce Cycle Time, reduce

Effort, increase Productivity, increase Return on Investment, increase Quality, and enable predictable software process performance by building and validating software source code once, and reusing it many times (with much greater ease). Unfortunately, Software Reuse is just that, a notion. Software Reuse is not characterized by a precisely defined software life cycle or process, such as those exhibited by the PSP, Clean Room, Software Inspection Process, or even Testing. According to Lim, Software Reuse consists of four main phases, Managing the Reuse Infrastructure, Producing Reusable Assets, Brokering Reusable Assets, and Consuming Reusable Assets (see Table 11). Software Reuse consists of five main phases, Characterize, Collect Data, Analyze Data, Taxonomy, and Evaluate (see Table 10), according to Schafer, Prieto-diaz, and Matsumoto (1994). Despite Software Reuse's lack of a standard life cycle or methodology, Software Reuse is still considered a prescriptive SPI method, because it is characterized by a pointedly specific tactical element, "reuse software source code." Even more so than Clean Room, Software Reuse places little emphasis on process definition, performance, and measurement. Software Reuse was also chosen because of an abundance of economic analyses, Productivity, Quality, Cycle Time, and other software measurement data as a result of using Software Reuse. Like Clean Room, Software Reuse tends to be more of a technical, versus management, based methodology. Software Reuse had a tremendous amount of momentum and popularity throughout the 1980s and early 1990s, riding the coat-tails of the object oriented analysis, design, and programming movement, manifesting themselves in third generation programming languages such as Ada and C++. Software Reuse was even considered by a few management scientists, most notably Cusumano (1991), Poulin, and Lim, to be the single most strategic SPI method. However, Software Reuse seems to have fallen victim to a few insurmountable maladies, it's reputation as a technical approach, lack of compelling economic analyses, lack of firmly defined processes, inability to motivate the actual reuse of software source code, and the sheer difficulty of managing third generation computer programming languages. And, once again, this study views Lim's, Poulin's, and McGibbon's books, studies, and economic analyses as the Rosetta stones to deciphering the costs and benefits of Software Reuse. And, it is their abundant economic analyses that led to the selection of Software Reuse for comparative analyses against other SPI methods, as discovered by the Literature Survey.

Defect Prevention Process

The Defect Prevention Process "is the process of improving quality and productivity by preventing the injection of defects into a product," according to Mays, Jones, Holloway, and Studinski (1990). According to Humphrey (1989), "the fundamental objective of software defect prevention is to make sure that errors, once identified and addressed, do not occur again." Gilb and Graham (1993) state that "the Defect Prevention Process is a set of practices that are integrated with the development process to reduce the number of errors developers actually make." Paulk, Weber, Curtis, and Chrissis (1996) of the Software Engineering Institute (SEI) formally assert that "the purpose of Defect Prevention is to identify the cause of defects and prevent them from recurring." Latino and Latino (1999) define Root Cause Failure Analysis (RCFA), which is similar to Defect Prevention, as "a technique for uncovering the cause of a failure by deductive reasoning down to the physical and human root(s), and then using inductive reasoning to uncover the much broader latent or organizational root(s)." Like Software Reuse, Defect Prevention is not characterized by a standard software life cycle or process, such as those exhibited by the PSP, Clean Room, Software Inspection Process, and Testing. However, the Defect Prevention Process defined by Jones (1985) serves as a commonly accepted de facto standard, primarily consisting of five sub-processes, Stage Kickoff Meeting, Causal Analysis Meeting, Action Database, Action Team, and Repository. Defect Prevention is characterized by software defect data collection, defect classification, defect tracking, root-cause analysis, implementation of preventative actions, and most notably in-process

education of commonly committed software defects. Defect Prevention is highly prescriptive, with the explicit goal of increasing software quality and reliability, and directly results in such. Defect Prevention is a classical SPI method that like Clean Room, has the explicit goal of reducing the number of software defects committed, reducing reliance on the Software Inspection Process and Testing. Defect Prevention relies heavily on rigorously collected and highly structured software defect data that is collected by less than 95% of all software organizations (Software Engineering Institute, 1999), and thus is the weakness of this approach. Conventional wisdom still holds that software defect data isn't representative of software quality in any way, shape, or form, and is commonly and intuitively believed not to be a strategic part of software development and SPI (Lauesen and Younessi, 1998; Binder, 1997). If software defect data collection is meaningless, as popularly held (Lauesen and Younessi; Binder), then the strategic justification for the PSP, Clean Room, Defect Prevention, Software Inspection Process, and Testing has been removed completely. It is the fundamental premise of this study that software defect data is the cornerstone of the software engineering and SPI disciplines (Kan, 1995; Smith, 1993), thus elevating the importance of Defect Prevention to that of a critically strategic SPI method. These are the reasons that Defect Prevention was chosen for examination and comparative analyses. Because, defect data is strategic (Kan; Smith), Defect Prevention is strategic (Mays, Jones, Holloway, and Studinski; Kan; Humphrey; Gilb; Latino and Latino), Defect Prevention is well defined (Mays, Jones, Holloway, and Studinski), and there is a good amount of data available (Mays, Jones, Holloway, and Studinski; Gilb; Latino and Latino).

Software Inspection Process

The Software Inspection Process is an early, in-process product appraisal activity, and is an instrumental component of contemporary software quality methodologies (Fagan, 1976). Inspections consist of six main sub-processes, Planning, Overview, Preparation, Inspection, Rework, and Followup. Inspections are characterized by highly structured team reviews by qualified peers, software defect identification, and software quality estimation based on discovered software defects. More importantly, Inspections are characterized by concisely defined, repeatable, and measurable processes, ushering in blockbuster ideas like the Software Engineering Institute's (SEI's) Capability Maturity Model for Software (Radice, Harding, Munnis, and Phillips, 1985; Radice, Roth, O'Hara, Jr., and Ciarfella, 1985). Inspections may be considered the cornerstone of modern quantitative software quality engineering methodologies (Kan, 1995; Humphrey, 1989, 1995, and 2000), such as Defect Prevention, CMM, software life cycle reliability modeling, software quality modeling, PSP, and the Team Software Process (TSP). Inspections are also characterized by software process metrics and measurements, and may yield more than 30 process and product software measurements per Inspection. A small product of 10,000 source lines of code may require 42 individual inspections, and may result in up to 1,260 individual software measurements. One organization performed 5,000 Inspections in three years, potentially yielding 150,000 individual software measurements (Weller, 1993). Like the PSP, or should it be said that the PSP is like Inspection, Inspection is a highly prescriptive, step-by-step, measurement-intensive software process for validating software with the explicit goal of improving software process performance, achieving SPI, and resulting in measurably high quality software products. While Inspections are even better defined and prescriptive than the PSP, Inspections only cover one aspect of software development, validation. Whereas, the PSP is an entire software life cycle that contains its own validation technique (Humphrey, 2000), though the TSP (Humphrey), a group form of the PSP, does use Inspections and not the individual validation review employed by the PSP (Humphrey). Inspections were selected for examination and comparative analysis because of the abundance of literature on Inspections, in both journals and textbooks, the abundance of reported and validated costs and benefits, and ability to develop ROI models and analyses based on Inspections, because of its precise characterization and measurability. In fact, several key studies

motivated the selection of Inspections for comparative analyses, McGibbon (1996), Grady (1997), Weller (1993), Russell (1989), and Rico (1996a and 1996b). McGibbon performed comparative analyses of Inspections, Clean Room, and Software Reuse, showing that Inspections exhibit an ROI beyond that of any known SPI method to him. Inspections were a cornerstone SPI method to Grady's landmark study and comparison of SPI methods, reporting that the use of Inspections have saved Hewlett Packard over $400 million. Weller and Russell demonstrated that Inspections are extremely quantitative and effective, each responsible for helping change the image of Inspections from a qualitative Walkthrough-style technique to its real quantitative characterization. Rico (1993, 1996, and 1999) showed how simple it is to examine the costs and benefits of Inspections, because of their measurability. Still, Inspections, like Clean Room and the PSP, have an unshakable reputation as being overly bureaucratic, too expensive, and too difficult to learn, with only marginal benefits. Russell, Weller, McGibbon, Grady, Humphrey, and Rico begin to show for the first time in three decades that these misperceptions are exactly that, untrue.

Software Test Process

The Software Test Process is a late, post-process product appraisal activity, that is commonly misperceived to be software quality assurance, verification and validation, and independent verification and validation (Rico, 1999). According to IEEE (Std 1012-1986; Std 1059-1993), the Software Test Process consists of eight main sub-processes, Test Plan Generation, Test Design Generation, Test Case Generation, Test Procedure Generation, Component Testing, Integration Testing, System Testing, and Acceptance Testing. According to IEEE (J-Std 016-1995), the Software Test process consists of seven main sub-processes, Test Planning, Test Environment Preparation, Unit Testing, Unit Integration Testing, Item Qualification Testing, Item Integration Testing, and System Qualification Testing. According to IEEE (Std 12207.0-1996), the Software Test process consists of six main sub-processes, Qualification Test Planning, Integration Test Planning, Unit Test Planning, Unit Testing, Integration Testing, and Qualification Testing. Testing is characterized by dynamic execution of software upon code and implementation based on predefined test procedures, usually by an independent test group other than the original programmer. According to Pressman (1997) and Sommerville (1997), Testing is also characterized by a variety of dynamic white box (e.g., basis path and control structure) and black box (e.g., specification, interface, and operational) Testing techniques. Blackburn's (1998) Testing approach is based on the theory that among the myriad of Testing techniques, boundary analysis is the most fruitful area for finding defects, and goes on to assert a direct correlation between the absence of boundary analysis defects and the overall absence of software product defects. Testing can be prescriptive, with a somewhat misguided, but honorable, goal of improving software quality. Testing is somewhat misguided for several important reasons, Testing doesn't involve estimating defect populations, little time is devoted to Testing, and Testing is usually conducted in an ad hoc and unstructured fashion, which all contribute to passing an inordinately large latent defect population right into customer hands (Rico, 1999). However, there seems to be some controversy as to the strategic importance of Testing, as Lauesen and Younessi (1998) claim that 55% of defects can only be found by Testing, while Weller (1993) and Kan (1995) assert that better than 98% of defects can be found before Testing begins. And, of course, Lauesen and Younessi go on to assert the popular notion that software defect levels don't represent ultimate customer requirements, while Kan firmly shows a strong correlation between defect levels and customer satisfaction. Testing was chosen because there is an abundance of literature exhibiting the costs and benefits of Testing, primarily when Testing is being compared to the Software Inspection Process. Testing was also chosen because interest in Testing-based process improvement is growing at a rapid pace (Burnstein, Suwannasart, and Carlson, 1996a and 1996b; Burnstein, Homyen, Grom, and Carlson, 1998). Thus, it now becomes imperative to examine various SPI methods, quantify their individual costs and benefits, and direct SPI resources to important areas yielding optimal ROI. Ironically, highly structured

Testing is practiced by very few organizations, perhaps less than 95% (Software Engineering Institute, 1999). So, perhaps, Testing-based process improvement isn't such a bad strategy, given that there is a substantial ROI for good Testing (as long as it is realized that there are superior SPI methods to Testing).

Capability Maturity Model for Software (CMM)

The CMM is a software process improvement framework or reference model that emphasizes software quality (Paulk, Weber, Curtis, and Chrissis, 1995). The CMM is a framework of SPI criteria or requirements organized by the following structural decomposition, Maturity Levels, Key Process Areas, Common Features, and Key Practices (Paulk, Weber, Curtis, and Chrissis). There are five Maturity Levels, Initial, Repeatable, Defined, Managed, and Optimizing (see Table 4 and Figure 24). Key Process Areas have Goals associated with them. There are 18 Key Process Areas divided among the Maturity Levels, zero for Initial, six for Repeatable, seven for Defined, two for Managed, and three for Optimizing (see Table 4 and Figure 24). There are five Common Features associated with each of the 18 Key Process Areas, Commitment to Perform, Ability to Perform, Activities Performed, Measurement and Analysis, and Verifying Implementation. And, there are approximately 316 individual Key Practices or SPI requirements divided among the 90 Common Features. The CMM is characterized by best practices for software development management, with a focus on software quality management. That is, the CMM identifies high-priority software management best practices, and their associated requirements. Thus, a software producing organization that follows the best practices prescribed by the CMM, and meets their requirements, is considered to have good software management practices. And, software-producing organizations that don't meet the CMM's requirements are considered to have poor software management practices. The CMM is a series of five stages or Maturity Levels of software management sophistication, Maturity Level One—Initial being worst and Maturity Level Five—Optimizing being considered best. At the first stage or Maturity Level, software management is asserted to be very unsophisticated or "immature" in CMM terminology. At the last or highest stage or Maturity Level, software management is asserted to be very sophisticated or "mature" in CMM terminology. The first or Initial Level has no SPI requirements and characterizes poor software management practices. The second or Repeatable Level has six major best practices largely centered on software project planning and management. The third or Defined Level has seven major best practices centered on organizational SPI management, process definition, and introduces some software quality management practices. The fourth or Managed Level only has two best practices emphasizing the use of software metrics and measurement to manage software development, as well as an emphasis on software quality metrics and measurement. The fifth and highest Optimizing Level focuses on Defect Prevention, the use of product technologies for process improvement, and carefully managed process improvement. In essence, the CMM requires the definition of software project management practices, the definition of organizational software development practices, the measurement of organization process performance, and finally measurement-intensive process improvement. This is where the controversy enters the picture, while the CMM is reported to be prescriptive for SPI, the CMM is not prescriptive for software project management, software development, or software measurement. The CMM merely identifies or names some important software processes, vaguely describes their characteristics, and even asserts a priority and order of SPI focus (e.g., Maturity Levels). Common issues are that the CMM doesn't identify all important software processes, doesn't group, prioritize, and sequence SPI requirements appropriately, doesn't provide step-by-step prescriptive process definitions, and may actually impede SPI by deferring software process and quality measurement for several years. Ironically, many commonly misperceive the CMM's 316 Key Practices to be the concise prescriptive requirements for software management and engineering. Fulfilling the CMM's 316 Key Practices will merely make an organization CMM-compliant. However, the CMM's 316 Key Practices neither fully describe functional software processes nor describe a best-in-class software life

cycle like the PSP, TSP, or even the Clean Room Methodology do. In other words, the CMM attempts to describe the "essence" of best practices, but doesn't contain the detail necessary to define and use the recommended best-practices by the CMM (a common misconception). One more time for emphasis, the CMM is not a software engineering life cycle standard like ISO/IEC 12207, EIA/IEEE 12207, or J-STD-016. Nevertheless, the CMM is the de facto, international SPI method and model, and there is an abundance of software measurement data associated with its use, particularly in the works of Herbsleb, Carleton, Rozum, Siegel, and Zubrow (1994), Diaz and Sligo (1997), and Haskell, Decker, and McGarry (1997). While these studies have exhibited some rather impressive costs and benefits associated with using the CMM, it is unclear how many additional resources and techniques were required to meet the CMM's requirements. And, whether actually meeting the CMM's requirements may have actually been due to using other SPI methods such as the Software Inspection Process and the use of software defect density metrics, and attributing these successful outcomes to use of the CMM.

ISO 9000

According to Kan (1995), "ISO 9000, a set of standards and guidelines for a quality assurance management system, represent another body of quality standards." According to NSF-ISR (1999), an international quality consulting firm, "ISO 9000 Standards were created to promote consistent quality practices across international borders and to facilitate the international exchange of goods and services." NSF-ISR goes on to assert that "meeting the stringent standards of ISO 9000 gives a company confidence in its quality management and assurance systems." According the American Society for Quality Control (1999), "The ISO 9000 series is a set of five individual, but related, international standards on quality management and quality assurance." The American Society for Quality Control goes on to say ISO 9000 standards "were developed to effectively document the quality system elements to be implemented in order to maintain an efficient quality system in your company." In short, ISO 9000 is a set of international standards for organizational quality assurance (QA) standards, systems, processes, practices, and procedures. ISO 9000-3, Quality Management and Quality Assurance Standards—Part 3: Guidelines for the Application of ISO 9001 to the Development, Supply, and Maintenance of Software, specifies 20 broad classes of requirements or elements. The first 10 ISO 9000-3 quality system elements are, Management Responsibility, Quality System, Contract Review, Design Control, Document Control, Purchasing, Purchaser-Supplied Product, Product Identification and Traceability, Process Control, and Inspection and Testing. The last 10 ISO 9000-3 quality system elements are, Inspection, Measuring, and Test Equipment, Inspection and Test Status, Control of Nonconforming Product, Corrective Action, Handling, Storage, Packaging, and Delivery, Quality Records, Internal Quality Audits, Training, Servicing, and Statistical Techniques. ISO 9000 is characterized by the creation, existence, and auditing of a "quality manual" that "aids in implementing your quality system; communicates policy, procedures and requirements; outlines goals and structures of the quality system and ensures compliance," according to Johnson (1999), an international quality consulting firm. ISO 9000 describes the essence of an organizational quality management system at the highest levels, much like the CMM, and is thus highly descriptive, like the CMM, and not very prescriptive at all. While, prescriptive SPI strategies like the PSP, TSP, Clean Room, and Inspections require actual conformance to step-by-step software quality methodology, there seems to be some question as to the operational nature of an ISO 9000-compliant "quality manual" or quality management system. In fact, Johnson claims that it can help organizations become ISO 9000 registered in as little as three to six months. Johnson sends in a team of consultants to actually write an ISO 9000-compliant "quality manual" for its clients. ISO 9000 was chosen for examination and comparative analyses as a SPI method, because as Kaplan, Clark, and Tang (1995) state, "the whole world was rushing to adopt ISO 9000 as a quality standard." Studies by Kaplan, Clark, and Tang and Haskell, Decker, and McGarry (1997) were instrumental keys to unlocking the costs and

benefits of ISO 9000 as a SPI method. Ironically, many authoritative surveys have been conducted measuring international organizational "perceptions" of using ISO 9000-compliant quality management systems. According to Arditti (1999), Lloyd Register reports survey respondent perceptions such as, improved management—86%, better customer service—73%, improved efficiency and productivity—69%, reduced waste—53%, improved staff motivation and reduced staff turnover—50%, and reduced costs—40%. Irwin Publishing reports respondent perceptions such as, higher quality—83%, competitive advantage—69%, less customer quality audits—50%, and increased customer demand—30%, according to Arditti. According to Garver (1999), Bradley T. Gale reports survey respondent perceptions such as, Improved Management Control—83%, Improved Customer Satisfaction—82%, Motivated Workforce—61%, Increased Opportunity To Win Work—62%, Increased Productivity/Efficiency—60%, Reduced Waste—60%, More Effective Marketing—52%, Reduced Costs—50%, and Increased Market Share—49%. While these statistics certainly sound great, these statistics do not reflect "actual" benefits, but merely "perceived" ones. It's completely unclear how much, if any, actual benefits arise from using ISO 9000-compliant quality management systems. However, as mentioned before Kaplan, Clark, and Tang and Haskell, Decker, and McGarry, among others, have provided enough quantitative cost and benefit information to include the use of ISO 9000 as a SPI method, given its tremendous popularity, and perceived ubiquity. It is important to note that very few firms actually employ ISO 9000, at least domestically. Some large U.S. states have as few as three ISO 9000-registered firms, which could be considered statistically insignificant.

Defect Removal Model

The defect removal model is a tool for managing software quality as software products are developed, by evaluating phase-by-phase software defect removal efficiency (Kan, 1995). The defect removal model has historically been used to model software process, software project management, and software verification and validation effectiveness (Sulack, Lindner, and Dietz, 1989; Humphrey, 1989 and 1995; Gilb, 1993; Kan, 1995; McGibbon, 1996; Ferguson, Humphrey, Khajenoori, Macke, and Matvya, 1997; Rico, 1999). Software process improvement (SPI) costs and benefits, particularly Return-On-Investment (ROI), are also modeled by the defect removal model (Gilb, 1993; Grady, 1994 and 1997; McGibbon, 1996). The defect removal model is similarly represented by the dynamics of the Rayleigh life cycle reliability model shown in Figure 28. The notion being that software defects should be eliminated early in software life cycles, and that the economics of late defect elimination are cost-prohibitive.

According to Kan, "the phase-based defect removal model summarizes the interrelations among three metrics—defect injection, defect removal, and effectiveness." Or, arithmetically speaking, "defects at the exit of a development setup = defects escaped from previous setup + defects injected in current setup – defects removed in current setup." Kan cautiously and conservatively warns that the defect removal model is a good tool for software quality management, not software reliability modeling and estimation. Kan goes on to say that parametric models such as exponential models and reliability growth models (e.g., Jelinski-Moranda, Littlewood, Goel-Okumoto, Musa-Okumoto, and the Delayed S and Inflection S Models) are best for software reliability estimation, not the defect removal model.

While, Kan favors the use of the lesser known, but deadly accurate Rayleigh model for software quality management, Grady (1994 and 1997), Humphrey (1995), and McGibbon (1996) have established strong empirical foundations for using defect removal models for evaluating the costs and benefits of SPI, as well as ROI. Rico's (1999) basic defect removal model, comparing the costs and benefits of the Personal Software Process (PSP), Software Inspection Process, and Software Test Process, was expanded upon to establish the basic framework of the methodology for this entire study.

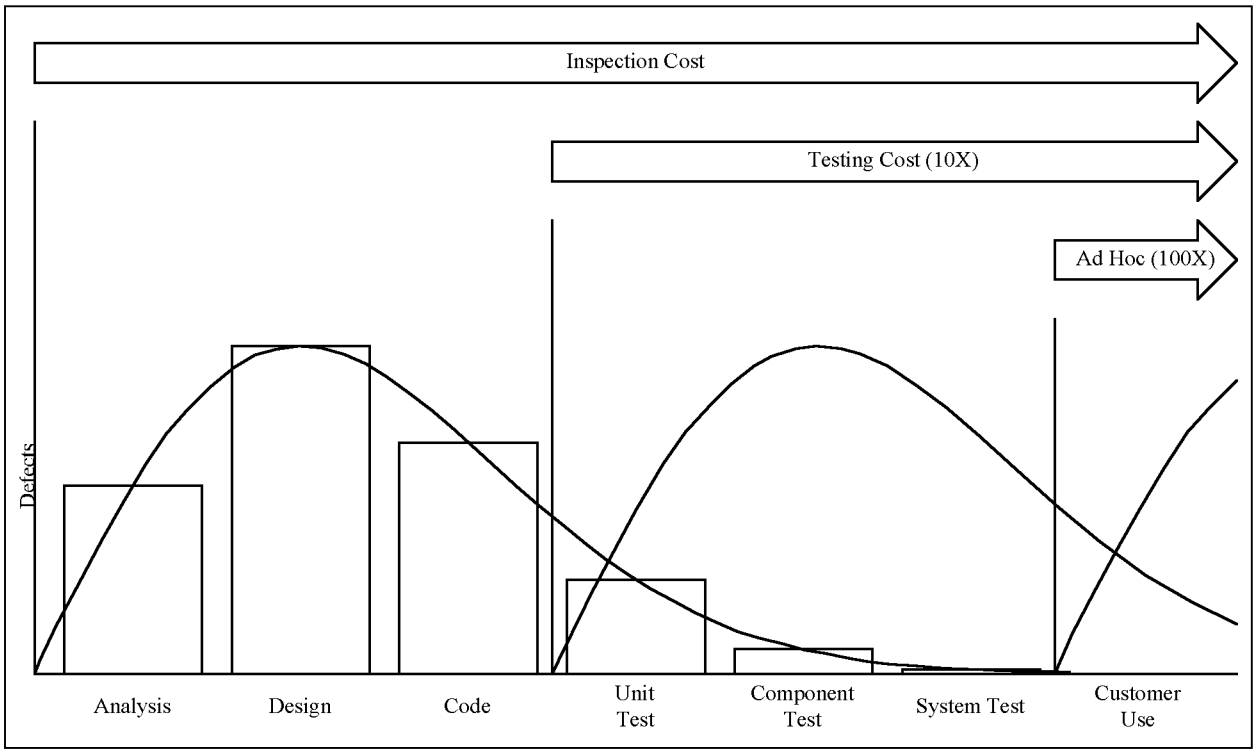


Figure 28. Defect Removal Model Theory

In addition to establishing the basic methodology for this study, the defect removal model was used to design and construct an empirically valid ROI model, as well as the empirical framework for evaluating the costs and benefits of the targeted SPI methods. As mentioned earlier, this study will evaluate the costs and benefits of the PSP, Clean Room, Reuse, Prevention, Inspection, Test, CMM, and ISO 9000. So, if a particular ROI or break even point is asserted for the PSP, Inspection, or Test, in which these will be critically strategic comparative factors, then a strong empirical foundation has been established to validate these assertions.

Table 79: Humphrey's Defect Removal Model

Defects	High Level Design	Detailed Level Design	Code	Unit Test	Integration Test	System Test	Usage
Residual	0	4	13	34	19	139	9
Injected	10	21	63	5	2	2	3
Removed	6	12	42	20	8	6	12
Remaining	4	13	34	19	13	9	0
Injection Rate	10	21	63	5	2	2	3
Removal Efficiency	60%	48%	55%	51%	38%	40%	100%
Cumulative Efficiency	60%	58%	64%	81%	87%	91%	100%
Inspection Defects	6	18	60	-	-	-	-
Development Defects	6	18	60	80	8	94	-
Inspection Efficiency	-	-	-	-	-	63.8%	-

Humphrey

One of the first defect removal models was presented by Humphrey (1989) to explain defect removal efficiency, is his seminal book on the SEI's CMM (see Table 79). Humphrey presents seven software life cycle phases or stages, High Level Design, Detailed Level Design, Code, Unit Test, Integration Test, System Test, and Usage, for software quality analysis on a stage-by-stage basis. Humphrey also used 10 software measurements for in-process software quality analysis. Residual defects are the estimated starting defects at the beginning of each stage. Injected is the number of new defects committed in each stage. Removed is the number of defects eliminated in each stage. Remaining is injected less removed defects. Injected Rate is the same as Injected defects in this example. Removal Efficiency is a ratio of Removed to Residual and Injected defects. Cumulative Efficiency is a ratio of all Removed to all Residual and Injected defects. Inspection Defects are software defects found by the Software Inspection Process. Development Defects are software defects committed before product delivery. And Inspection Efficiency is an estimate of the overall Software Inspection Process effectiveness, or ratio of software defects found by Inspections to total estimated defects. This is a realistic model because it portrays modest Inspection efficiencies, and stage-by-stage software defect injection.

Table 80: Sulak's Defect Removal Model

Phase	System/36	System/38	Future	AS/400
Product Objectives	Review	Review	Review	Walkthrough
Architecture	Review	Walkthrough	Inspection	Inspection
Specification	Review	Walkthrough	Inspection	Inspection
High-Level Designs	Review	Inspection	Inspection	Inspection
Intercomponent Interfaces	Review	Inspection	Inspection	Inspection
Low-Level Designs	Inspection	Inspection	Inspection	Inspection
Code	Inspection	Inspection	Inspection	Inspection
Test Plan	Inspection	Inspection	Inspection	Inspection
Test Cases	Inspection	Inspection	Inspection	Inspection

Sulack

If Humphrey's (1989) defect removal model was the first quantitative analyses of defect removal efficiencies in strategic "what-if" terms, Sulack, Linder, and Dietz (1989) presented the first qualitative, though holistic, defect removal model in tactical "how-to" terms (see Table 80). Actually, Sulack, Linder, and Dietz show four defect removal models, three for existing software products, and one notional or "future" defect removal model. Nine software life cycle stages or phases are shown for each defect removal model, Product Objectives, Architecture, Specification, High-Level Design, Intercomponent Interfaces, Low-Level Design, Code, Test Plan, and Test Cases. The first product, System/36, used informal reviews for the first half of the life cycle and the Software Inspection Process for the second half. The second product, System/38, extended Inspections into software design, and structured walkthroughs into Architecture and Specification. A Future, or ideal, defect removal model would systematically employ Inspections throughout the software life cycle, with an informal initial review. Instead, the third product, AS/400, used Inspections throughout the software life cycle, on a phase-by-phase, product-by-product basis, in order to identify software defects as early as possible. This strategy helped generate $14B in revenue, win the Malcolm Baldrige National Quality Award, become ISO 9000 Registered, and employ a world-class software quality management system.

Table 81: Gilb's Defect Removal Model

Life Cycle Phase	System Construction	Testing Execution	Early Field Use	Later Field Use	Final Use
Where Defects Found	Inspection	Testing	Use	Use	Use
Defects Found	60	24	10	4	2
Estimated Effectiveness	75%	71%	63%	61%	60%
Cost to Fix	$10	$100	$1,000	$1,000	$1,000
Cost with Inspection	$600	$3,000	$13,000	$17,000	$19,000
Defects Found W/O Inspection	0	60	48	10	2
Cost W/O Inspection	$0	$6,000	$540,000	$64,000	$66,000

Gilb

While, defect removal models by Humphrey (1989) and Sulack, Lindner, and Dietz (1989) were some of the earliest works, depicting strategic and tactical models, Gilb (1993) was one of the first to attach the costs and benefits to his defect removal model (see Table 81). Gilb's model presents five notional stages of software product evolution, System Construction, Testing Execution, Early Field Use, Later Field Use, and Final Use. Gilb's defect removal model also introduced seven basic software metrics, Where Defects Found, Defects Found, Estimated Effectiveness, Cost to Fix, Cost with Inspection, Defects Found w/o Inspection, and Cost w/o Inspection, being one the first models to introduce the notion of cost. Where Defects Found identifies the activity that uncovered the software defect, Inspection, Test, or customer use. Defects Found are the proportional number of software defects uncovered by the activity, Inspection, Test, or customer use, and the phase in which they were found. Estimated Effectiveness is the percentage of defects found by Inspection, Testing, or customer use for that phase. Cost to Fix is the dollars per defect for the given phase and activity. Cost with Inspection is total dollars per phase and activity, with Inspections used in the System Construction Phase. Defects Found w/o Inspection is the number of software defects found per phase and activity without use of Inspections. Cost w/o Inspection is the cost per phase and activity without use of Inspections. For a modest $600 investment in Inspections, $623,400 is saved according to Gilb.

Table 82: Kan's Defect Removal Model

Phase	(A) Defect Escaped from Previous Phase (per KSLOC)	(B) Defect Injection (per KSLOC)	Subtotal (A+B)	Removal Effectiveness	Defect Removal (per KSLOC)	Defects at Exit of Phase (per KSLOC)
Requirements	-	1.2	1.2	-	-	1.2
High Level Design	1.2	8.6	9.8	74%	7.3	2.5
Low Level Design	2.5	9.4	11.9	61%	7.3	4.6
Code	4.6	15.4	20	55%	11	9
Unit Test	9	-	9	36%	3.2	5.8
Component Test	5.8	-	5.8	67%	3.9	1.9
System Test	1.9	-	1.9	58%	1.1	0.8
Field	0.8	-	-	-	-	-

Kan

The defect removal model by Kan (1995) is very similar to Humphrey's (1989), only simplified and more focused (see Table 82). In this model, Kan shows eight software development phases, Requirements, High Level Design, Low Level Design, Code, Unit Test, Component Test, System Test, and Field. Kan also introduces six software metrics to measure software quality, Defect Escaped from Previous Phase (per KSLOC), Defect Injection (per KSLOC), Subtotal (A + B), Removal Effectiveness, Defect Removal (per KSLOC), and Defects at Exit of Phase (per KSLOC). Defect Escaped from Previous Phase (per KSLOC) is the number of software defects present before phases begin (normalized to thousands of source lines of code—KSLOC). Defect Injection (per KSLOC) is the number of software defects created during a phase (normalized to KSLOC). Subtotal (A + B) is the sum of software escaped and injected defects, that are present during any given phase. Removal Effectiveness is the percentage of software defects eliminated by Inspections or Test per phase. Defect Removal (per KSLOC) is the number of software defects eliminated by Inspections or Test per phase (normalized to KSLOC). And, Defects at Exit of Phase (per KSLOC) are the number of residual software defects present, or not eliminated by Inspections or Test per phase (normalized to KSLOC).

Table 83: McGibbon's Defect Removal Model (Part I)

Phase	Formal Inspections	Informal Inspections
Design		
% Defects lntroduced	35%	35%
Total Defects Introduced	98 Defects	98 Defects
% Defects Detected	65%	40%
Defects Detected	64 Defects	39 Defects
Rework Hours/Defect	2.5 Hours	2.5 Hours
Total Design Rework	159 Hours	98 Hours
Coding		
% Defects Introduced	65%	65%
Total Defects Introduced	182 Defects	182 Defects
% Defects Detected	70%	35%
Defects Detected 151 Defects	84 Defects	
Rework Hours/Defect	2.5 Hours	2.5 Hours
Total Coding Rework	378 Hours	211 Hours
Test		
Defects Found in Test	51 Defects	114 Defects
Rework Hours/Defect	25 Hours	25 Hours
Total Test Rework	1,271 Hours	2,861 Hours
% of Defects Removed	95%	85%
Maintenance		
Defects Left for Customer	14 Defects	42 Defects
Post Release Defects/KSLOC	0.35/KSLOC	1.05/KSLOC
Rework Hours/Defect	250 Hours	10,491 Hours
Total Maintenance Rework	3,497 Hours	3,497 Hours
Totals		
Total Rework	5,306 Hours	13,660 Hours
Total Rework Costs	$206,918	$532,752
Total Savings	$325,834	

McGibbon

Like Humprey's (1989) and Kan's (1995) defect removal models, McGibbon (1996) designed a detailed model and attached costs like Gilb (1993), but upped the ante by comparing the costs and benefits of Formal and Informal Inspections (see Table 83). McGibbon uses four major software life cycle phases, Design, Coding, Test, and Maintenance, also introducing 23 individual software metrics for evaluating the costs and benefits of defect removal efficiencies for Formal and Informal Inspections. % Defects Introduced represents the proportion of software defects created during the Design and Coding phases. Total Defects Introduced represents the number of software defects created during the Design and Coding phases. % Defects Detected represent the proportion of software defects eliminated by Formal and Informal Inspections during the Design and Coding phases. Defects Detected represent the number of software defects eliminated by Formal and Informal Inspections during the Design and Coding phases. Rework Hours/Defect are the effort required to eliminate each software defect by Formal and Informal Inspections during the Design and Coding phases. Total Design Rework is the effort required to repair all defects found by Formal and Informal Inspections during the Design and Coding phases. Defects Found in Test are residual or remaining software defects escaping Formal and Informal Inspections into the Test phase. Rework Hours/Defect are the effort to eliminate each software defect by dynamic analysis during the Test phase. Total Test Rework is the effort required to repair all defects found by dynamic analysis during the Test phase. % of Defects Removed are the proportion of software defects eliminated by Formal and Informal Inspections, as well as dynamic analysis, during the Design, Coding, and Test phases. Defects Left for Customer are the total number of software defects remaining in software products delivered to customers, not found by Formal and Informal Inspections, or dynamic analysis, during the Design, Coding, and Test phases. Post Release Defects/KSLOC are the number of Defects Left for Customer normalized to thousands of source lines of code (KSLOC). Rework Hours/Defect are the effort to eliminate each software defect during the Maintenance phase. Total Maintenance Rework is the effort required to repair all defects during the Maintenance phase. Total Rework is the effort required to repair all defects found during the Design, Coding, Test, and Maintenance phases. Total Rework Cost is Total Rework in dollars. And, Total Savings are the benefit of using Formal Inspections over Informal Inspections.

McGibbon

After designing his defect removal model in Table 83, McGibbon (1996) extended his analysis to include comparing the Clean Room Methodology, a formal methods-based software development approach, to Formal Inspections and Informal Inspections (see Table 84). McGibbon's model reported a 6:1 cost advantage of Clean Room over Inspections.

Table 84: McGibbon's Defect Removal Model (Part II)

Cost/Benefits	Clean Room	Formal Inspection	Informal Inspection
Lines of Code	39,967	39,967	39,967
Defects per KSLOC	5	7	7
Total Defects Expected	200	280	280
Design			
% Defects Introduced	35%	35%	35%
Total Defects Introduced	70	98	98
% Defects Detected	80%	65%	40%
Defects Detected	56	64	39
Rework Hours/Defect	2.5	2.5	2.5
Total Design Rework	140	159	98
Coding			
% Defects Introduced	65%	65%	65%
Total Defects Introduced	130	182	182
% Detects Detected	98%	70%	35%
Defects Detected	141	151	84
Rework Hours/Defect	2.5	2.5	2.5
Total Design Rework	353	378	211
Test			
Defects Found in Test	1	51	114
Rework Hours/Defect	25	25	25
Total Test Rework	22	1,271	2,861
% of Defects Removed	99%	95%	85%
Maintenance			
Defects Left for Customer	2	14	42
Post Release Defects/KSLOC	0.05	0.35	1.05
Rework Hours/Defect	250	250	250
Total Maintenance Rework	500	3,497	10,491
Maintenance $	$19,484	$136,386	$409,159
Totals			
Total Rework Hours	1,014	5,306	13,660
Total Rework Costs	$39,544	$206,918	$532,752
Effort $ + Maintenance $	$466,659	$2,618,814	$2,891,586
Clean Room $ Improvement		$2,152,155	$2,424,927
Clean Room % Improvement		82%	84%

Ferguson

This defect removal model (as shown in Table 85) was created from data by Ferguson, Humphrey, Khajenoori, Macke, and Matvya (1997). Size is the number of source lines of code. Defects are the total number of software defects created. Insertion is the ratio of Defects to Size. Review is the number of software defects eliminated by reviews. Efficiency is the ratio of Review to Defects. Test is the number of defects eliminated by Test. Efficiency is the ratio of Test to Defects (less Review). Fielded is the number of residual defects. 76% of software defects are found by individual review, 24% by dynamic analysis, and 0% are released to customers.

Table 85: Ferguson's Defect Removal Model

	Defect Containment Analysis							
Project	Size	Defects	Insertion	Review	Efficiency	Test	Efficiency	Fielded
1	463	13	3%	8	62%	5	100%	0
2	4,565	69	2%	59	86%	10	100%	0
3	1,571	47	3%	39	83%	8	100%	0
4	3,381	69	2%	47	68%	22	100%	0
5	5	0	0%	0	0%	0	0%	0
6	22	2	9%	2	100%	0	0%	0
7	1	]	100%	1	100%	0	0%	0
8	2,081	34	2%	33	97%	0	0%	1
9	114	15	13%	13	87%	2	100%	0
10	364	29	8%	27	93%	2	100%	0
11	7	0	0%	0	0%	0	0%	0
12	620	12	2%	10	83%	2	100%	0
13	720	9	1 %	7	78%	2	100%	0
14	3,894	20	1 %	18	90%	2	100%	0
15	2,075	79	4%	52	66%	27	100%	0
16	1,270	20	2%	19	95%	1	100%	0
17	467	17	4%	14	82%	3	100%	0
18	3,494	139	4%	89	64%	50	100%	0
Total	25,114	575	2%	438	76%	136	99%	1

Table 86: Rico's Defect Removal Model

Cost/Benefits	PSP	Inspection	Test
Program Size	10 KSLOC	10 KSLOC	10 KSLOC
Start Defects	1,000	1,000	1,000
Review Hours	97.24	708	n/a
Review Detects	666	900	n/a
Defects per Hour	6.85	1.27	n/a
Start Detects	333	100	1,000
Test Hours	60.92	1,144	11,439
Test Defects	333	90	900
Defects per Hour	5.47	12.71	12.71
Total Hours	400 *	1,852	11,439
Total Defects	1,000	990	900
Quality Benefit	100X	10X	n/a
Delivered Detects	0	10	100
Cost Benefit	29X	6X	n/a

* PSP hours include development time—others only validation time

Rico

The defect removal model in Table 86 was created by Rico (1999), and is a hybrid of models by Ferguson, Humphrey, Khajenoori, Macke, and Matvya (1997), and McGibbon 1996. Program Size is thousands of source lines of code. Start Defects are the estimated software defects. Review Hours are the number of static analysis hours. Review Defects are the number of defects found by static analysis. Defects per Hour are the ratio of Review Defects to Review Hours. Start Defects are the number of defects escaping reviews. Test Hours are the number of dynamic analysis hours. Test Defects are the number of defects found by dynamic analysis. Defects per Hour are the ratio of Test Defects to Test Hours. Total Hours are the sum of Review Hours and Test Hours (except PSP, which includes total effort). Total Defects are the sum of Review Defects and Test Defects. Quality Benefit is a ratio of poorest Delivered Defects to next best Delivered Defects. Delivered Defects are the numbers of defects escaping static and dynamic analysis. Cost Benefit is a ratio of poorest Total Hours to next best Total Hours.

Humphrey

While Figure 20 represents a Rayleigh life cycle reliability model (Kan, 1995), it is an excellent illustration of a grossly simplified defect removal model developed for the Personal Software Process (PSP) by Humphrey (1995). Humphrey introduced a model, he called the Appraisal to Failure Ratio (A/FR). Mathematically, Appraisal (A) is expressed as 100 * (design review time + code review time) / total development time. And, Failure Ratio (FR) is expressed as 100 * (compile time + test time) / total development time. A/FR is simply the ratio of static analysis effort to dynamic analysis effort. While, Kan advocates the use of Rayleigh models, Humphrey has discovered the much simpler, but extremely powerful, axiom or software engineering law stating that if more than twice as much effort is spent on static analysis than dynamic analysis, few, if no software defects will be delivered to customers. And, the corollary to A/FR is, if more than twice as many software defects are found by static analysis than dynamic analysis, no defects will be delivered to customers. These axioms prove valid for the 18 software releases depicted in Table 85, where 76% of software defects were found by static analysis, 24% of software defects were found by dynamic analysis, and none by customers.

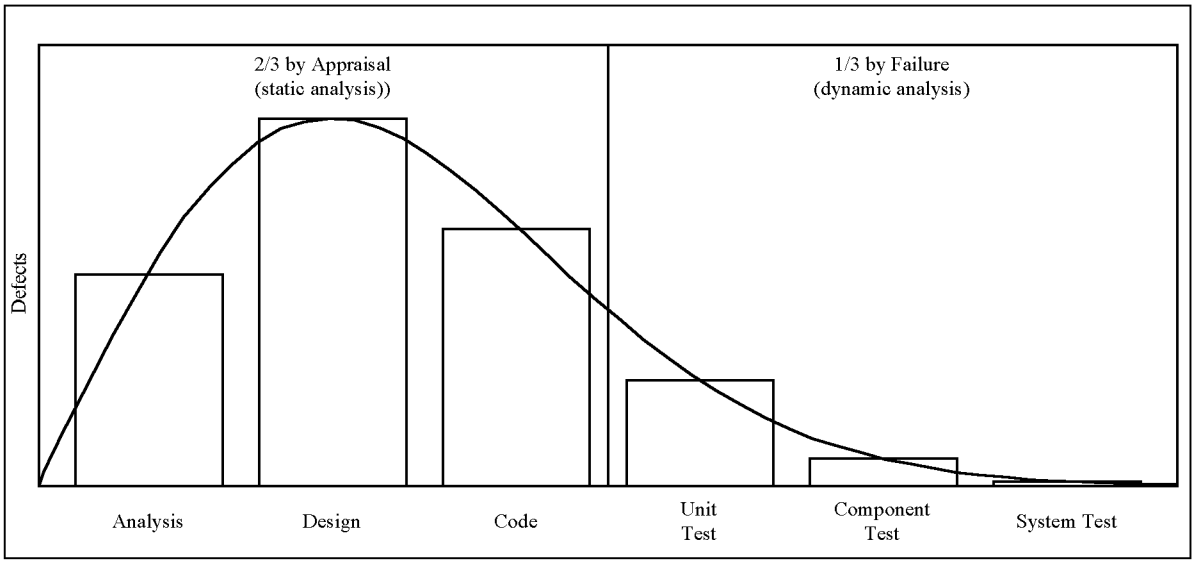


Figure 29. Humphrey's Defect Removal Model (Part II)

Return-on-Investment Model

Since very little ROI data is reported, available, and known for SPI methods, it became necessary to design a new ROI model in order to act as an original source of ROI data, and establish a fundamental framework and methodology for evaluating SPI methods (see Table 87).

Table 87: Basic Quality-Based Return-on-Investment (ROI) Model

	PSP	AT&T Inspection	Basic Inspection	BNR Inspection	GilbHP Inspection	Inspection	Test	Ad Hoc
Software Size	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Start Defects	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Review Efficiency	67%	67%	67%	67%	67%	67%	0%	0%
Review Hours	97	500	708	960	970	1,042	0	0
Review Defects	667	667	667	667	667	667	0	0
Review Detects/Hour	6.86	1.33	0.94	0.69	0.69	0.64	0	0
Review Hours/Defect	0.15	0.75	1.06	1.44	1.46	1.56	0	0
Remaining Defects	333	333	333	333	333	333	1,000	1,000
Test Efficiency	100%	67%	67%	67%	67%	67%	67%	0%
Test Hours	61	1,667	2,361	3,200	3,233	3,472	8,360	0
Test Defects	333	222	222	222	222	222	667	0
Test Defects/Hour	5.47	0.13	0.09	0.07	0.07	0.06	0.08	0
Test Hours/Defect	0.18	7.50	10.63	14.40	14.55	15.63	12.54	0
Validation Defects	1,000	889	889	889	889	889	667	0
Released Defects	0	111	111	111	111	111	333	1,000
Maintenance Hours/Defect	2	75	106	144	146	156	125	125
Development Hours	242	5,088	5,088	5,088	5,088	5,088	5,088	5,088
Validation Hours	158	2,167	3,069	4,160	4,203	4,514	8,360	0
Maintenance Hours	0	8,333	11,806	16,000	16,167	17,361	41,800	125,400
Total Hours	400	15,588	19,963	25,248	25,458	26,963	55,248	130,488
QBreak Even/Ad Hoc	0.78	6.67	6.67	6.67	6.67	6.67	66.67	
PBreak Even/Ad Hoc	6.15	1.65	1.72	1.81	1.81	1.84	10.37	
PBreak Even/Test	14.59	4.79	5.38	6.33	6.38	6.72		
PBreak Even/lnspection	35.96							
Slope (Life Cycle Cost)	25.00	0.64	0.50	0.40	0.39	0.37	0.18	0.08
Y Intercept (w/lnvestment)	-2000.00	- 12.19	-9.52	-7.53	-7.46	-7.05	- 14.12	
HBreak Even/Ad Hoc	80.25	21.58	22.43	23.56	23.61	23.95	135.27	
HBreak Even/Test	80.58	26.47	29.75	34.99	35.24	37.11		
HBreak Even/lnspection	81.44							
ROI/Ad Hoc	1,290:1	234:1	160:1	114:1	113:1	104:1	10:1	
ROI/Test	430:1	67:1	42:1	27:1	26:1	23:1		
ROI/Inspection	143: 1							

This original software quality-based ROI model is a direct extension of an earlier work by Rico (1999) as exhibited by Table 65, that was designed for the express purpose of evaluating ROI. It is a seemingly simple, though intricately complex composite of multiple sub-models, simulating the effects of several SPI methods on efficiency, productivity, quality, cost, break-even points, and ROI. Some of the sub-models represented include a defect removal model and multiple empirical statistical parametric linear and log-linear software cost models.

The defect removal model or defect containment analysis model is an experimentally, scientifically, empirically, and commercially validated software quality-based approach to examining SPI method effectiveness and ROI, introduced and used extensively by several major studies (Kan, 1995; Grady, 1994 and 1997; McGibbon, 1996). The defect removal model is based on statistically modeling software defect populations and the costs and efficiencies of SPI methods for eliminating those same software defect populations. The method involves estimating software defect populations, estimating the efficiency of SPI methods for eliminating software defects, estimating the residual software defect population after applying a particular SPI method, and estimating the cost of eliminating the residual software defect population delivered to customers. If a particular SPI method is expensive and inefficient, then a large and expensive software defect population is delivered to customers. Likewise, if a SPI method is inexpensive and efficient then a small and inexpensive software defect population is delivered to customers. It is these relationships that establish an empirically valid basis for analyzing and comparing the costs, benefits, and ROI of using several similar software quality-based SPI methods. While, Kan warns that defect removal models may not be good for precision software reliability modeling, Kan does identify them as a strategic software quality management tools. Like, Gilb (1993), Grady, and McGibbon, this model has been extended to approximate ROI.

Software Size

The Software Size chosen for this ROI model is 10,000 source lines of code (SLOCs). When this model was originally designed (Rico, 1999), it was thought that this Software Size was too small and non-representative of software-based products and services. Classical Software Sizes ranged in the hundreds of thousands and even millions of SLOCs for second and third generation programming languages (Kan, 1995). However, this number may not be too small, but too large, as modern websites range in the dozens and hundreds of SLOCs. A typical software maintenance release may involve as little as a single SLOC, and average around five to ten SLOCS. So, an input into an ROI model of only 10,000 SLOCs doesn't seem so unreasonably small after all.

Start Defects

The Start Defects chosen for this ROI model are 1,000, or about 10%. This number wasn't arbitrarily chosen, and isn't necessarily unreasonably high. It was based on empirical studies that report software defect insertion rates ranging from 10% to 15%, and occasionally as high as 150% (Humphrey, 1995 and 1996). This ROI model input is a little more controversial, since several authoritative studies report Start Defects as low as 1% to 3%. What these numbers represent is number of defective SLOCs before any kind of Testing. For a person to have a 1% Start Defect rate, would be for only one in a hundred SLOCs to be defective upon initial computer programming. A 10% Start Defect rate means that ten out of a hundred SLOCs are defective upon initial computer programming. Start Defects of 1,000 or 10% is a good and solid assumption. If anything, Start Defects probably exceed 10%, driving the ROI of the best performing SPI methods up rather sharply. Varying this input would make an excellent study.

Review Efficiency

Review Efficiency refers to the ratio of software defects eliminated to remaining software defects, after applying a pre-Test-based SPI method, such as the Personal Software Process (PSP) or the Software Inspection Process. Review Efficiency is also based on estimating statistical defect populations, and evaluating the number of software defects eliminated by a SPI method, versus the estimated residual software defect population. In other words, the number of software defects before and after applying a SPI method are estimated, and the Review Efficiency is estimated based on the number of software defects eliminated by the SPI method. For example, if a software defect population is estimated to be 10 and a SPI method eliminates seven software defects, then the Review Efficiency of the SPI method is estimated to be 70%. Siy (1996) identified three basic kinds of software defect estimation methods, Capture-Recapture, Partial Estimation of Detection Ratio, and Complete Estimation of Detection Ratio. Siy reported Capture-Recapture to be invalid, and Complete Estimation of Detection Ratio to be best. Ironically, Capture-Recapture methods are emerging as one of the most useful techniques for these purposes as reported by the Fraunhofer-Institute (Briand, El Emam, Freimut, and Laitenberger, 1997; Briand, El Emam, and Freimut, 1998; Briand, El Emam, Freimut, and Laitenberger, 1998). Humphrey (2000) also reports that a form of Capture-Recapture methods is the preferred software quality estimation method of the Team Software Process (TSP). Review Efficiencies for the Software Inspection Process are pessimistically reported to hover around 67% (McGibbon, 1996; Gilb, 1993). However, Fagan (1986) reports 93% Review Efficiencies and Weller (1993) reports a high of 98.7%. A Review Efficiency of 67% is very solid assumption, and doesn't risk offending Software Inspection Process Review Efficiency conservatives. In the case of the PSP, a 67% Review Efficiency was derived from a PSP study by Ferguson, Humphrey, Khajenoori, Macke, and Matvya (1997). Increasing Review Efficiency increases the ROI of using the Software Inspection Process, and decreases the ROI of using the PSP. Varying this input would also make an excellent study.

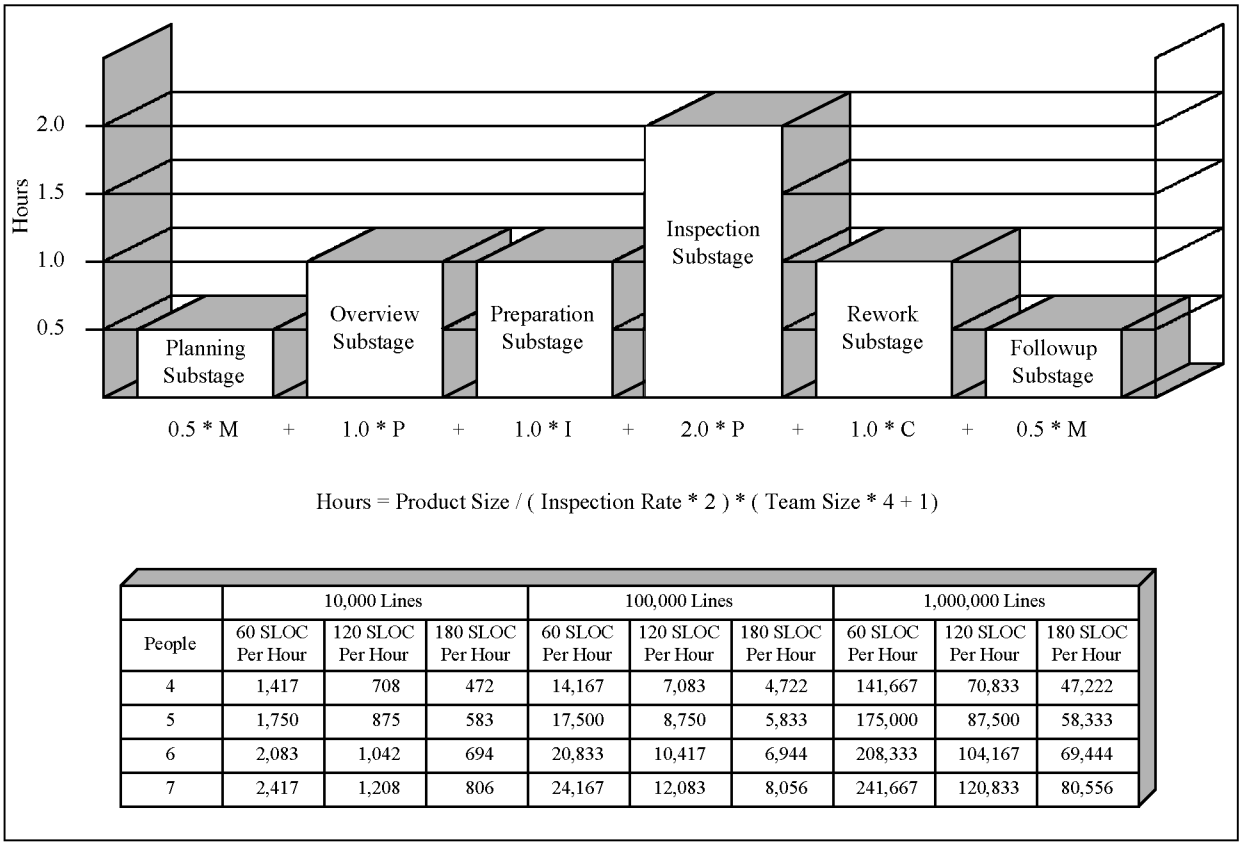
Review Hours

Review Hours were estimated from six-different software cost models (see Table 88). PSP Review Hours came from a custom software cost model developed by Rico (1998), which itself was derived from software productivity data for the PSP, as reported by Hays and Over (1997). Average PSP Review Hours were derived from Hays' and Over's study.

Table 88: Six Software Cost Models for Two Strategies

Method	Software Cost Model	Author	Source
PSP	SLOC /25	Rico (1998)	Hays (1997)
Inspection	SLOC / (Rate * 2) * (Team Size * 4 + 1)	Rico (1993)	Russell (1991)
	SLOC / (Rate * 2) * 25	Grady (1994)	Hewlett Packard
	50 * KSLOC	Barnard (1994)	AT&T
	3 * KSLOC * 4 * 8	Russell (1991)	Bell Northern
	SLOC / (Rate * 2) * (5.76 * Team Size)	Gilb (1993)	Fagan (1976)

Hays and Over reported an average PSP design and code Review Hour percentage of 24.31% for Programs seven, eight, and nine, involving data from 298 engineers. Review Hours of 97 is a factor of 24.31% and 400 total PSP hours as derived from Rico's PSP software cost model for 10,000 SLOCs. Review Hours of 500, 708, 960, 970, and 1,042 were derived from the Software Inspection Process software cost models shown in Table 88 as derived by Rico (1993 and 1996). Figure 30 depicts the architecture of Rico's (1993) Software Inspection Process cost model and how it was designed. Rico used Russell's study (1991) as a basis for designing and validating his model. Rate refers to the number of SLOCs per hour to be reviewed, and was input as 120, twice as much as optimally recommended. Team Size was input as four inspectors. These five Software Inspection Process effort estimates were part of a sensitivity analysis exhibiting the range of costs and benefits for the Software Inspection Process in industrial use, and the associated ROI. While this study refrained from varying Start Defects and Review Efficiency as too low level of a sensitivity analysis, it was felt that exhibiting a wide range of authoritative Software Inspection Process cost models would lend authority and validity to this newly designed ROI model. Average ROIs will be used for later SPI method cost and benefit analyses.



	10,000 Lines			100,000 Lines			1,000,000 Lines		
People	60 SLOC Per Hour	120 SLOC Per Hour	180 SLOC Per Hour	60 SLOC Per Hour	120 SLOC Per Hour	180 SLOC Per Hour	60 SLOC Per Hour	120 SLOC Per Hour	180 SLOC Per Hour
4	1,417	708	472	14,167	7,083	4,722	141,667	70,833	47,222
5	1,750	875	583	17,500	8,750	5,833	175,000	87,500	58,333
6	2,083	1,042	694	20,833	10,417	6,944	208,333	104,167	69,444
7	2,417	1,208	806	24,167	12,083	8,056	241,667	120,833	80,556

Figure 30. Software Inspection Process Cost Model Architecture

Review Defects

Review Defects, that is the number of software defects eliminated by the SPI method from the total estimated software defect population, were estimated by multiplying Start Defects by Review Efficiency, yielding 667 Review Defects out of 1,000 Start Defects. While, these numbers may seem small and inefficient, the economic savings of these relatively conservative numbers will yield extremely beneficial results, as reported later. A Testing-only approach, which is quite common, involves no pre-Test reviews, SPI methods, or Review Efficiencies, nor does an ad hoc software development approach.

Review Defects/Hour

Review Defects/Hour are estimated by dividing estimated Review Defects by the estimated Review Hours, yielding 6.86, 1.33, 0.94, 0.69, 0.69, 0.69, and 0.64. This is actually a phenomenal computation, especially for the PSP. Historically (Russell, 1991; Weller, 1993), the Software Inspection Process has yielded approximately one major software defect per Software Inspection Process hour. However, as evident, the PSP is yielding nearly seven software defects per Review Hour. This will obviously increase the ROI of using the PSP over the Software Inspection Process, Software Test Process, and ad hoc methods. And, this number both challenges and validates an entire body of research from the likes of Fagan (1976 and 1986), Humphrey (1989), Russell (1991), Weller (1993), and Siy (1996). Fagan, Humphrey, Russell, and Weller claim that the Software Inspection Process is one of the most efficient review, defect removal, or static analysis methods in existence, dwarfing defect removal efficiencies of individual review methods. University of Maryland researchers, epitomized by Siy, claim that the Software Inspection Process is no more efficient, but rather equally as efficient, as individual reviews. Ferguson, Humphrey, Khajenoori, Macke, and Matvya (1997) have demonstrated that both the industrial and academic researchers weren't completely correct. Ferguson, Humphrey, Khajenoori, Macke, and Matvya have shown that individual review processes can be seven times more efficient than the Software Inspection Process, seemingly eliminating the team dynamic as a contributing factor to Review Efficiency. Once again, Testing and ad hoc methods don't yield pre-Test Review Defects/Hour.

Review Hours/Defect

Review Hours/Defect, signifying how many hours are required to find a software defect using the prescribed SPI method, are estimated by dividing estimated Review Hours by estimated Review Defects, yielding 0.15, 0.75, 1.06, 1.44, 1.46, and 1.56. The PSP yields a software defect every nine minutes, while the Software Inspection Process takes over an hour and a half to yield a software defect, in the worst case, a difference of over 10:1 in the PSP's favor. Of course, Testing and ad hoc methods don't yield pre-Test Review Hours/Defect.

Remaining Defects

Remaining Defects refer to the estimated residual software defect population following application of a pre-Test SPI method such as the PSP or the Software Inspection Process, yielding an estimated pre-Test software defect population of 333, except for the Software Test Process and ad hoc methods which start at 1,000. Once again, this number is derived from estimated total software defect populations, less estimated Review Efficiencies. Higher Review Efficiencies using the Software Inspection Process are practically possible, as reported by Fagan (1986), Russell (1991), and Weller (1993), reaching almost 99% in some cases. A best-in-class Review Efficiency of nearly 99% would result in an estimated 10 Remaining Defects and would change the outcomes of the ROI model exhibited by Table 87.

Test Efficiency

Test Efficiency refers to the ratio of software defects eliminated to remaining software defects, after applying a Software Test Process. Test Efficiency is also based on estimating statistical defect populations, and evaluating the number of software defects eliminated by Testing, versus the estimated residual software defect population. In other words, the number of software defects before and after applying Testing are estimated, and the Test Efficiency is estimated based on the number of software defects eliminated by Testing. For example, if a software defect population is estimated to be 10 and Testing eliminates seven software defects, then the Test Efficiency estimated to be 70%. The PSP yields a Test Efficiency of 100% as reported by Ferguson, Humphrey, Khajenoori, Macke, and Matvya (1997), which is further corroborated by a much more detailed study by Hays and Over (1997). 100% is remarkably impressive for Testing, as is probably due to the highly prescriptive nature of the PSP. Test Efficiency usually averages around 67% for best-in-class organizations as reported by Humphrey (1989), and is typically much lower as reported by preliminary findings by Burnstein, Homyen, Grom, and Carlson (1998). Yamamura (1998) and Asada and Yan (1998) report much higher Test Efficiencies reaching better than 99%, but are certainly not the norm. Sommerville (1997) reports that organizations typically allocate 30% to 40% of organizational resources to Test. But, in fact organizations typically allocate about 1% of organizational resources to ad hoc and highly unstructured Testing yielding Test Efficiencies of much lower than 67%, as alluded to by Burnstein, Homyen, Grom, and Carlson. In fact, a Test Efficiency of 67% is actually far too generous, and lowering this to 5% or 10% would not be unreasonable. Even some best-in-class Testing approaches don't estimate statistical defect populations, basing software quality estimation decisions on the use of reliability and exponential growth models (Asada and Yan, 1998), potentially grossly underestimating and ignoring software defect populations. Other best-in-class Testing approaches that do estimate statistical software defect populations rely largely on Testing to eliminate them (Yamaura, 1998), spending as much as 10X more than necessary. It is the economic inefficiency of Testing that is ignored or unknown by Testing advocates (Yamaura; Asada and Yan; Burnstein, Homyen, Grom, and Carlson), because Testing costs more than 10X the effort of Inspections. Ad hoc methods have no Test Efficiency.

Test Hours

Test Hours are estimated to be the product of estimated Remaining Defects, Test Efficiency, and Review Defects/Hour (multiplied by 10), for the Software Inspection Process and the Software Test Process, yielding 1,667, 2,361, 3,200, 3,233, 3,472, and 8,360. Test Efficiency for the Software Test Process was derived from the same basic model, except that Review Defects/Hours were an average of the five Software Inspection Process Review Defects/Hour. Hays and Over (1997) reported an average PSP Test Hour percentage of 15.23% for Programs seven, eight, and nine, involving data from 298 engineers. Test Hours of 60.92 is a factor of 15.23% and 400 total PSP hours as derived from Rico's (1998) PSP software cost model for 10,000 SLOCs. Ad hoc methods have no Test Hours.

Test Defects

Test Defects, that is the number of software defects eliminated by Testing from the estimated software defect population, were estimated by multiplying Remaining Defects by Test Efficiency, yielding 333 for the PSP-based Testing, 222 for post-Inspection-based Testing, and 667 for Testing alone. Ad hoc methods have no Test Defects.

Test Defects/Hour

Test Defects/Hour are estimated by dividing estimated Test Defects by the estimated Test Hours, yielding 5.47, 0.13, 0.09, 0.07, 0.07, 0.06, and 0.08, for the PSP, post-Inspection-based Testing, and Testing alone. What this shows is that post-Inspection-based Testing and Testing alone yield about a tenth of a defect per Test Hour, while PSP-based Testing yields nearly six defects per Test Hour, a difference of nearly 66:1 in the PSP's favor. Ad hoc methods have no Test Defects/Hour.

Test Hours/Defect

Test Hours/Defect, signifying how many hours are required to find a software defect using the Software Test Process, are estimated by dividing estimated Test Hours by estimated Test Defects, yielding 0.18, 7.5, 10.63, 14.4, 14.55, 15.63, and 12.54, for PSP-based Testing, post-Inspection-based Testing, and Testing alone. The PSP yields a software defect every 11 minutes, while post-Inspection-based Testing and Testing alone require over 12.5 hours to yield a defect. Ad hoc methods have no Test Hours/Defect.

Validation Defects

Validation Defects are the sum of Review Defects and Test Defects, signifying the total number of estimated software defects eliminated by the various SPI methods, yielding, 1,000 or 100% for the PSP, 889 or 89% for Inspections and post-Inspection-based Testing, and 667 for Testing alone. It's remarkable that the PSP is reported to have a nearly 100% defect removal efficiency as reported by Ferguson, Humphrey, Khajenoori, Macke, and Matvya (1997). While, the PSP is reported to have a Review Efficiency of only 67%, the PSP's Testing approach is reported to have a 100% Test Efficiency. Once again, this can only be attributed to the highly structured and prescriptive nature of the PSP. For the PSP, it's time to start analyzing the benefits. But, for Inspections, Testing, and ad hoc approaches, it's time to begin weighing the costs of inefficiency. Ad hoc methods, in the worst case, have no Validation Defects. This is very significant, because it is theorized that more than 95% of world-wide software producing organizations neither use Inspections or Test, as alluded to by the Software Engineering Institute (1999) and Burnstein, Homyen, Grom, and Carlson (1998). What this means is that the typical software producing organizations probably delivers the majority of a rather significant software defect population to its customers. It also means, that it wouldn't be typical for software producing organizations to be yielding the Validation Defects as exhibited by the PSP, Inspections, and even the much maligned Testing.

Released Defects

Released Defects are the number of estimated Start Defects less Review Defects and Test Defects for the various SPI methods, yielding 0.0 for the PSP, 111 for Inspections and post-Inspection-based Testing, 333 for Testing alone, and 1,000 for ad hoc methods. A low Release Defect value is the signature of a good quality-based SPI method, such as the PSP, Inspections, and even good Testing. Unfortunately, Release Defects are the strategic metric ignored by modern practitioners and even Testing enthusiasts, who couldn't possibly cost-effectively remove estimated software defect populations, and end up ignoring Released Defects.

Maintenance Hours/Defect

Maintenance Hours/Defect are estimated by multiplying Test Hours/Defect by 10, yielding 2, 75, 106, 144, 146, 156, and 125, for the PSP, Inspections, and Test. What this shows is that software maintenance costs an order of magnitude more than Testing, as commonly attested to by Russell (1991), Weller (1993), Kan (1995), and McGibbon (1996). Since ad hoc methods don't have Test Hours/Defect, 125 is assumed to be the Maintenance Hours/Defect, which is an average of post-Inspection-based Testing estimates.

Table 89: Five Software Cost Models for Estimating Software Development Effort

Software Cost Model	Author	Source	Form	Output
SLOC /25	Rico (1998)	Hays (1997)	Linear	Hours
3 * KSLOC ^ 1.12	McGibbon (1997)	Boehm	Log-Linear	Months
5.2 * KSLOC A 0.91	McGibbon (1997)	Walston/Felix	Log-Linear	Months
5.5 + 0.73 * KSLOC ^ 1.15	McGibbon (1997)	Bailey/Basili	Log-Linear	Months
5.288 * KSLOC ^ 1.047	McGibbon (1997)	Doty	Log-Linear	Months

Development Hours

Development Hours refer to the complete effort to produce a software product, and were estimated from five different linear and log-linear empirical statistical parametric software cost estimation models (see Table 89), yielding 242 for the PSP and 5,088 for Inspections, Testing, and ad hoc methods. Rico's (1998) PSP software cost model derived from a study by Hays and Over (1997) was used to yield the 242 PSP Development Hours. Inspections and Testing are only software validation methods, and their associated effort reported in Review Hours doesn't account for total software development effort. Thus, it is necessary to estimate the total software development effort and add it to Inspection and Test Effort, in order to arrive at an estimate that can be compared to the PSP and ad hoc methods for analytical purposes. In this case, it was decided to use an average of software cost models by Boehm, Walston/Felix, Bailey/Basili, and Doty, as reported by McGibbon (1997). McGibbon's models output staff months, so it was necessary to transform their output into staff hours by multiplying each software cost model output by 2,080/12, before averaging them. Since Sommerville (1997) reports that 30% to 40% of software development effort is Testing, a conservative 25% was removed from the software cost model estimates before averaging them. This last transformation was necessary to remove validation cost built into each model.

Validation Hours

Validation Hours are the sum of estimated Review Hours and Test Hours, representing the total validation effort for PSP, Inspection, and Testing, yielding 158, 2,167, 3,069, 4,160, 4,203, 4,514, and 8,360. There are two surprising elements of these estimates, the unusually small total Validation Hours for the PSP, yielding an advantage of nearly 22:1 in the PSP's favor over Inspections, and a 53:1 PSP advantage over Testing. Ad hoc methods are assumed to have no Validation Hours.

Maintenance Hours

Maintenance Hours are estimated to be the product of Released Defects and Maintenance Hours/Defect, representing only the cost of eliminating software defect populations estimated to have escaped elimination, primarily by Inspections, Testing, and ad hoc methods, yielding 0, 8,333, 11,806, 16,000, 16,167, 17,361, 41,800, and 125,400. A study by Ferguson, Humphrey, Khajenoori, Macke, and Matvya (1997) estimates that the PSP allows no defects to escape, thus resulting in no software maintenance effort to remove residual software defects. Inspection averages a phenomenally large 13,933 software maintenance hours to remove residual software defects. This is the part of the equation that is dangerously ignored by lightweight Testing methods such as those advocated by Asada and Yan (1998) or dealt with by Testing alone, as in the case of Yamaura (1998). Ad hoc methods yield a seemingly astronomical software maintenance cost of 125,400 hours. This study now begins to explode the contemporary myth that high software process maturity is more expensive than low software process maturity as Rico (1998) attempts to debunk SPI myths as well, and explode myths that SPI methods like PSP and Inspections cost more than not using them at all.

Total Hours

Total Hours are estimated to be the sum of Development Hours, Validation Hours, and Maintenance Hours, for the PSP, Inspections, Testing, and ad hoc methods, yielding 400, 15,588, 19,963, 25,248, 25, 458, 26,963, 55,248, and 130,488. Total Hours for the PSP are a miniscule 400, compared to an average Inspection-based cost of 22,644 hours, for a 57:1 PSP advantage. Total Testing-based Hours are 138X larger the PSP, and a surprisingly small 2.44X larger than Inspection-based hours. Total ad hoc hours are 326X larger than PSP, 2.36X larger than Testing-based hours, and 5.76X larger than Inspection-based hours.

QBreak Even/Ad Hoc

QBreak Even/Ad Hoc is estimated by dividing the Review Hours or Testing Hours by the Maintenance Hours/Defect, which is based on estimating software maintenance hours saved or avoided by applying the SPI methods, yielding 0.78 hours for the PSP, 6.67 hours for Inspections, and 66.67 hours for Testing. QBreak Even/Ad Hoc is a special software quality-based break even point algorithm, which derives its estimate based the number of defects eliminated by a particular SPI method in order to pay for itself. PSP QBreak Even/Ad Hoc was uniquely calculated by dividing its Review Hours by the average Inspection-based Maintenance Hours/Defect, in order to have a normalizing effect for comparison to Inspection-based QBreak Even/Ad Hoc. Otherwise, the PSP QBreak Even/Ad Hoc would appear rather large, because the cost of PSP-based software maintenance is 63X lower than Inspection-based software maintenance. QBreak Even/Ad Hoc is one of the single most interesting results yielded by this study, because it averages a ridiculously low 14.4 hours. This means that after only 14 hours into the application of the PSP, Inspections, and Testing, each of these SPI methods have already paid for themselves based on the QBreak Even/Ad Hoc algorithm. Let's state this another way, an organization could apply these methods without additional special funding and come in under budget. Yet another contemporary myth surrounding the application of SPI methods has been surprisingly and unexpectedly exploded or shattered by this study. While, QBreak Even/Ad Hoc is a valid software quality-based model for break even analysis, it is unconventional, demanding a more conventional break-even algorithm called PBreak Even.

PBreak Even/Ad Hoc

PBreak Even/Ad Hoc, signifying "productivity-based" break even point, is estimated by dividing the investment in the higher productivity SPI method by the difference in SPI method productivity, and multiplying the result by the product of the SPI method productivity, as shown in Figure 31. This SPI break even point algorithm is a new custom model created especially for this study, based on classical linear programming methods as found in textbooks, such as those by Turban and Meridith (1994) and Garrison and Noreen (1997). PBreak Even/Ad Hoc yields 6.15, 1.65, 1.72, 1.81, 1.81, 1.84, and 10.37 break even SLOCs for SPI methods over ad hoc software development approaches. PSP's PBreak Even/Ad Hoc is 6.15 SLOCs, while Inspection-based development averages 1.77 SLOCs, and Testing-based development needs to produce a mere 10.37 SLOCs before each of these SPI methods pay for themselves, based on classical productivity analysis and data derived from Table 87. If it hasn't started to sink in yet, these numbers are astonishingly low, given that three decade long resistance to SPI methods is rooted in the myth and fallacy that SPI methods never pay for themselves, and must be used at a loss in profit. The plain fact of the matter is that SPI method benefits in quality and productivity can be invested in and achieved while still yielding an excellent profit. SPI doesn't seem to be the "long journey" that it once was believed to be (Billings, Clifton, Kolkhorst, Lee, and Wingert, 1994).

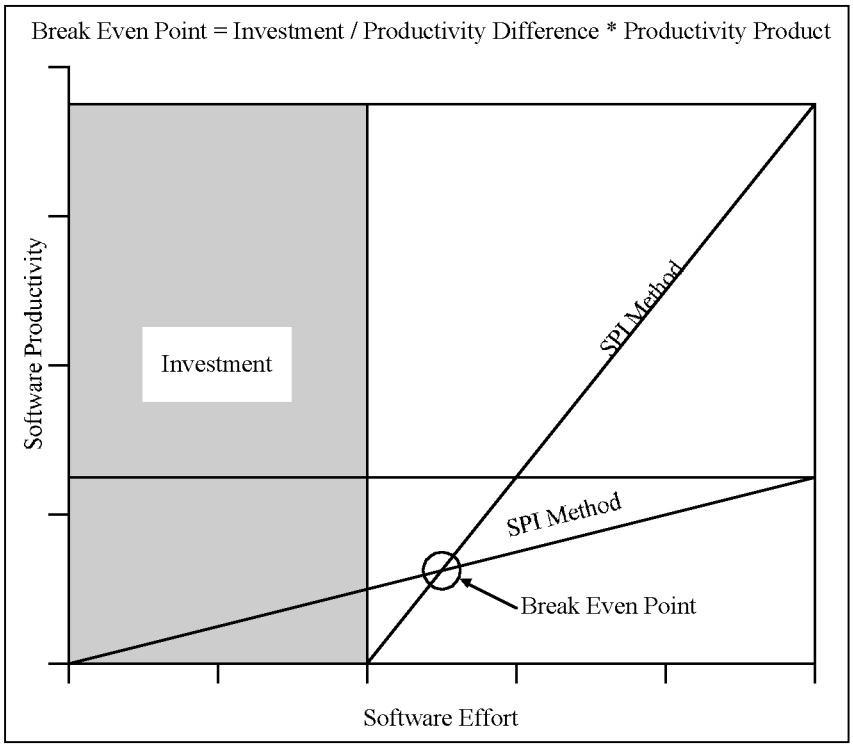


Figure 31. Custom Software Process Improvement (SPI) Break Even Model

PBreak Even/Test

PBreak Even/Test, once again, is estimated by dividing the investment in the higher productivity SPI method by the difference in SPI method productivity, and multiplying the result by the product of the SPI method productivity, as shown in Figure 31. PBreak Even/Test yields 14.59, 4.79, 5.38, 6.33, 6.38, and 6.72 break even SLOCs for SPI methods over Testing. PSP's PBreak Even/Test is 14.59 SLOCs, while Inspection-based development need only produce an average of 5.92 SLOCs before overtaking the benefits of Testing alone. The reason the PSP and Inspection PBreak Even/Test rose slightly, but insignificantly, is because of the increased productivity of Testing over ad hoc software development approaches.

PBreak Even/Inspection

PBreak Even/Inspection is estimated by dividing the investment in the higher productivity SPI method by the difference in SPI method productivity, and multiplying the result by the product of the SPI method productivity, as shown in Figure 31. PBreak Even/Inspection yields 35.96 break even SLOCs for PSP over an average of Inspection productivity. The PSP need only produce 35.96 SLOCs before overtaking the benefits of Inspection-based development alone. The reason the PSP PBreak Even/Inspection rose sharply, but still insignificantly, is because of the increased productivity of Inspection over Testing. This study has examined two break even point algorithms, one based on software quality and the other based on productivity, yielding 19.5 SLOCs (0.78 PSP hours by 25 PSP SLOCs per Hour) for the first and 35.96 SLOCs for the second. One of the reasons, other than being fundamentally different ROI algorithms and approaches, is that QBreak Even doesn't factor in initial SPI method investment costs. All of these results are first-time findings yielded by this study. They were not anticipated and were quite surprising. It took several months of effort to analyze the preliminary findings and validate the results, which are likely, due to the fact that software development isn't a capital-intensive industry, like manufacturing.

Slope (Life Cycle Cost)

Slope (Life Cycle Cost) is a linear model or equation representing total software life cycle costs, estimated by dividing Software Size by Total Hours, yielding 25, 0.64, 0.5, 0.4, 0.39, 0.37, 0.18, and 0.8, for each of the SPI methods (including ad hoc). The larger the slope is, the higher the productivity. Larger slopes should always overtake smaller slopes at some point in time. The trick is analyzing whether a higher productivity SPI method will overtake lower productivity methods in a reasonable length of time. That is, before the schedule expires. That doesn't seem to be a problem with these SPI methods, as they overtake the lower productivity ones in a matter of hours, not even days.

Y Intercept (w/Investment)

Y Intercept (w/Investment) is a key term in a new linear model or equation representing total software life cycle costs, factoring in initial SPI method investment costs, yielding –2000, –12.19, –9.52, –7.53, –7.46, –7.05, and –14.12, for each of the SPI methods (except ad hoc). The literal Y Intercept (w/Investment) equation is, (Slope (Life Cycle Cost) – Slope (Life Cycle Cost) * (Investment * 2 + 1)) / 2. The higher the Y Intercept (w/Investment) is, the higher the initial investment cost is and the later it will break even.

HBreak Even/Ad Hoc

HBreak Even/Ad Hoc determines the break even point in effort for each SPI method over ad hoc approaches, estimated by dividing the sum of PBreak Even/Ad Hoc and Y Intercept (w/Investment) by the Slope (Life Cycle Cost), yielding 80.25, 21.58, 22.43, 23.56, 23.61, 23.95, and 135.27 hours. Now we start getting to some meaningful numbers. Again, HBreak Even/Ad Hoc represents the effort required to break even using each SPI method over ad hoc approaches. PSP requires 80.25 hours of investment effort to break even, over ad hoc approaches, based on total software life cycle costs. Be careful, not to mistakenly equate HBreak Even/Ad Hoc with the initial investment effort itself. For instance, the initial investment effort for PSP is 80 hours, while PSP HBreak Even/Ad Hoc is 80.25. The reason that the PSP requires only 15 minutes more effort over its initial investment effort is because the PSP is a highly productive SPI method, when total software life cycle costs are factored in. It is conceivable that a SPI method could have a much longer HBreak Even/Ad Hoc because its associated productivity is very low.

HBreak Even/Test

HBreak Even/Test determines the break even point in effort for each SPI method over Test, estimated by dividing the sum of PBreak Even/Test and Y Intercept (w/Investment) by the Slope (Life Cycle Cost), yielding 80.58, 26.47, 29.75, 34.99, 35.24, and 37.11 hours. Again, HBreak Even/Test represents the effort required to break even using each SPI method over Test. PSP requires 80.58 hours of investment effort to break even, over Test approaches, based on total software life cycle costs. See the previous paragraph for a caution on interpreting this result.

HBreak Even/Inspection

HBreak Even/Inspection determines the break even point in effort for PSP over Inspection, estimated by dividing the sum of PBreak Even/Inspection and Y Intercept (w/Investment) by the Slope (Life Cycle Cost), yielding 81.44 hours. Again, HBreak Even/Inspection represents the effort required to break even using PSP over Inspection. PSP requires 81.44 hours of investment effort to break even, over Inspection approaches, based on total software life cycle costs. PBreak Even/Inspection highlights an important point. Notice that PBreak Even/Inspection is 35.96 while Hbreak Even/Inspection is 81.44. And, PBreak Even/Inspection is 2.46X larger than PBreak Even/Test. However, HBreak Even/Inspection is merely

1.01X larger than HBreak Even/Test. What this means is that for an additional 8.4 minutes of PSP effort, PSP not only breaks even over Test, but highly lauded Inspections as well.

ROI/Ad Hoc

ROI/Ad Hoc is estimated by subtracting Maintenance Hours for each SPI method from Maintenance Hours for ad hoc methods and then dividing the result by Review Hours or Test Hours, characterizing the difference as ROI, yielding 1,290:1, 234:1, 160:1, 113:1, 104:1, and 10:1. PSP's ROI continues the trend of astonishing cost and benefit analysis, while Inspections average a sobering 145:1 advantage over ad hoc methods, and Testing brings up the rear with a 10:1 ratio. Inspections have carried an unjustifiable stigma as being too expensive to implement, while this study shows that it costs more not to use Inspections than to use them. Humphrey's (2000) Team Software Process (TSP), one of the newest team-based software quality methodologies continues to feature Inspections as the principal validation method.

ROI/Test

ROI/Test is estimated by subtracting Maintenance Hours for each SPI method from Maintenance Hours for Testing and then dividing the result by Review Hours, characterizing the difference as ROI, yielding 430:1, 67:1, 42:1, 27:1, 26:1, and 23:1. PSP's ROI/Test is an extremely high 430:1, barely justifying improvement of the Testing process alone, while Inspections average a 37:1 ROI advantage over Testing.

ROI/Inspection

ROI/Inspection is estimated by subtracting PSP Maintenance Hours from the average of Inspection-based Maintenance Hours and then dividing the result by PSP Review Hours, characterizing the difference as ROI, yielding an ever impressive 143:1 PSP ROI advantage over Inspections. The PSP still garners a seemingly astronomical ROI/Inspection.

Break Even Point Model

Eight software life cycle cost models and seven software life cycle cost models with initial investment effort factored into them were designed for the seven SPI methods and ad hoc approach, previously identified in the ROI model, for supporting graphical break even point analyses (see Table 90).

Table 90: Graphical Break Even Point Analysis with Software Life Cycle Cost Models

Method	Life Cycle Cost *	Life Cycle Cost **
Ad Hoc	SLOC /0.08	
Test	SLOC / 0.18	(SLOC + 14.12) / 0.18
HP Inspection	SLOC /0.37	(SLOC + 07.05) /0.37
Gilb Inspection	SLOC /0.39	(SLOC + 07.46) /0.39
BNR Inspection	SLOC /0.40	(SLOC + 07.53) /0.40
Basic Inspection	SLOC /0.50	(SLOC + 09.52) /0.50
AT&T Inspection	SLOC /0.64	(SLOC + 12.19) /0.64
PSP	SLOC /25.0	(SLOC + 2000) / 25.0

* Yields effort in hours
** Yields effort in hours (includes initial investment effort)

While only an afterthought at first, minor break even analyses were initially performed. However, initial break even analyses proved instrumental to understanding fundamental SPI method costs and benefits, as well as management implications of implementing, and even not implementing various SPI methods. The first approach was to conduct graphical break even analyses. These attempts were initially inadequate and led to mathematical break even analyses, and the formulation of QBreak Even. QBreak Even didn't support classical break even analyses, because it didn't factor in initial investment costs. This led to the formulation of PBreak Even, which did factor in initial investment costs, calculating the number of units (SLOCs) that had to be produced to break even. Further graphical analyses indicated that break even analyses were somewhat inadequate and initially misinterpreted, leading to the formulation of HBreak Even. HBreak Even, like PBreak Even factored in initial investment costs, calculating effort required to break even. So, both mathematical and graphical break even analyses were instrumental to identifying break even points, formulating break even algorithms and models, validating break even analyses, and making correct interpretations. Graphical break even analyses using software life cycle cost models identified in Table 90, that may now be considered the lynch pin of this entire study—certainly the ROI model, are now illustrated.

Once again, graphical break even analysis proved infinitely valuable to finding some initial problems in software life cycle cost model formulation, precision calibration in the graphical analysis itself, and overall validation of PBreak Even and HBreak Even equations and models. For instance, the axes on the graphs were initially formatted for display as whole numbers without fractional or decimal portions. So, when the break-even points were circled and identified, this simple technique pointed out multiple problems or errors. The graphical solution didn't match the mathematical solution. The second problem was with the software life cycle cost models in Table 90. The cost models were placed there for a reason, to serve as the basis for graphical analyses and solutions. That is, the cost models were exhibited in order to validate the break even analysis model. But, when the cost models were exercised, they yielded incorrect values. Without graphical analyses, it may have been difficult at best to identify mathematical and interpretation errors. In fact, it was more of an iterative process of mathematical modeling, graphical modeling, mathematical modeling, graphical modeling, and so on.

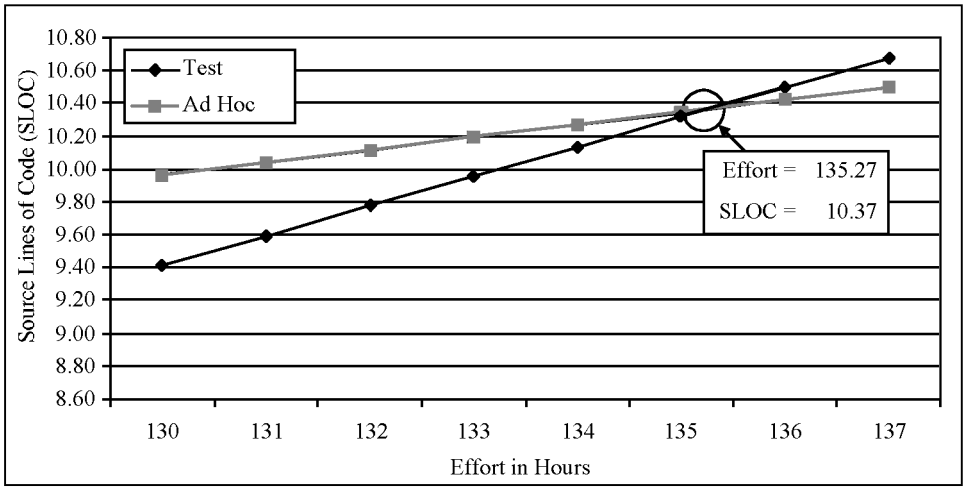


Figure 32. Test vs. Ad Hoc Graphical Break Even Analysis

Test vs. Ad Hoc

Testing-based SPI methods overtake ad hoc software development after only 135.25 hours of effort (as shown in Figure 32). This is both surprising and perhaps troubling to some. It's surprising, because for large projects, little more than three staff weeks are needed to both train Testers and have Testing pay for itself. For large projects, the Testing HBreak Even/Ad Hoc more than justifies investment in sound Testing methodologies. For small projects and websites, three staff weeks may just about consume an entire program's cost. Keep in mind, however, that this graph only represents a one-time "startup" cost. Once sound Testing methodologies have been invested in, then Testing begins paying for itself after only one hour, because its slope is greater than the slope of ad hoc approaches. Keep in mind, that this break even analysis is only calibrated for the cost of one individual. None of the software life cycle cost models were derived to input variable size organizational groups. It's not to say that more robust break even equations and models can't be formulated. But, that the software life cycle models in this study weren't designed for that purpose. This would be a great independent study, developing software life cycle cost models for variable organizational sizes. Once again, these models were for analytical purposes, and are not currently scaleable for industrial use, as shown.

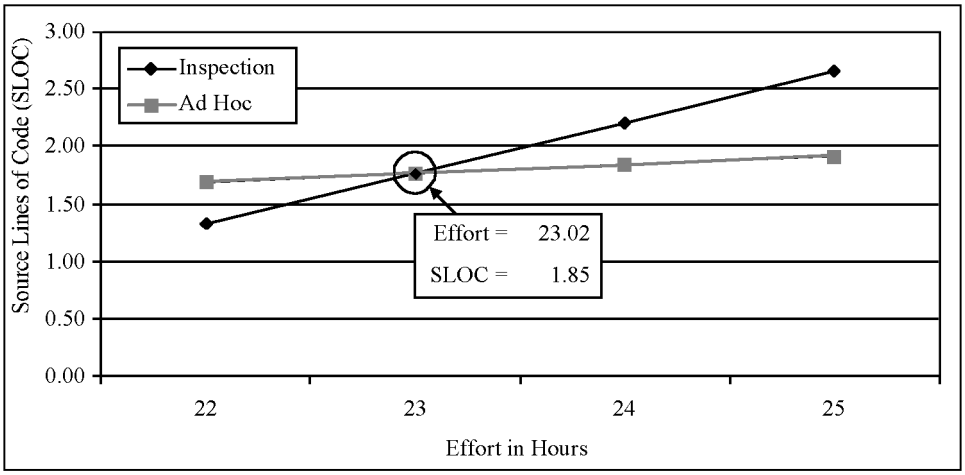


Figure 33. Inspection vs. Ad Hoc Graphical Break Even Analysis

Inspection vs. Ad Hoc

Inspection-based SPI methods overtake ad hoc software development after only 23.02 hours of effort (as shown in Figure 33). Inspection-based SPI methods seem to break even over ad hoc approaches 5.88X sooner than Test-based SPI methods. This is primarily the result of two reasons, Inspection-based SPI methods are reported to have a lower initial investment cost, and Inspection-based SPI methods are 225% more productive than Test-based SPI methods. Once again, these models are for analytical purposes and weren't designed to be scaleable for multiple size organizational use, as is.

PSP vs. Ad Hoc

PSP-based SPI methods overtake ad hoc software development after only 80.25 hours of effort (as shown in Figure 34). PSP-based SPI methods seem to break even over ad hoc approaches 3.49X later than Inspection-based SPI methods, because initial PSP investment costs are 4.21 times higher than those of Inspection. However, PSP is 54.35X more productive than Inspection-based SPI methods. Once again, these models are for analytical purposes and weren't designed to be scaleable for multiple size organizational use, as is.

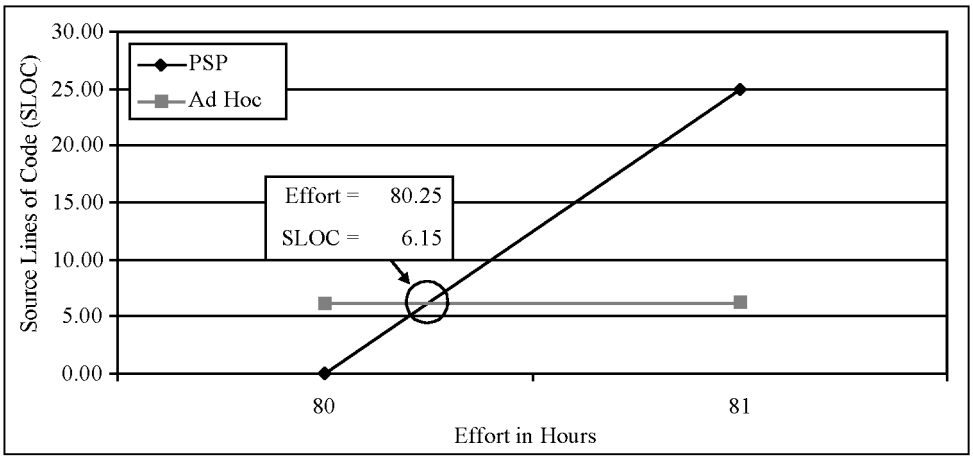


Figure 34. PSP vs. Ad Hoc Graphical Break Even Analysis

Inspection vs. Test

Inspection-based SPI methods overtake Test-based SPI methods after 32.71 hours of effort (as shown in Figure 35). Inspection-based SPI methods are 2.56X more productive than Test-based SPI methods, though the graphical analysis doesn't seem to illustrate the disparity in productivity. This is probably because of the scale of the graph, with increments of single digit hours and SLOCs. This graph doesn't seem to have the dramatic spread between productivity slopes, such as those exhibited by the PSP. However, 32.71 hours are less than a single staff week, and are no less impressive for projects of all sizes, small, medium, and large. Once again, these models are for analytical purposes and weren't designed to be scaleable for multiple size organizational use, as is. Keep in mind that these break even point models only factor in a one-time initial investment cost.

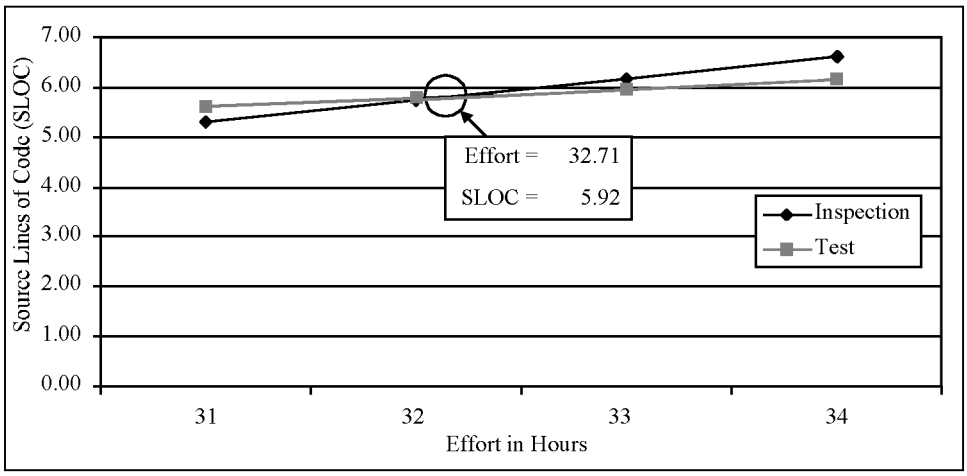


Figure 35. Inspection vs. Test Graphical Break Even Analysis

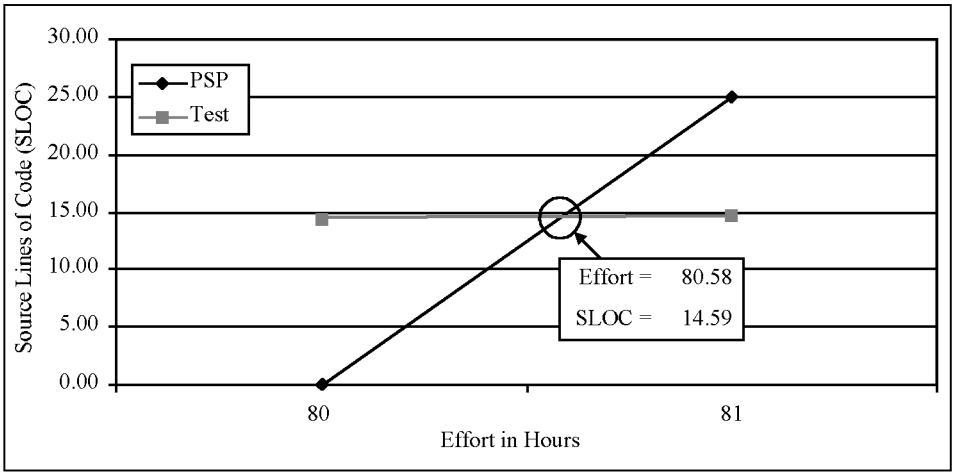


Figure 36. PSP vs. Test Graphical Break Even Analysis

PSP vs. Test

PSP-based SPI methods overtake Test-based SPI methods after 80.58 hours of effort, and then rapidly dwarf the productivity of Testing (as shown in Figure 36). Note how flat the Testing-based productivity curve is, and how sharply pronounced the PSP productivity curve is. PSP's productivity 138.89X greater than that of Test's productivity. Keep in mind that the 80.58 hours of initial effort are only for one-time initial investment costs. PSP's associated productivity seems to make it the SPI method of choice. It's hard to ignore the merits of the PSP's performance characteristics. Once again, these models are for analytical purposes, and aren't designed to be scaleable for multiple size organizational use.

PSP vs. Inspection

Finally, PSP-based SPI methods overtake Inspection-based SPI methods after 81.44 hours of effort, and then rapidly dwarf the productivity of Inspections, much like PSP performs against Testing (as shown in Figure 37). But, then remember how close the Inspection and Test graphs were in Figure 35. Once again, note how flat the Inspection-based productivity curve is, and how sharply pronounced the PSP productivity curve is. PSP's productivity 54.35X greater than that of Inspection's productivity. Keep in mind that the 81.44 hours of initial effort are only for one-time initial investment costs. And finally don't forget, these models are for analytical purposes, and aren't designed to be scaleable for multiple size organizational use.

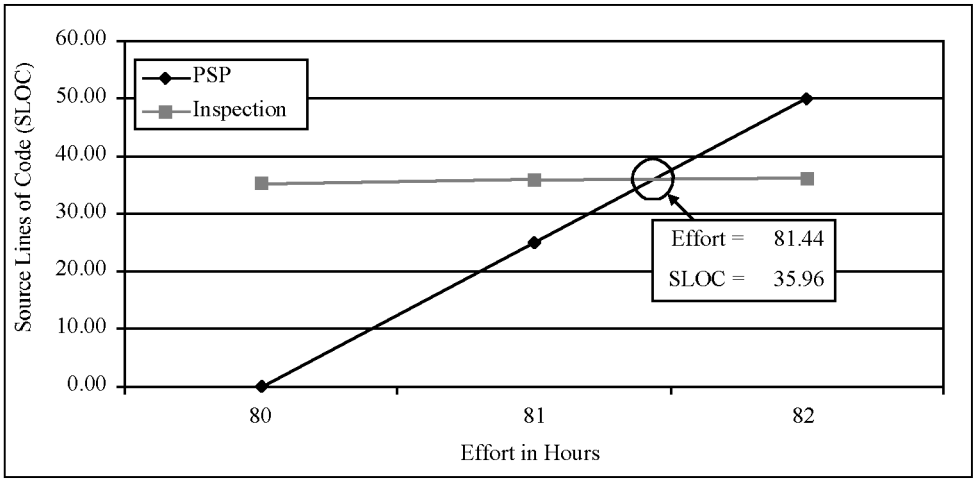


Figure 37. PSP vs .Inspection Graphical Break Even Analysis

Cost and Benefit Model

The Cost and Benefit Model is a composite summary of economic analyses as a result of analyzing the eight SPI strategies, PSP, Clean Room, Reuse, Defect Prevention, Inspections, Testing, CMM, and ISO 9000 (as shown in Table 91).

Table 91: Costs and Benefits of Eight Software Process Improvement (SPI) Strategies

	PSP	Cleanroom	Reuse	Prevent	Inspect	Test	CMM	ISO	Average
Breakeven Hours	80	53	8,320	527	7	3,517	10,021	4,973	3,437
Training Hours/Person	80	201	3,316	31	19	78	227	64	502
Training Cost/Person	$7,456	$8,089	$298,440	$5,467	$1,794	$13,863	$12,668	$9,475	$44,656
Effort (Hours)	400	3,245	16,212	2,100	836	37,510	94,417	53,800	26,065
Cycle Time Reduction	164.03x	3.53x	3.69x	1.69x	5.47x	6.15x	2.99x	1.14x	23.58x
Productivity Increase	109.49x	4.27x	2.70x	1.88x	5.47x	6.15x	2.92x	1.13x	16.75x
Quality Increase	253.62x	42.22x	4.33x	4.77x	9.00x	5.75x	4.55x	12.44x	42.09x
Return-on-lnvestment	1,290: 1	27: 1	3: 1	75: 1	133: 1	9: 1	6: 1	4: 1	193: 1

As explained in the Methodology introduction, the Cost and Benefit Model is a complex composite of multiple models, most notably the Costs and Benefits of Alternatives (appearing later in this section), Break Even Point Model, Return-on-Investment Model, and ultimately the Defect Removal Model. The Cost and Benefit Model, as carefully explained throughout the Methodology, is also composed of a complex network of predictive empirical statistical parametric cost estimation models. And, of course, the Cost and Benefit Model is composed of empirically based costs and benefits extracted or derived from authoritative studies.

The results of Table 91 will be addressed by the Data Analysis chapter, and won't be explained in detail here. However, differences between best and worst performers include 1,432X for Break Even Hours, 175X for Training Hours/Person, 40X for Training Cost/Person, 236X for Effort (Hours), 144X for Cycle Time Reduction, 97X for Productivity Increase, 59X for Quality Increase, and 430X for Return-on-Investment.

Table 92: Costs and Benefits of Personal Software Process (PSP)

	ROI Model	CMU	AIS	Motorola	Webb	Hays	SKI	Average
Breakeven Hours	80.25							80.25
Training Hours/Person							80	80
Training Cost/Person		$995					$13,917	$7,456
Effort (Hours)	400							400
Cycle Time Reduction	326.22x			1.85x				164.03x
Productivity Increase	326.22x		1.07x		1.19x			109.49x
Quality Increase	1,000.00x		4.47x		1.62x	8.40x		253.62x
Return-on-Investment	1,290: 1							1,290: 1

Personal Software Process (PSP)

Data for the PSP primarily came from six authoritative sources (as shown in Table 92), the ROI model (Table 87), Carnegie Mellon University (1999), Ferguson, Humphrey, Khajenoori, Macke, and Matvya (1997), Webb and Humphrey (1999), Hays and Over (1997), and the Software Engineering Institute (1998). The ROI model yielded Breakeven Hours of 80.25. The Software Engineering Institute reports that it takes 80 Training Hours/Person of training for PSP courses I and II, 40 hours each. Training Cost/Person comes from two sources, $13,917 from the Software Engineering Institute and $995 from Carnegie Mellon University, for an average of $7,496. The ROI model yielded Effort (Hours) of 400, based on an input of 10,000 source lines of code (SLOC) into Rico's (1998) PSP cost model, which was derived from Hays' and Over's study. A Cycle Time Reduction of 326.22X was convincingly yielded by the ROI model, and 1.85 Hours was reported by Motorola in a study by Ferguson, Humphrey, Khajenoori, Macke, and Matvya, for an average of 164.03X. A Productivity Increase of 326.22X, once again, was yielded by the ROI model, while AIS reported a 1.07X Productivity Increase in a study by Ferguson, Humphrey, Khajenoori, Macke, and Matvya, and Webb and Humphrey came up with a 1.19 Productivity Increase, for an average of 109.49X. A 1,000X Quality Increase was determined by the ROI Model, AIS reported a respectable 4.47X Quality Increase, Webb and Humphrey came up with 1.62X, and Hays and Over had a convincing finding of an 8.4X Quality Increase, for an average of 253.62X. Finally, the ROI model yielded a phenomenal ROI of 1,290:1. The reason that such a large disparity exists between the ROI model and the authoritative independent studies is because the ROI model responsibly calculates total life cycle costs, including software maintenance, while the other studies merely report development cycle attributes.

Table 93: Costs and Benefits of Clean Room Methodology

	McGibbon	Kaplan	Prowell	CSR	Average
Breakeven Hours	42	64			53
Training Hours/Person	318	84			201
Training Cost/Person	$12,398	$3,780			$8,089
Effort (Hours)	3,245				3,245
Cycle Time Reduction	3.53x .	3.53x			
Productivity Increase	3.53x			5.00x	4.27x
Quality Increase	100.00x	16.67x		10.00x	42.22x
Return-on-lnvestment	33:1		20:1		27:1

Clean Room Methodology

As mentioned earlier, data for Clean Room primarily came from four sources (as shown in Table 93), or Rosetta Stones as previously stated, McGibbon (1996), Kaplan, Clark, and Tang (1995), Prowell, Trammell, Linger, and Poor (1999), and Cleanroom Software Engineering (1996). McGibbon and Kaplan, Clark, and Tang reported approximate Clean Room Breakeven Hours of 42 and 64, for an average of 53 hours. Training Hours/Person were a quite diverse 318 and 84, as reported by the same two studies, for an average of 201. McGibbon's training hours were based on a study by the U.S. Army's Life Cycle Software Engineering Center at Picatinny Arsenal, New Jersey. Training Cost/Person comes to $12,398 and $3,780, for an average of $8,089, based on the same two studies. McGibbon reported 3,245 Effort (Hours) and an approximate Cycle Time Reduction of 3.53X. McGibbon also reported a Productivity Increase of 3.53X, while Cleanroom Software Engineering reports a 5X Productivity Increase, for an

average of 4.27X. Quality Increases of 100X, 16.67X, and 10X for an average of 42.22X, were reported by McGibbon, Kaplan, Clark, and Tang, and Cleanroom Software Engineering. McGibbon reported an impressive 33:1 ROI for Clean Room, while Prowell, Trammell, Linger, and Poor reported a 20:1 ROI, averaging a good 27:1.

Software Reuse

While core Clean Room data came primarily from McGibbon's (1996) unique seminal study, Software Reuse data came from three very authoritative cost and benefit studies (as shown in Table 94), such as those from McGibbon, Poulin's (1997) landmark study, and Lim's (1998) taxonomic study of Software Reuse. Don't let the small numbers of primary studies referenced here be deceiving, as Software Reuse probably has the broadest ranging collection of reported costs and benefits of any single SPI strategy or method. In fact, after only making brief mention of the plethora of Software Reuse economic studies, Poulin and Lim go to construct scholarly economic metrics, models, and taxonomies for Software Reuse, based on the robust set of reported Software Reuse costs and benefits. Once again, while Software Reuse wasn't initially targeted for analysis by this study, the Literature Survey uncovered such a rich availability of cost and benefit data that the economic characteristics of Software Reuse couldn't be ignored, and had to be included in the final analysis. Lim starts off the Software Reuse cost and benefit survey by reporting Breakeven Hours for two Hewlett Packard divisions of $4,160 and $12,480, averaging $8,320. Lim also reports Training Hours/Person of $450 and $6,182, for an average of $3,316. Lim also provides one of the most in-depth studies and analyses of Training Cost/Person, at a whopping $40,500 and $556,380, averaging an uncomfortably high $298,440. McGibbon and Lim report Effort (Hours) of 22,115, 9,360, and 17,160, for an average of 16,212. A modest 3.33X and 5X Cycle Time Reduction, averaging 3.69X, is reported by Lim and Poulin. A broader array of Productivity Increases are reported by Poulin and Lim, including 6.7X, 1.84X, 2X, 1.57X, and 1.4X, for a relatively flat Productivity Increase average of 2.7X. Quality Increases of 2.8X, 5.49X, 2.05X, and 1.31X, are also revealed by Poulin and Lim, averaging 2.7X. But, probably the most surprisingly low performance indicators were ROI data of 4:1, 4:1, and 2:1, averaging a convicting 3:1 ROI for Software Reuse.

Table 94: Costs and Benefits of Software Reuse

	McGibbon	NEC	Lim	Raytheon	DEC	Reifer	HP	HP	Average
Breakeven Hours							4,160	12,480	8,320
Training Hours/Person							450	6,182	3,316
Training Cost/Person							$40,500	$556,380	$298,440
Effort (Hours)	22,115						9,360	17,160	16,212
Cycle Time Reduction			3.33x		5.00x		1.71x	4.70x	3.69x
Productivity Increase		6.70x	1.84x	2.00x			1.57x	1.40x	2.70x
Quality Increase		2.80x	5.49x			1 O.OOx	2.05x	1.31x	4.33x
Return-on-lnvestment	4:1						4:1	2:1	3:1

Defect Prevention Process

Data for Defect Prevention came from a six excellent sources (as shown in Table 95), Kaplan, Clark, and Tang (1995), Gilb (1993), Mays, Jones, Holloway, and Studinski (1990), Humphrey (1989), Grady (1997), Kajihara (1993), and Latino and Latino (1999). Mays, Jones, Holloway, and Studinski were the seminal source for works by Kaplan, Clark, and Tang, Gilb, and Humphrey. Kajihara was an original piece coming from the world-class software laboratories of NEC in Japan. And, finally Latino and Latino is one of the newest and comprehensive examinations of the dynamics of Defect Prevention, what they call Root Cause Analysis (RCA), including highly structured economic analyses of Defect Prevention. All in all, though Defect Prevention was initially perceived to be sorely lacking in data, it turned out to be a strong SPI method or strategy for cost and benefit analysis. Kaplan, Clark, and Tang, Gilb, and Mays reported Breakeven Hours of 1,560, 10, and 11, averaging 527 hours. Training Hours/Person were 12, 40, and 40, averaging 31, as reported by Kaplan, Clark, and Tang, and Latino and Latino. Once again, this duo reported Training Cost/Person to be $900, $7,500, and $8,000, for an average cost of $5,467. Kaplan, Clark, and Tang, Gilb, Mays, Jones, Holloway, and Studinski, and Latino and Latino, reported a wide variety of Effort (Hours), including 4,680, 1,625, 1,747, and 347, averaging 2,100. Two sources, Mays, Jones, Holloway, and Studinski, and Grady reported Cycle Time Reductions of 2X and 1.37X, averaging a modest 1.69X. Productivity Increases of 2X and 1.76X, for another modest average of 1.88X, were reported by Mays, Jones, Holloway, and Studinski, and included Kajihara this time. The most commonly reported Defect Prevention results were reported for Quality Increase, by Kaplan, Clark, Tang, Mays, Jones, Holloway, and Studinski, Humphrey, Grady, Kajihara, and Latino and Latino. They ganged up to report seemingly small Quality Increases of 2X, 2.17X, 4.55X, 4X, 10X, 7X, and 3.67X, averaging 4.77X. ROI came from two principle sources, Gilb and Latino and Latino, reporting 7:1, 40:1, and 179:1. Latino and Latino gave the most convincing accounts of ROI associated with Defect Prevention, and were a late addition to this study.

Table 95: Costs and Benefits of Defect Prevention Process

	Kaplan	Gilb	Mays	Humphrey	Grady	Kajihara	Latino	Latino	Average
Breakeven Hours	1,560	10	11					527	
Training Hours/Person	12					40	40	31	
Training Cost/Person	$900					$7,500	$8,000	$5,467	
Effort (Hours)	4,680	1,625	1,747				347	2,100	
Cycle Time Reduction			2.00x	1.37x				1.69x	
Productivity Increase			2.00x		1.76x			1.88x	
Quality Increase	2.00x		2.17x	4.55x	4.00x	l0.00x	7.00x	3.67x	4.77x
Return-on-lnvestment		7:1					40:1	179:1	75:1

Software Inspection Process

Cost and benefit data for Inspections came from eight solid sources (as shown in Table 96), McGibbon (1996), Fagan (1986), Barnard and Price (1994), Rico (1993), the ROI Model (Table 87), Russell (1991), Gilb (1993), and Grady (1997). The most significant contributors to Inspection cost and benefit data were the ROI model designed for this study, which was unexpected, and Grady's excellent text on SPI showing total Inspection savings of better than $450 million. The ROI model yielded a convincing Breakeven Hours average of 7 for Inspection cost models by Barnard and Price, Rico, Russell, Gilb, and Grady. Training Hours/Person primarily came from McGibbon, Fagan, and Gilb, reporting 12, 24, and 20, for an insignificant average of 19. The same three sources reported a Training Cost/Person of $468, $2,800, and $2,114, averaging $1,794. Barnard and Price, Rico, Russell, Gilb, and Grady reported Effort (Hours) of 500, 708, 960, 970, and 1,042, for a modest average of 836. A flat Cycle Time Reduction and Productivity Increase of 5.47X was the average of 1.55X, 6.77X, 8.37X, 6.54X, 5.17X, 5.13, and 4.84X, from all seven sources. Quality Increase was a uniform 9X from all sources other than McGibbon and Fagan as primarily derived from the ROI model. And lastly, McGibbon, Barnard and Price, Rico, Russell, Gilb, and Grady reported relatively high ROI figures of 72:1, 234:1, 160:1, 114:1, 113:1, and 104:1, averaging a solid 133:1.

Table 96: Costs and Benefits of Software Inspection Process

	McGibbon	Fagan	AT&T	ROI Model	BNR	Gilb	HP	Average
Breakeven Hours			7	7	7	7	7	7
Training Hours/Person	12	24				20		19
Training Cost/Person	$468	$2,800				$2,114		$1,794
Effort (Hours)			500	708	960	970	1,042	836
Cycle Time Reduction	1.55x	6.67x	8.37x	6.54x	5.17x	5.13x	4.84x	5.47x
Productivity Increase	1.55x	6.67x	8.37x	6.54x	5.17x	5.13x	4.84x	5.47x
Quality Increase			9.00x	9.00x	9.00x	9.00x	9.00x	9.00x
Return-on-Investment	72: 1		234: 1	160: 1	114: 1	113: 1	104: 1	133: 1

Software Test Process

Cost and benefits for Testing came from seven sources (as shown in Table 97), the ROI model (Table 87), Farren and Ambler (1997), Rice (1999), Yamaura (1998), Graham (1999), Ehrlich, Prasanna, Stampfel, and Wu (1993), and Asada and Yan (1998). Breakeven Hours were reported to be 135, 5,400, and 5,017 by the ROI model, Ehrlich, Prasanna, Stampfel, and Wu, and Asada and Yan, averaging 3,517. Rice and Graham reported extensive Training Hours/Person to be 84 and 72, averaging 78, as input into the ROI model. Training Cost/Person was subsequently derived from Rice and Graham, being $16,800 and $10,926, for an average of $13,863. Effort (Hours) were quite high at 8,360, 54,000, and 50,170, as reported or derived by the ROI model, Ehrlich, Prasanna, Stampfel, and Wu, and Asada and Yan, averaging an astronomical 37,510. Cycle Time Reduction and Productivity Increase were both computed to be 2.36X, 5X, 3.37X, 10X, and 10X, averaging 6.15X, by the ROI model, Farren and Ambler, Yamaura, Ehrlich, Prasanna, Stampfel, and Wu, and Asada and Yan. Quality Increase is 3X, 2X, 9X, and 9X, for an average of 5.75X, as reported by the ROI model, Farren and Ambler, Ehrlich, Prasanna, Stampfel, and Wu, and Asada and Yan. Finally, the same sources yield 10:1, 5:1, 10:1, and 10:1, for a respectable average ROI of 9:1 for Testing.

Table 97: Costs and Benefits of Software Test Process

	ROI Model	Farren	Rice	Yarnaura	Graham	Ehrlick	Asada	Average
Breakeven Hours	135					5,400	5,017	3,517
Training Hours/Person			84		72			78
Training Cost/Person			$16,800		$10,926			$13,863
Effort (Hours)	8,360					54,000	50,170	37,510
Cycle Time Reduction	2.36x	5.00x		3.37x		10.00x	10.00x	6.15x
Productivity Increase	2.36x	5.00x		3.37x		10.00x	10.00x	6.15x
Quality Increase	3.00x	2.00x				9.00x	9.00x	5.75x
Return-on-Investment	10:1	5:1				10:1	10:1	9:1

Capability Maturity Model (CMM)

Cost and benefit data for the CMM came from seven of the most authoritative sources thus far (as shown in Table 98), Herbsleb, Carleton, Rozum, Siegel, and Zubrow (1994), Putnam (1993), Haskell, Decker, and McGarry (1997), Vu (1998), Diaz and Sligo (1997), Haley (1996), and Jones (1997a). Breakeven Hours are reported to be 2,318, 345, 1,092, and 36,330 by Herbsleb, Carleton, Rozum, Siegel, and Zubrow, Haskell, Decker, and McGarry, Diaz and Sligo, and Jones, for an average of 10,021. Training Hours/Person came out to be 64 and 389, according to Herbsleb, Carleton, Rozum, Siegel, and Zubrow and Jones, for an average of 227. The same two sources reported Training Cost/Person to be $9,820 and $15,516 for an average of $12,668. Herbsleb, Carleton, Rozum, Siegel, and Zubrow, Haskell, Decker, and McGarry, Diaz and Sligo, and Jones report Effort (Hours) to be around 23,184, 3,450, 10,920, and 363,298, for a rather large average of 94,417. According to Herbsleb, Carleton, Rozum, Siegel, and Zubrow, Putnam, Vu, Diaz and Sligo, Haley, and Jones, Cycle Time Reduction is 1.85X, 7.46X, 1.75X, 2.7X, 2.9X, and 1.26X, averaging 2.99X. The same researchers and studies report Productivity Increase to be 2.89X, 7.46X, 2.22X, 0.80X, 2.9X, 1.26X, averaging 2.92X. And, once again, this same group reports Quality Increase to be 3.21X, 8.25X, 5X, 2.17X, 3X, and 5.68X, for a noticeable average of 4.55X. Only, Herbsleb, Carleton, Rozum, Siegel, and Zubrow, Diaz and Sligo, and Haley reported ROI of 5:1, 4:1, and 8:1, for a decent average of 6:1. As a special metric, all studies, except Putnam's, reported Years to SEI Level 3 as 3.5, 7, 5, 3, 7, and 3.56, for a significant average of 4.84.

Table 98: Costs and Benefits of Capability Maturity Model (CMM)

	Herbsleb	Putnam	Haskell	Vu	Diaz	Haley	Jones	Average
Breakeven Hours	2,318		345		1,092		36,330	10,021
Training Hours/Person	64						389	227
Training Cost/Person	$9,820						$15,516	$12,668
Effort (Hours)	23,184		3,450	10,920	363,298	94,417		
Cycle Time Reduction	1.85x	7.46x		1.75x	2.70x	2.90x	1.26x	2.99x
Productivity Increase	2.89x	7.46x		2.22x	0.80x	2.90x	1.26x	2.92x
Quality Increase	3.21x	8.25x		5.00x	2.17x	3.00x	5.68x	4.55x
Return-on-Investment	5:1				4:1	8:1		6:1
Years to SKI Level 3	3.50		7.00	5.00	3.00	7.00	3.56	4.84

ISO 9000

Cost and benefit data for ISO 9000 came from eight primary sources (as shown in Table 99), Roberson (1999), Hewlett (1999), Armstrong (1999), Russo (1999), Kaplan, Clark, and Tang (1995), Haskell, Decker, and McGarry (1997), Garver (1999), and El Emam and Briand (1997). Breakeven Hours were reported to be a rather large 4,160, 10,400, and 360 by Roberson, Kaplan, Clark, and Tang, and Haskell, Decker, and McGarry, averaging 4,973. Armstrong, Russo, and Haskell, Decker, and McGarry report Training Hours/Person to be 88, 24, and 80, for an average of 64. Training Cost/Person, from the same studies, comes out to be $8,775, $12,650, and $7,000. According to Kaplan, Clark, and Tang and Haskell, Decker, and McGarry, Effort (Hours) are 104,000 and 3,600, averaging an eye opening 53,800. Roberson reports Cycle Time Reduction to be 1.14X. Productivity Increase is reported to be 1.14X and 1.11X, averaging a small 1.13X by Roberson and Hewlett. Quality Increase is reported to be 1.22X, 1.11X, and 35X for a significant 12.44X average. Kaplan, Clark, and Tang and Haskell, Decker, and McGarry report numbers of 1:1 and 7:1, averaging a respectable 4:11 ROI. Finally, Haskell, Decker, and McGarry were able to get a CSC unit ISO 9000 Registered after only one year, while El Emam and Brian find an average of 2.14 years for ISO 9000 Registration.

Table 99: Costs and Benefits of ISO 9000

	Roberson	Hewlett	Armstrong	Russo	Kaplan	Haskell	Garver	El Emam	Average
Breakeven Hours	4,160				10,400	360			4,973
Training Hours/Person			88	24		80			64
Training Cost/Person			$8,775	$12,650		$7,000			$9,475
Effort (Hours)					104,000	3,600			53,800
Cycle Time Reduction	1.14x								1.14x
Productivity Increase	1.14x	l.l lx							1.13x
Quality Increase	1.22x	l.l lx					35.00x		12.44x
Return-on-lnvestment					1: 1	7:1			4: 1
Years to ISO 9001						1.00		2.14	1.57

Data Analysis

This chapter sets forth to analyze, evaluate, and interpret the results of the Methodology, primarily the Cost and Benefit Model depicted by Table 91, which was identified as a key part of satisfying the objectives of this study. The Data Analysis will provide the reader with an interpretive analysis of the costs and benefits of the eight SPI strategies, PSP, Clean Room, Reuse, Defect Prevention, Inspection, Testing, CMM, and ISO 9000 (as shown in Table 100).

Table 100: Normalized Costs and Benefits of Eight Strategies

	PSP	Cleanroom	Reuse	Prevent	Inspect	Test	CMM	ISO	Average
Breakeven Hours	9 97	9.98	6.97	9.81	10.00	8.72	6.36	8.19	8.75
Training Hours/Person	9.80	9.50	1.74	9.92	9.95	9.81	9.44	9.84	8.75
Training Cost/Person	9.79	9.77	1.65	9.85	9.95	9.61	9.65	9.73	8.75
Effort (Hours)	9.98	9.84	9.22	9.90	9.96	8.20	5.47	7.42	8.75
Cycle Time Reduction	8.69	0.19	0.20	0.09	0.29	0.33	0.16	0.06	1.25
Productivity Increase	8.17	0.32	0.20	0.14	0.41	0.46	0.22	0.08	1.25
Quality Increase	7.53	1.25	0.13	0.14	0.27	0.17	0.14	0.37	1.25
Return-on-lnvestment	8.34	0.17	0.02	0.49	0.86	0.06	0.04	0.03	1.25
	72.28	41.03	20.13	40.34	41.68	37.35	31.46	35.73	

Table 100 normalizes the Cost and Benefit Criteria values for each of the eight SPI strategies against one another, based on the raw data in Table 91. While the raw cost and benefit data in Table 91 is interesting and useful, normalized representations of the data will aid in rapid comprehension and interpretive analysis of the costs and benefits of the eight SPI strategies. Since costs are considered undesirable, normalization for the costs was computed by inverting the raw criterion value divided by the sum of all the values for the given criterion, and multiplying the result by 10. Since benefits are considered desirable, normalization for the benefits was computed by dividing the raw criterion value by the sum of all the values for the given criterion, and multiplying the result by 10. The normalization technique, as described here, yields a table populated with uniform data values between 0 and 10, for rapid comprehension and analysis. Low numbers are considered poor, and high numbers are considered better. The criterion values for each SPI strategy were also summed vertically, in order to yield an overall score that could be used for comparing the SPI strategies themselves very simply.

Several preliminary results seem to be evident from Table 100 and Figure 38, little variation seems to exist between costs, and wide disparity exists between the benefits. The PSP scores values near ten for each of its costs and scores near eight and nine for each of its benefits. Clean Room scored near ten for each of its costs, but scored well under one for each of its benefits. Reuse scored the worst for cost and near zero for its benefits. Defect Prevention scored extremely well for its costs, but surprisingly low for its benefits. Inspection scored the only ten for costs or benefits, scoring around 0.5 for most of its benefits. Test also scored well for costs and low for benefits. CMM scored moderately for cost and low for benefits. ISO 9000 scored well for costs, but probably worst for benefits. Several results became immediately visible from these analyses, costs, at least identified by this study don’t seem to be a differentiator, and the PSP benefits seem to dwarf the benefits of the other seven SPI strategies.

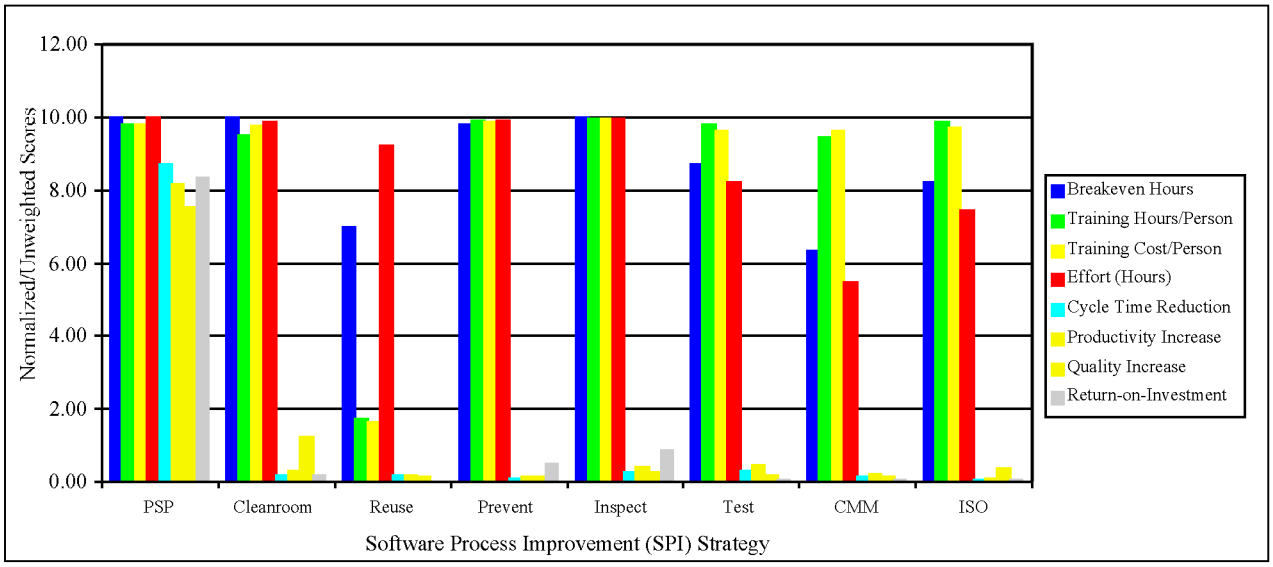


Figure 38. Normalized Cost and Benefits of Eight Strategies

Cost/Benefit-Based Comparison of Alternatives

A composite graph averaging all of the costs and benefits together for each SPI strategy and then comparing them to one another seems to yield some useful comparative analyses (as shown in Figure 39).

Overall, this analysis seems to indicate uniformity in the average costs and benefits for each SPI strategy, and may mislead one to assert that any SPI strategy is the right one. Table 100, Figure 38, and later analyses will reveal that the seeming uniformity in costs and benefits is largely due to the homogeneity of the costs, and any differentiation is due to disparity in the benefits. This analysis reveals a modest factor of 3.59X between the best and worst performer, PSP and Reuse. Aside from PSP, the difference between the best and worst performer is a factor of 2X, Inspection and Reuse. The overall costs and benefits of Clean Room, Defect Prevention, Inspection, Test, CMM, and ISO 9000 seem to be surprisingly uniform. Following is a closer look at each of the individual criterion, in order to highlight differentiation between costs and benefits for each of the SPI strategies.

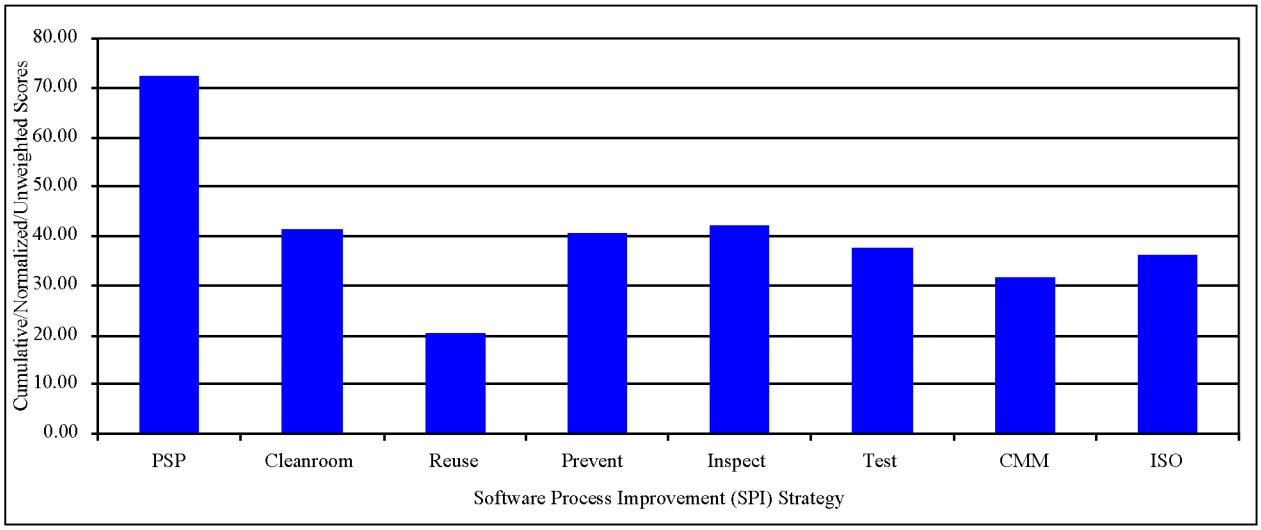


Figure 39. Average Cost and Benefits of Eight Strategies

Breakeven Hours

Normalized values for Breakeven Hours range from six to near ten for as many as four of the SPI strategies (as shown in Figure 40). Breakeven Hours from left to right are 9.97, 9.98, 6.97, 9.81, 10, 8.72, 6.36, and 8.19, for an average of 8.75. Inspection is the best and CMM is the worst in this analysis. The difference between best and worst is a factor of 1.43X.

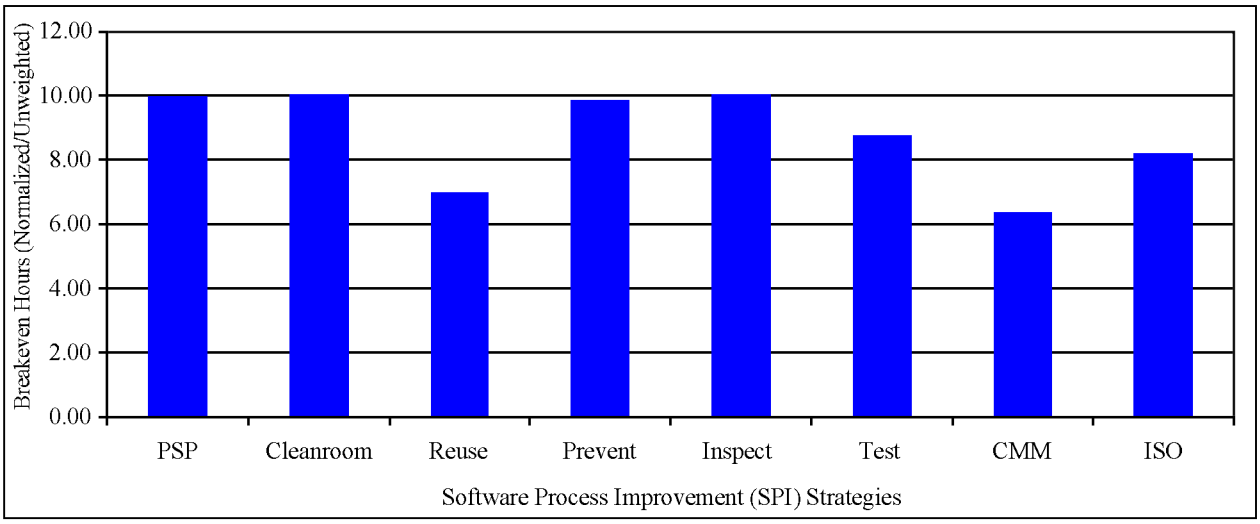


Figure 40. Breakeven Hours Comparison of Eight Strategies

Training Hours/Person

Normalized values for Training Hours/Person range from just under two to near ten for as many as seven of the SPI strategies (as shown in Figure 41). Training Hours/Person from left to right are 9.8, 9.5, 1.74, 9.92, 9.95, 9.81, 9.44, and 9.84, for an average of 8.75. Inspection is the best and Reuse is the worst in this analysis. The difference between best and worst is a factor of 5.72X.

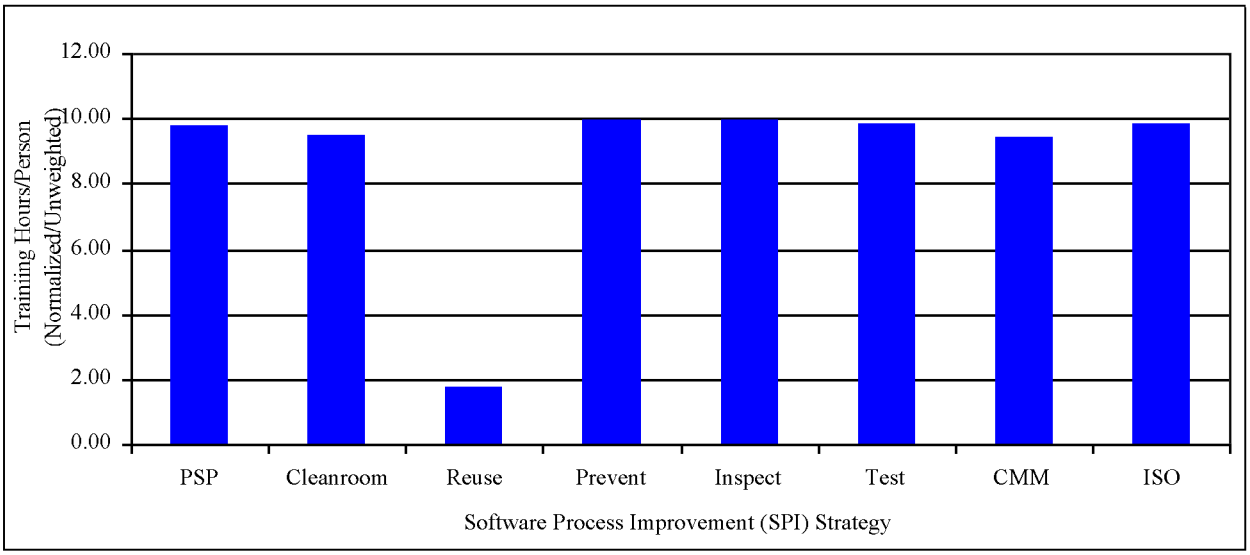


Figure 41. Training Hours/Person Comparison of Eight Strategies

Training Cost/Person

Normalized values for Training Cost/Person once again range from just under two to near ten for as many as seven of the SPI strategies (as shown in Figure 42). Training Cost/Person from left to right is 9.79, 9.77, 1.65, 9.85, 9.95, 9.61, 9.65, and 9.73, for an average of 8.75. Once again, Inspection is the best and Reuse is the worst in this analysis. The difference between best and worst is a factor of 6.03X. The technique of collecting consultant costs for both Training Hours/Person and Training Cost/Person was most likely responsible for the uniformity in most of the values, as well as the disparity in the case of Reuse. Consulting costs seem to be relatively uniform, despite the SPI strategy, for competitive reasons, while Reuse costs were derived from McGibbon's (1996) study factoring in life cycle considerations.

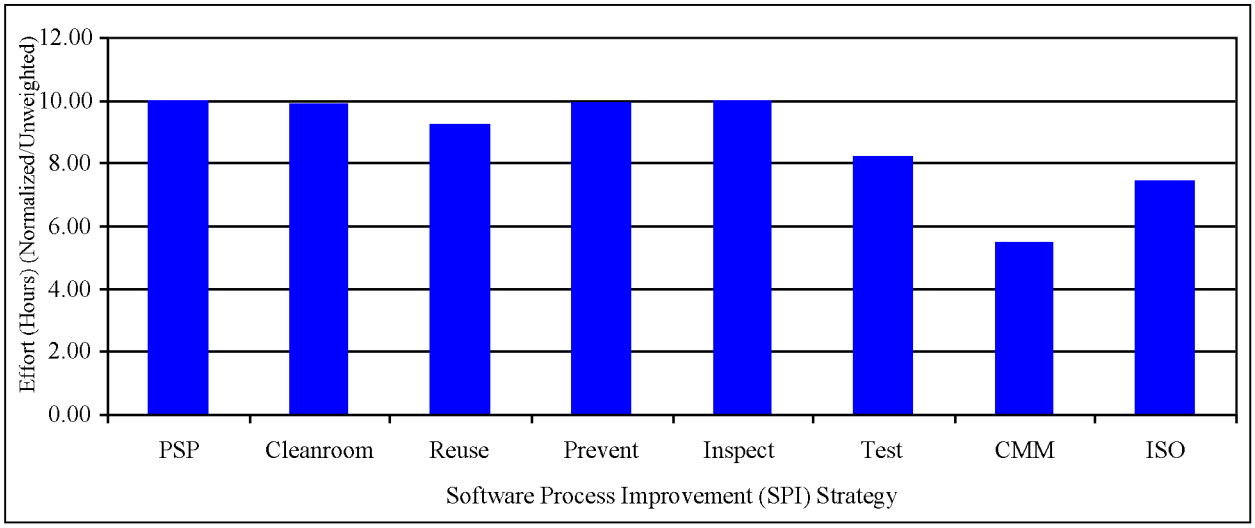


Figure 42. Training Cost/Person Comparison of Eight Strategies

Effort (Hours)

Normalized values for Effort (Hours) range from around five to near ten for as many as four of the SPI strategies (as shown in Figure 43). Effort (Hours) from left to right are 9.98, 9.84, 9.22, 9.9, 9.96, 8.2, 5.47, and 7.42, for an average of 8.75. PSP is the best and CMM is the worst in this analysis. The difference between best and worst is a factor of 1.82X. This normalization technique seems to be hiding some significant differentiation between criterion values, so the raw values in Table 91 should be analyzed and compared as well.

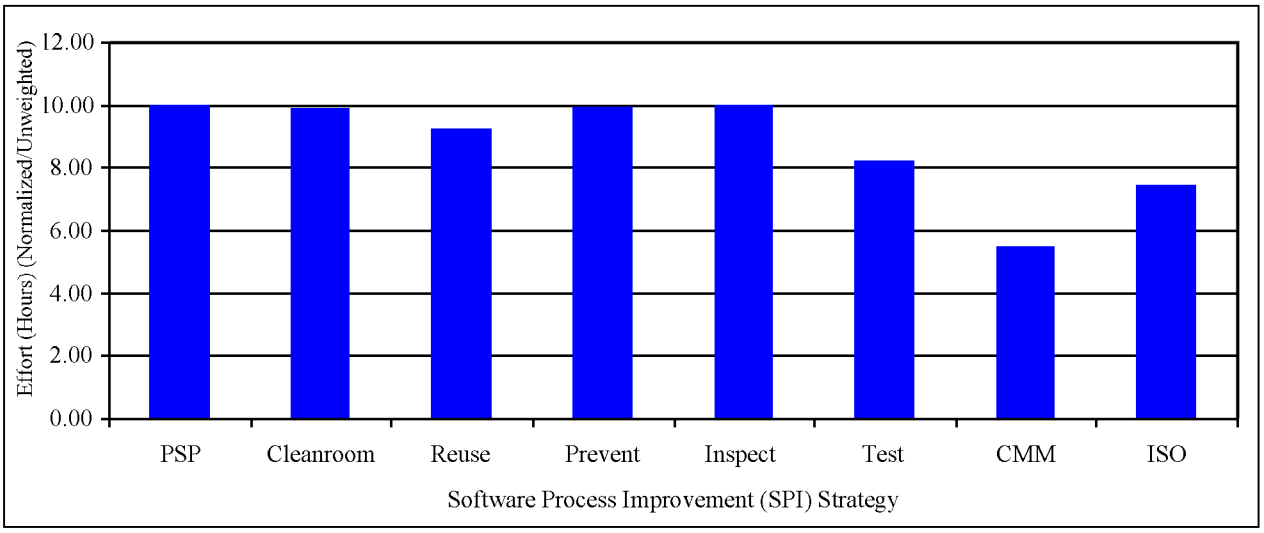


Figure 43. Effort (Hours) Comparison of Eight Strategies

Cycle Time Reduction

Normalized values for Cycle Time Reduction range from near zero to around nine for the PSP (as shown in Figure 44). Cycle Time Reduction from left to right is 8.69, 0.19, 0.20, 0.09, 0.29, 0.33, 0.16, and 0.06, for an average of 1.25. PSP is the best and ISO 9000 is the worst in this analysis. The difference between best and worst is a factor of 145X.

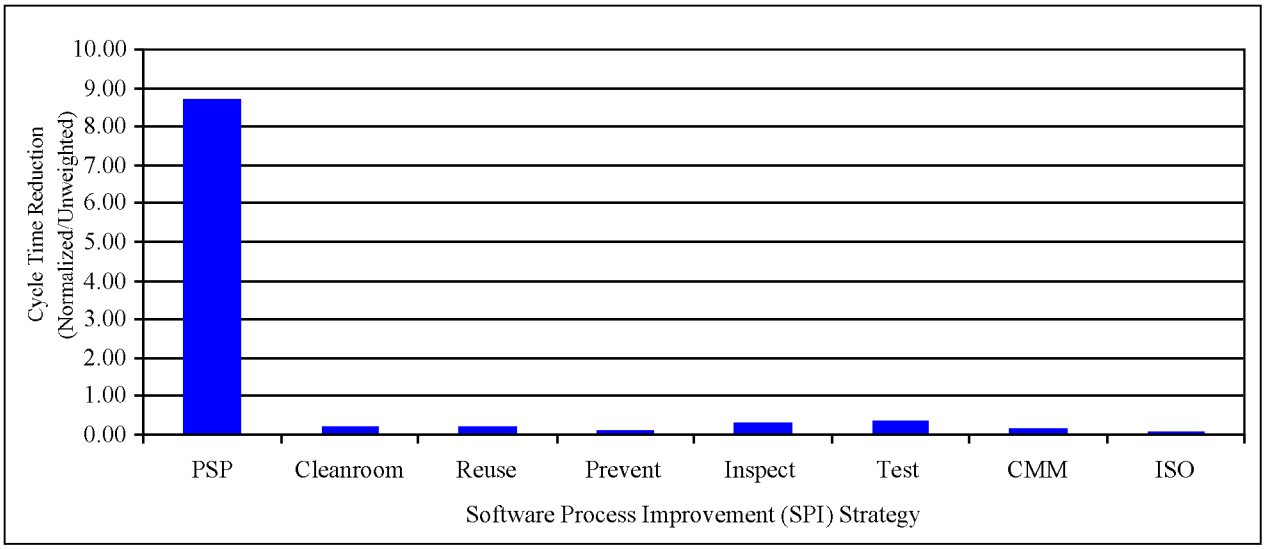


Figure 44. Cycle Time Reduction Comparison of Eight Strategies

Productivity Increase

Normalized values for Productivity Increase range from near zero to around eight for the PSP (as shown in Figure 45). Productivity Increase from left to right is 8.17, 0.32, 0.20, 0.14, 0.41, 0.46, 0.22, and 0.08, for an average of 1.25. PSP is the best and ISO 9000 is the worst in this analysis. The difference between best and worst is a factor of 102X. What's now becoming evident is that the PSP's benefits seem to be outweighing the benefits of the other seven SPI strategies by two orders of magnitude. Rather than let this singular result dominate and conclude this study, it is now becoming evident that PSP performance will have to be duely noted, and its data segregated for further analyses and evaluation of SPI strategy costs and benefits. One thing however, the PSP's excellent performance was not predicted going into this study. Further detailed analyses of the PSP's performance may be found in the ROI Model.

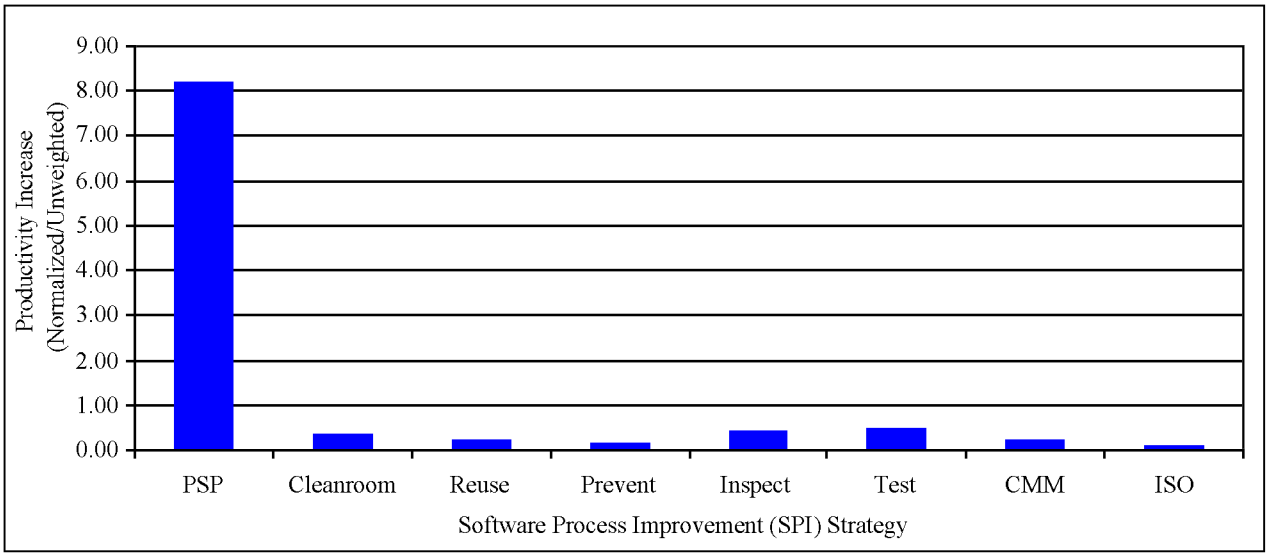


Figure 45. Productivity Increase Comparison of Eight Strategies

Quality Increase

Normalized values for Quality Increase range from near zero to under eight for the PSP (as shown in Figure 46). Quality Increase from left to right is 7.53, 1.25, 0.13, 0.14, 0.27, 0.17, 0.14, and 0.37, for an average of 1.25. PSP is the best and Reuse is the worst in this analysis. The difference between best and worst is a factor of 58X.

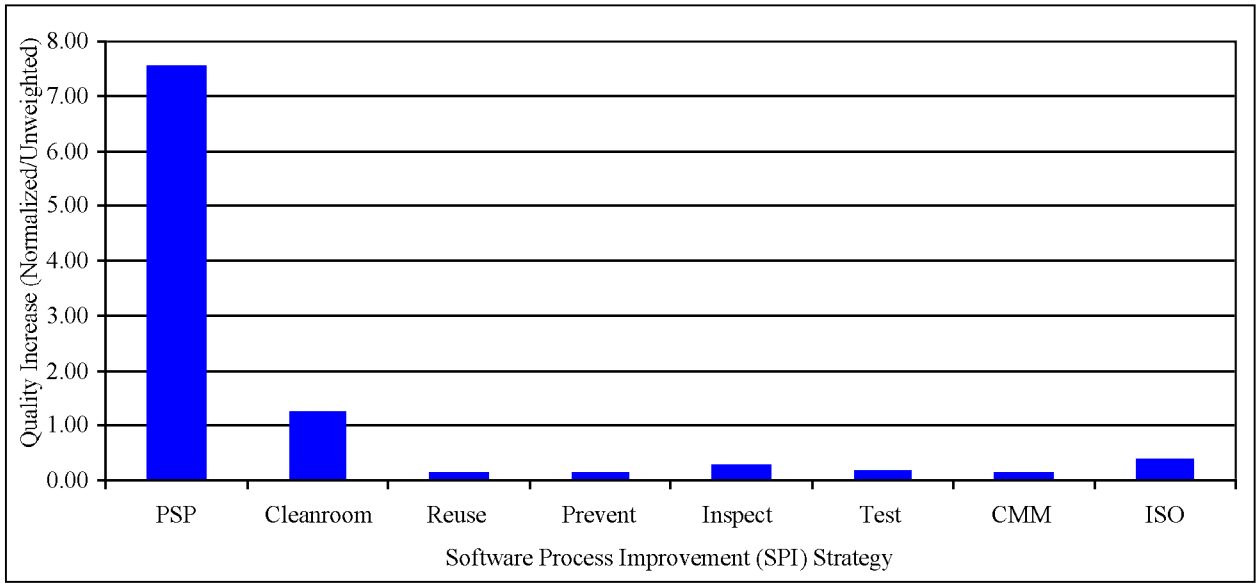


Figure 46. Quality Increase Comparison of Eight Strategies

Return-on-Investment

Normalized values for Return-on-Investment range from near zero to just over eight for the PSP (as shown in Figure 47). Return-on-Investment from left to right is 8.34, 0.17, 0.02, 0.49, 0.86, 0.06, 0.04, and 0.03, for an average of 1.25. PSP is the best and Reuse is the worst in this analysis. The difference between best and worst is a factor of 417X.

As mentioned earlier, these analyses revealed little differentiation in the costs and wide disparity in the benefits. The following sections and analyses were created to highlight differentiation between strategies that was not evident in the first round of analyses.

However, these analyses have revealed some significant findings. Inspection dominated the first three cost criteria with performances of 1.43X, 5.72X, and 6.03X, for an average 4.39X better than the worst performer. There is a correlation between these criteria in that they are all related to training costs, which are reported to be the lowest for Inspections

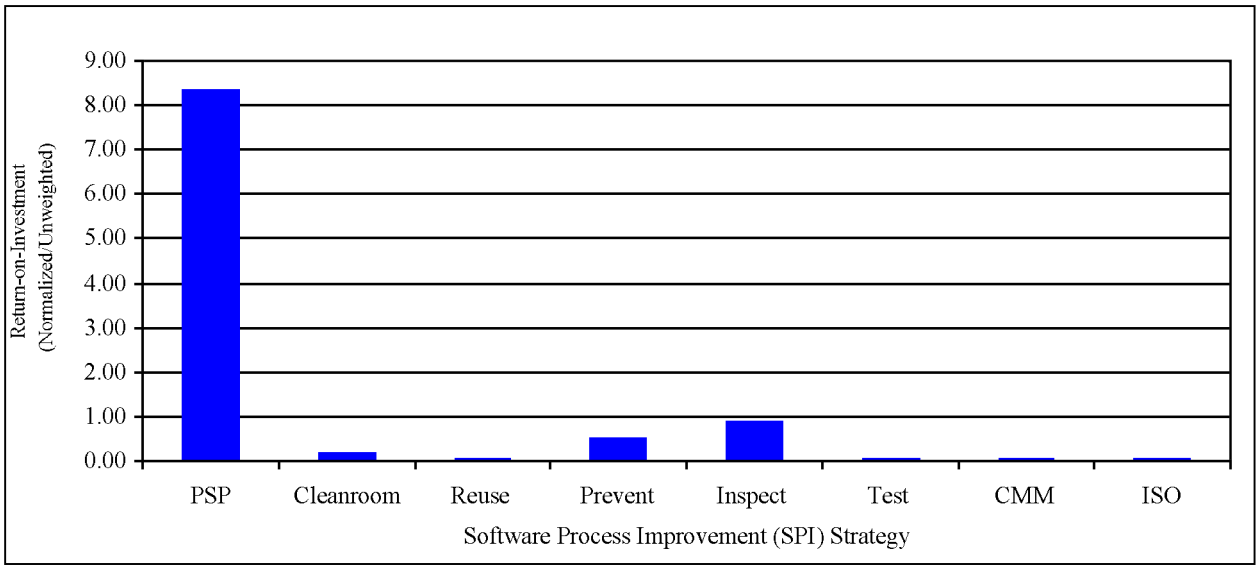


Figure 47. Return-on-Invesment Comparison of Eight Strategies

The PSP seems to have taken over from where Inspections left off. PSP dominated the final five criteria with performances of 1.82X, 145X, 102X, 58X, and 417X, for an average of 145X better than the worst performers. The explanation for the PSP's performance lies in two factors, the dominant productivity, and subsequently total life cycle cost over the other methods as revealed by the ROI Model, and that the PSP yields phenomenally high quality, resulting in near zero software maintenance costs (at least to repair defects).

But, these analyses really hide the merits of the other six SPI strategies, Clean Room, Reuse, Defect Prevention, Test, CMM, and ISO 9000. Further analyses will highlight the costs and benefits of these SPI strategies as well. Overall Inspection benefits are also hidden in the outstanding performance of the PSP. Further analyses will also highlight the benefits of Inspections. So much so, that it will be necessary to segregate out Inspection data and analyses in order to fully comprehend the benefits of the other SPI strategies in greater detail.

Benefit-Based Comparison of Alternatives

This section is designed to focus on, highlight, and further analyze only the "benefits" of the eight SPI strategies, PSP, Clean Room, Reuse, Defect Prevention, Inspection, Test, CMM, and ISO 9000, from Tables 100, and subsequently Table 91 (as shown in Table 101).

Table 101: Normalized Benefits of Eight Strategies

	PSP	Cleanroom	Reuse	Prevent	Inspect	Test	CMM	ISO	Average
Cycle Time Reduction	8.69	0.19	0.20	0.09	0.29	0.33	0.16	0.06	1.25
Productivity Increase	8.17	0.32	0.20	0.14	0.41	0.46	0.22	0.08	1.25
Quality Increase	7.53	1.25	0.13	0.14	0.27	0.17	0.14	0.37	1.25
Return-on-Investment	8.34	0.17	0.02	0.49	0.86	0.06	0.04	0.03	1.25
	32.74	1.93	0.55	0.86	1.82	1.01	0.55	0.54	

The preliminary Data Analysis revealed uniformity, homogeneity, and non-differentiation among the costs. Therefore, it is now necessary to begin focusing on the benefits of the eight SPI strategies. Now, differentiation between the SPI strategies hidden in the mire of Figure 38 and the averaging found in Figure 39 starts to become evident (as shown in Figure 48).

Table 100 and Figure 48 reveal two items of interest, the benefits of the PSP overwhelm the benefits of the remaining seven SPI strategies, and there exists further differentiation among the Clean Room, Reuse, Defect Prevention, Inspection, Test, CMM, and ISO, that needs to be examined in greater detail later.

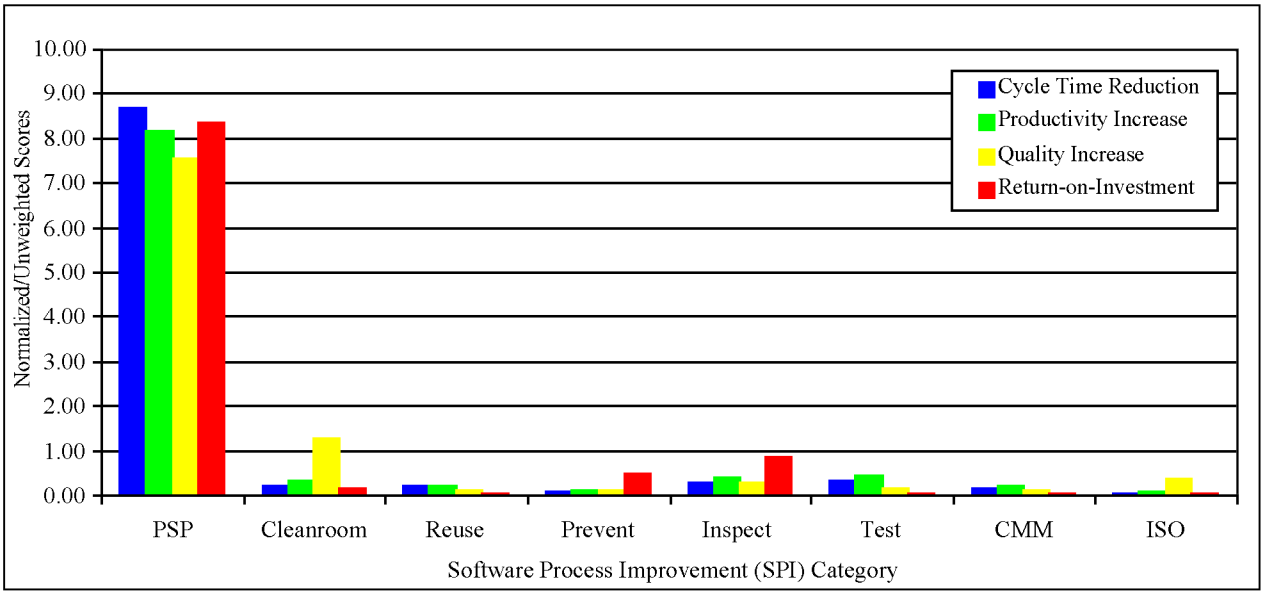


Figure 48. Normalization Benefits of Eight Strategies

Figure 49 is a composite average of benefits for PSP, Clean Room, Reuse, Defect Prevention, Inspection, Test, CMM, and ISO 9000, from Table 101 and Figure 48. Figure 49 shows that the average PSP benefits outperform the benefits of the other seven SPI strategies by a factor of 31.57X, while the factor between the PSP and the worst SPI strategy is a factor of 59.53X. In fact, Figure 49 shows that the difference between the worst PSP criterion and the best non-PSP criterion is a factor of 5.02X. PSP's Cycle Time Reduction is 46.6X greater than an average of the others. PSP's Productivity Increase is 31.28X greater. PSP's Quality Increase is 21.37X greater. And, PSP's Return-on-Investment is 35.25X greater. Figure 49 does reveal a 3.51X difference between the best and worst non-PSP SPI strategy.

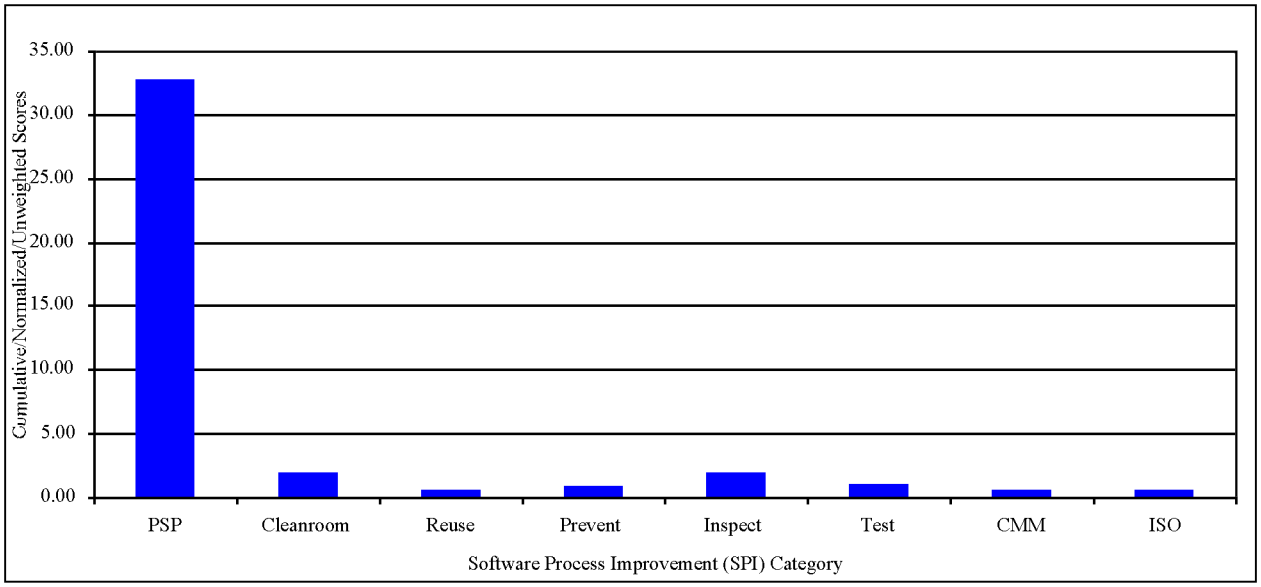


Figure 49. Average Benefits of Eight Strategies

Benefit-Based Comparison of Worst Alternatives

This section is designed to analyze and evaluate the benefits of the seven worst SPI strategies according to the Methodology, Clean Room, Reuse, Defect Prevention, Inspection, Test, CMM, and ISO 9000, by masking out the PSP (as shown in Table 102).

Table 102: Normalized Benefits of Worst Strategies

	Cleanroom	Reuse	Prevent	Inspect	Test	CMM	ISO	Average
Cycle Time Reduction	1.43	1.50	0.68	2.22	2.49	1.21	0.46	1.43
Productivity Increase	1.74	1.10	0.77	2.23	2.51	1.19	0.46	1.25
Quality Increase	5.08	0.52	0.57	1.08	0.69	0.55	1.50	1.25
Return-on-Investment	1.03	0.13	2.94	5.18	0.34	0.22	0.15	1.25
	9.29	3.25	4.97	10.71	6.04	3.17	2.57	

The PSP's benefits exhibited by Table 101, Figure 48, and Figure 49, previously dwarfed the benefits of the seven worst SPI strategies, necessitating the design of Table 102. This analysis reveals greater differentiation between these strategies, exhibiting high scores for Inspection and Clean Room, surprisingly mediocre scores for Defect Prevention, surprisingly high scores for Test, and low scores for Reuse, CMM, and ISO 9000 (as shown in Figure 50).

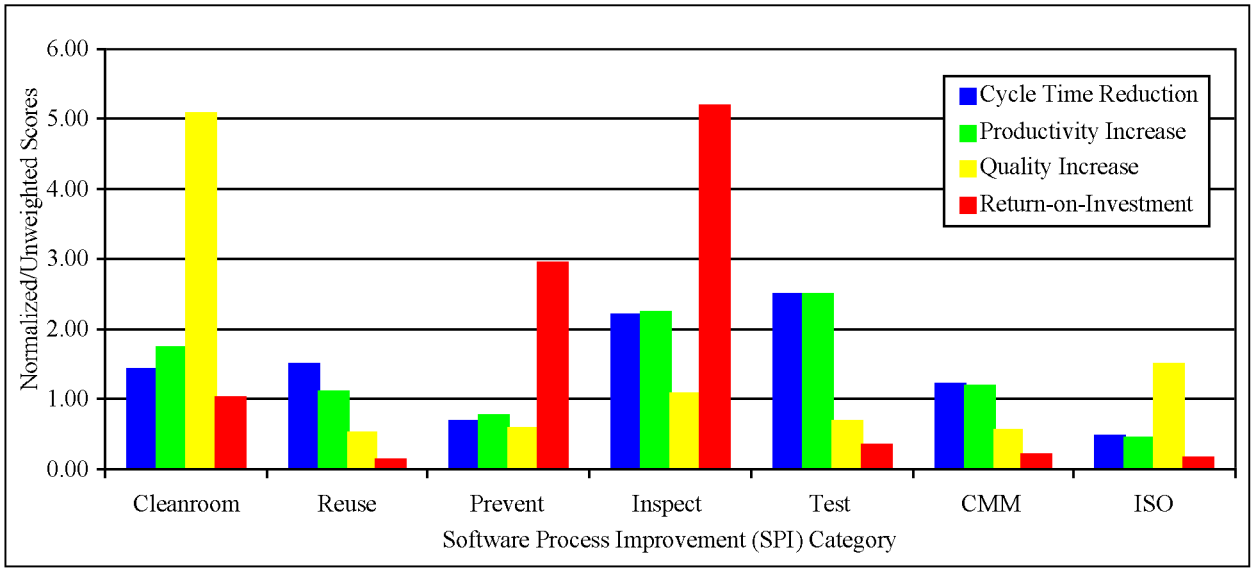


Figure 50. Normalized Benefits of Worst Strategies

A composite picture of the benefits of the seven worst SPI strategies, Clean Room, Reuse, Defect Prevention, Inspection, Test, CMM, and ISO 9000, provides useful analysis for determining the overall strengths of each SPI strategy (as shown in Figure 51).

Figure 51 reveals that Inspection has the best overall benefit average, followed closely by Clean Room, and then Test, Defect Prevention, Reuse, CMM, and ISO 9000. Inspection outpaces Clean Room by 1.15X, Test by 1.77X, Defect Prevention by 2.15X, Reuse by 3.3X, CMM by 3.38X, and ISO 9000 by 4.17X.

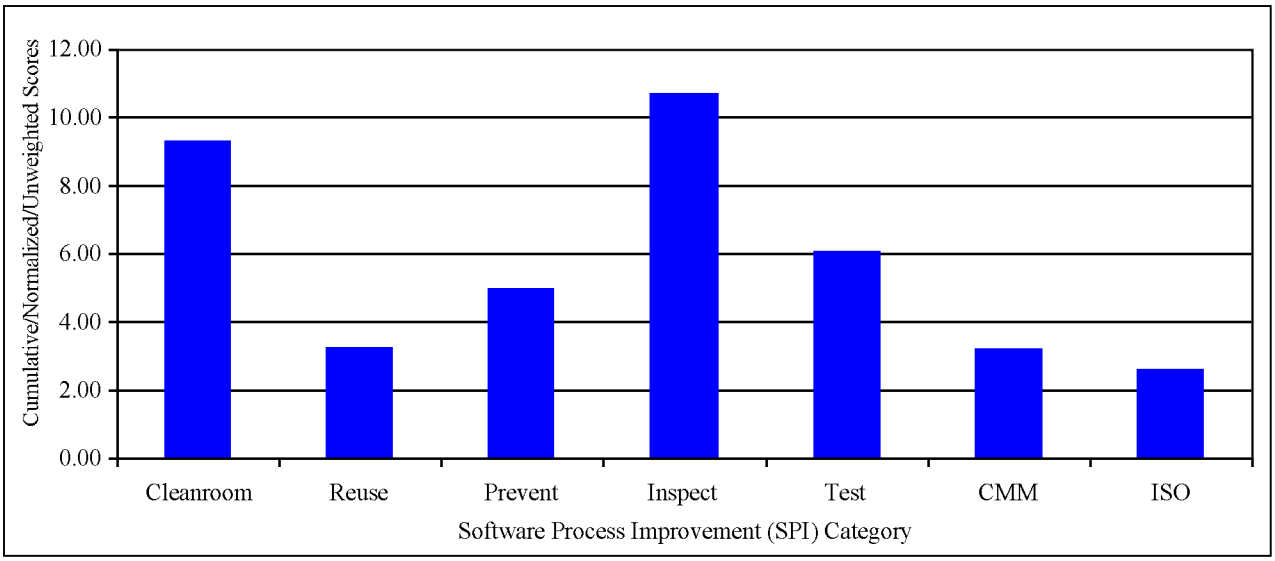


Figure 51. Average Benefits of Worst Strategies

Test seems to have the best Cycle Time Reduction and Productivity Increase, Clean Room has the best Quality Increase, and Inspection has the best Return-on-Investment of this group. Inspection's high Return-on-Investment and good performance in Cycle Time Reduction and Productivity propel Inspections to the top of this analysis.

It's somewhat surprising that Reuse and Defect Prevention are performing so poorly in this analysis, and that CMM and ISO 9000 seem to be performing so well. Reflecting on the Cost and Benefit model recalls authoritative data for Defect Prevention, but scant data for ISO 9000.

Benefit-Based Comparison of Poorest Alternatives

Once again, the overarching and overshadowing benefits of a few SPI strategies, Clean Room and Inspection, overshadow the benefits of the poorest SPI strategies, Reuse, Defect Prevention, Test, CMM, and ISO 9000, demanding a closer examination and comparative analyses of these alternatives (as shown in Table 103).

Table 103: Normalized Benefits of Poorest Strategies

	Reuse	Prevent	Test	CMM	ISO	Average
Cycle Time Reduction	2.36	1.08	3.93	1.91	0.73	2.00
Productivity Increase	1.83	1.27	4.16	1.98	076	2.00
Quality Increase	1.36	1.5	1.81	1.43	3.91	2.00
Return-on-Investment	0.34	7.78	0.90	0.58	0.40	2.00
	5.88	11.62	10.80	5.90	5.80	

Table 103 highlights the strengths of Test for Cycle Time Reduction and Productivity Increase, and relative parity among these criteria for Reuse, Defect Prevention, and CMM. ISO 9000 comes out on top for Quality Increase, with parity for Reuse, Defect Prevention, Test, and CMM. Defect Prevention has a towering Return-on-Investment as show in Figure 52).

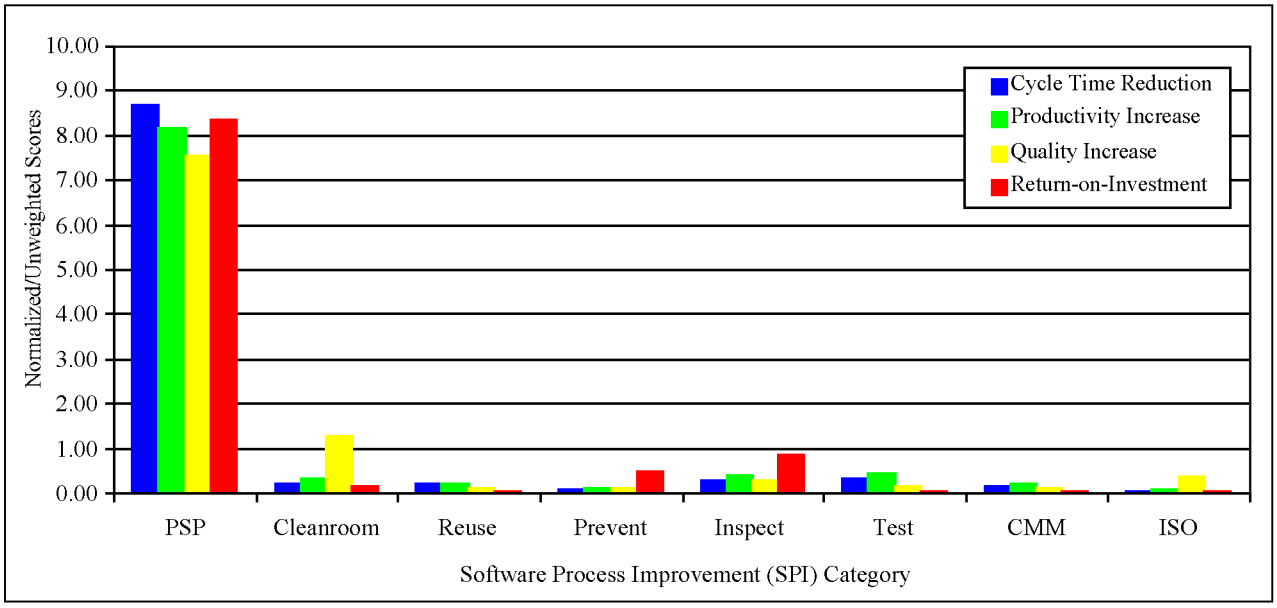


Figure 52. Normalized Benefits of Poorest Strategies

A composite graph of the benefits of the five poorest SPI strategies, Reuse, Defect Prevention, Test, CMM, and ISO 9000, provides useful analysis for determining the overall strengths of each SPI strategy (as shown in Figure 53).

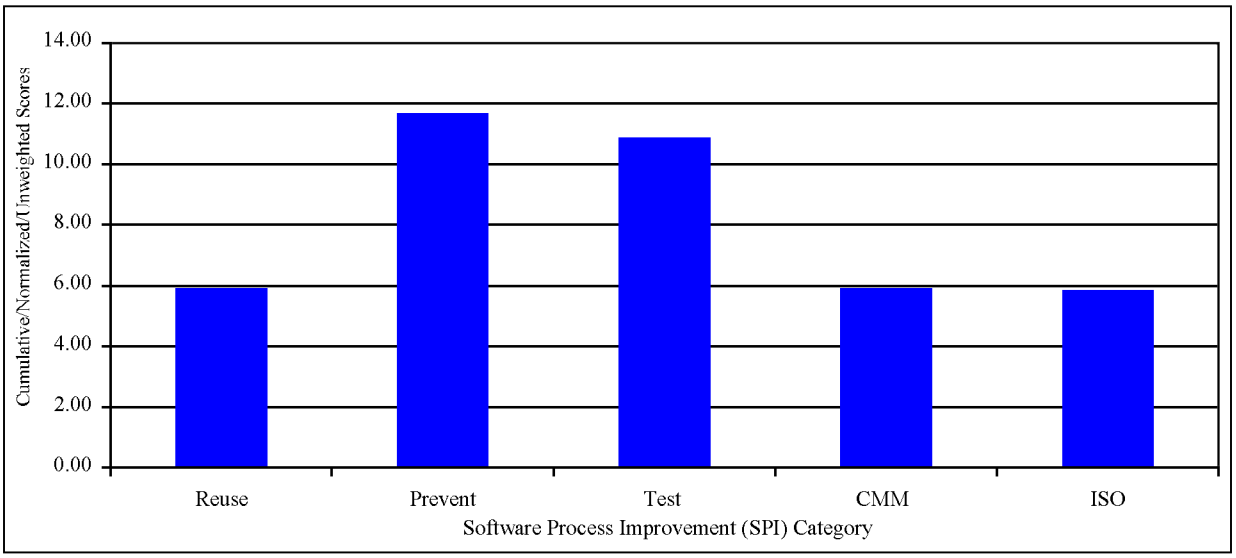


Figure 53. Average Benefits of Poorest Strategies

Figure 53 reveals that Defect Prevention has the best overall benefit average, followed closely by Test, and then CMM, Reuse, and ISO 9000. Defect Prevention outperforms Test by only 1.08X, CMM by 1.97X, Reuse by 1.98X, and ISO 9000 by 2X.

While Test does better than Defect Prevention in three out of four criteria, Defect Prevention does come out on top of this analysis. However, a composite of their average benefits places them on par, and reveals that they are an average of 2X better than the other three SPI strategies, CMM, Reuse, and ISO 9000. Reuse is performing much worse than anticipated at the outset of this study. While Reuse, wasn't targeted for initial analysis, Reuse cost and benefit data revealed by the Literature Survey made Reuse a natural candidate for inclusion in the analyses. However, Reuse was expected to perform better than the Vertical Process and Indefinite SPI strategies, which is largely attributed to the way Reuse training costs are computed.

Cost/Benefit-Based Comparison of Categories

This section is designed to analyze the costs and benefits, not of individual SPI strategies, but the three classes of SPI strategies referred to throughout this study as Vertical Life Cycle, Vertical Process, and Indefinite. Vertical Life Cycle SPI strategies included the PSP, Clean Room, and Reuse, Vertical Process SPI strategies included Defect Prevention, Inspection, and Test, and Indefinite SPI strategies included CMM and ISO 9000. Vertical Life Cycle, Vertical Process, and Indefinite strategy costs and benefits are analyzed here (as shown in Table 104).

Table 104: Costs and benefits of Categories

	Vertical Life Cycle	Vertical Process	Indefinite
Breakeven Hours	2,818	1,350	7,497
Training Hours/Person	1,199	42	145
Training Cost/Person	$104,662	$7,041	$11,072
Effort (Hours)	6,619	13,482	74,108
Cycle Time Reduction	57.08x	4.43x	2.06x
Productivity Increase	38.82x	4.50x	2.02x
Quality Increase	100.06x	6.51x	8.50x
Return-on-Investment	440:1	72:1	5:1

There are two interesting points to ponder about this analysis in Table 104, validity and significance. As for validity, it is theorized that the costs and benefits of Vertical Life Cycle SPI strategies would be superior because of increased efficiencies due to comprehensiveness. Vertical Process SPI strategies were theorized to be fast, streamlined, and highly efficient. And, Indefinite SPI strategies were hypothesized to fail in all criteria. The fundamental question is whether this classification is valid. After much analysis, the answer is a resounding "yes." PSP's costs, benefits, and efficiencies are overwhelming, though the PSP was not initially anticipated to exhibit these properties as strongly as it has. And, Clean Room and Reuse are much broader life cycle approaches, though clearly not as efficient and effective as PSP. The Vertical Process SPI strategies ended up much better than expected, behind strong performances in Return-on-Investment and low initial investment costs (at least as computed by this study). Indefinite SPI strategies performed extremely well, despite the fact that they were expected to perform extremely badly. Indefinite SPI strategies may have been helped by cost and benefit data that may have actually applied Vertical Process SPI strategies, along side the Indefinite approaches. This may have biased this study in favor of the Indefinite approaches, but not enough to overcome the raw power of the Vertical Life Cycle and Vertical Process SPI strategies. As for significance, the overwhelming cost and benefit efficiencies of PSP and Inspection over Indefinite SPI strategies increases the significance of this analysis, and highlights the continuing role of Vertical Process SPI strategies in the 21st century.

Cost and benefit data for the SPI categories in Table 104 were normalized to facilitate further analysis (as shown in Table 105 and Figure 54). Cost normalization was computed by inverting the raw criterion value divided by the sum of all the values for the given criterion, and multiplying the result by 10. Benefit normalization was computed by dividing the raw criterion value by the sum of all the values for the given criterion, and multiplying the result by 10.

Table 105: Normalized Costs and Benefits of Categories

	Vertical Life Cycle	Vertical Process	Indefinite
Breakeven Hours	7.58	8.84	3.57
Training Hours/Person	1.35	9.69	8.95
Training Cost/Person	1.48	9.43	9.10
Effort (Hours)	9.30	8.57	2.13
Cycle Time Reduction	8.98	0.70	0.32
Productivity Increase	8.56	0.99	0.45
Quality Increase	8.70	0.57	0.74
Return-on-Investment	8.51	1.40	0.09
	54.46	40.18	25.36

Breakeven Hours

Normalized values for Breakeven Hours range from near four to about nine for the SPI categories (as shown in Table 105 and Figure 54). Breakeven Hours from left to right are 7.58, 8.84, and 3.57. Vertical Process is the best and Indefinite is the worst in this analysis. The difference between best and worst is a factor of 2.39X.

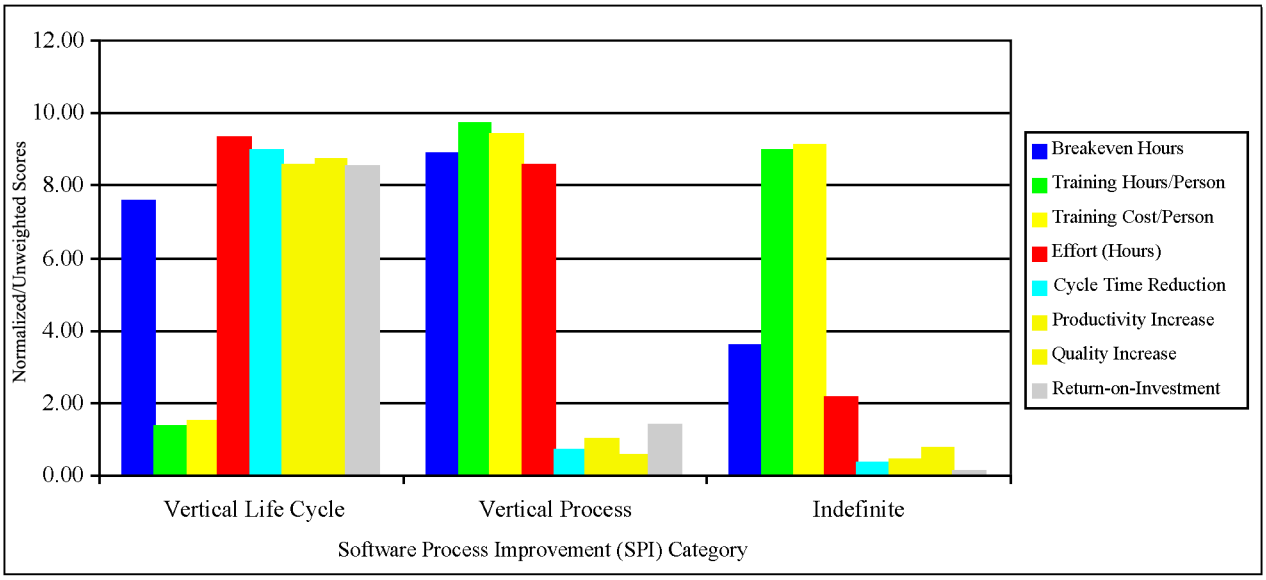


Figure 54. Normalized Costs and Benefits of Categories

Training Hours/Person

Normalized values for Training Hours/Person range from about one to nearly ten for the SPI categories (as shown in Table 105 and Figure 54). Training Hours/Person from left to right are 1.35, 9.69, and 8.95. Vertical Process is the best and Vertical Life Cyle is the worst in this analysis. The difference between best and worst is a factor of 7.18X. The auspicious and unusually high training costs for Clean Room and Reuse as derived by this study biased this analysis against Vertical Life Cycle strategies.

Training Cost/Person

Normalized values for Training Cost/Person range from near two to almost ten for the SPI categories (as shown in Table 105 and Figure 54). Training Cost/Person from left to right is 1.48, 9.43, and 9.10. Vertical Process is the best and Vertical Life Cycle is the worst in this analysis. The difference between best and worst is a factor of 6.37X. Once again, the unusual source values for this analysis require caution in interpreting these results.

Effort (Hours)

Normalized values for Effort (Hours) range from near two to nine for the SPI categories (as shown in Table 105 and Figure 54). Effort (Hours) from left to right are 9.30, 8.57, and 2.13. Vertical Life Cycle is the best and Indefinite is the worst in this analysis. The difference between best and worst is a factor of 4.37X.

Cycle Time Reduction

Normalized values for Cycle Time Reduction range from near zero to nine for the SPI categories (as shown in Table 105 and Figure 54). Cycle Time Reduction from left to right is 8.98, 0.70, and 0.32. Vertical Life Cycle is the best and Indefinite is the worst in this analysis. The difference between best and worst is a factor of 28.06X. Vertical Process faired nearly as badly as Indefinite.

Productivity Increase

Normalized values for Productivity Increase range from near zero to nine for the SPI categories (as shown in Table 105 and Figure 54). Productivity Increase from left to right is 8.56, 0.99, and 0.45. Vertical Life Cycle is the best and Indefinite is the worst in this analysis. The difference between best and worst is a factor of 19.02X. Vertical Process faired nearly as badly as Indefinite.

Quality Increase

Normalized values for Quality Increase range from almost one to about nine for the SPI categories (as shown in Table 105 and Figure 54). Quality Increase from left to right is 8.7, 0.57, and 0.74. Vertical Life Cycle is the best and Vertical Process is the worst in this analysis. The difference between best and worst is a factor of 15.26X. Indefinite faired nearly as badly as Vertical Process.

Return-on-Investment

Normalized values for Return-on-Investment range from near zero to about nine for the SPI categories (as shown in Table 105 and Figure 54). Return-on-Investment from left to right is 8.51, 1.4, and 0.09. Vertical Life Cycle is the best and Indefinite is the worst in this analysis. The difference between best and worst is a factor of 94.56X. Vertical Process was nearly as unimpressive as Indefinite.

A composite of overall cost and benefits for the three SPI categories, Vertical Life Cycle, Vertical Process, and Indefinite, exhibits greater parity between them (as shown in Figure 55). Vertical Life Cycle SPI strategies are 1.36X better than Vertical Process, and 2.15X better than Indefinite, according to this study and analysis. And, Vertical Process SPI strategies are 1.58X better than Indefinite, according to this study.

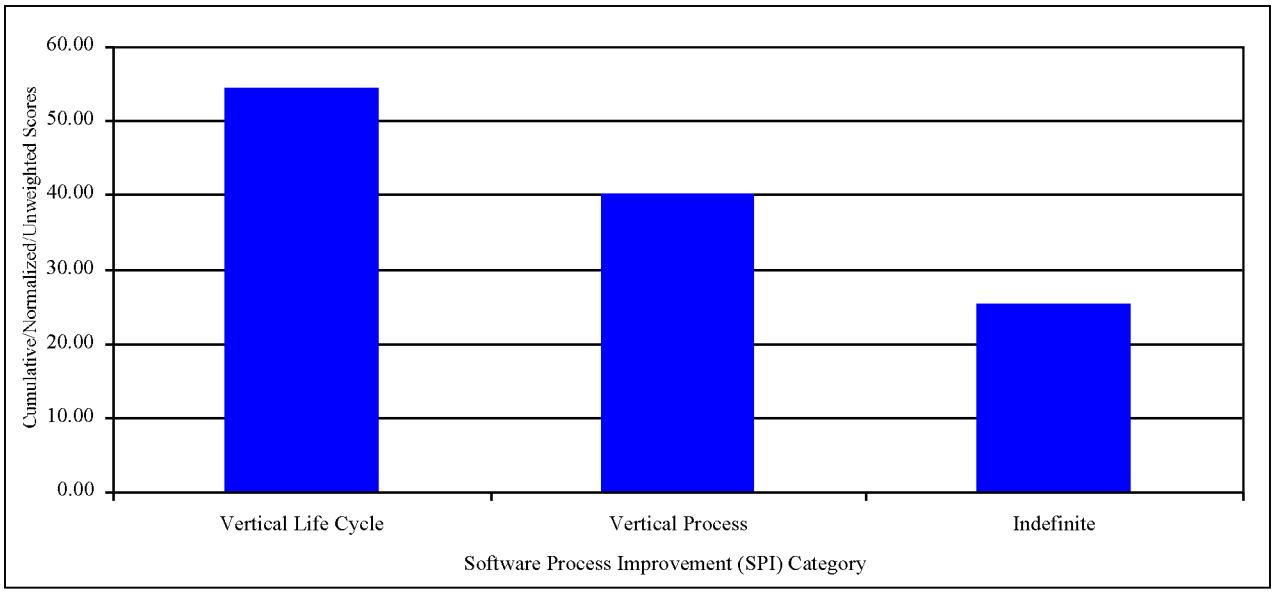


Figure 55. Average Costs and Benefits of Categories

The results of this analysis were not completely unexpected, as Vertical Life Cycle was expected to outperform Vertical Process and Indefinite, and it did. Vertical Process was expected to outperform Indefinite, and it did. And, it is not even surprising that there wasn't greater differentiation in the composite averages for each of the categories. This study will need to focus on the benefits of the categories, as well as segregate off the Vertical Life Cycle data.

Benefit-Based Comparison of Categories

Comparison of both the costs and benefits of Vertical Life Cycle, Vertical Process, and Indefinite SPI strategies suffered from the same dilemma as the earlier analysis did, parity and perhaps even insignificance of the costs associated with the SPI categories. Therefore, this section is designed to focus the readers attention on the benefits of the Vertical Life Cycle, Vertical Process, and Indefinite SPI strategies (as shown in Table 106).

Table 106: Normalized Benefits of Categories

	Vertical Life Cycle	Vertical Process	Indefinite
Cycle Time Reduction	8.98	0.70	0.32
Productivity Increase	8.56	0.99	0.45
Quality Increase	8.70	0.57	0.74
Return-on-Investment	8.51	1.40	0.09
	34.75	3.65	1.60

These are the same benefits found in Table 105. Table 106 indicates that PSP has a 9.52X benefit advantage over Vertical Process, and a 21.72X advantage over Indefinite. These normalized values are very revealing (as illustrated in Figure 56).

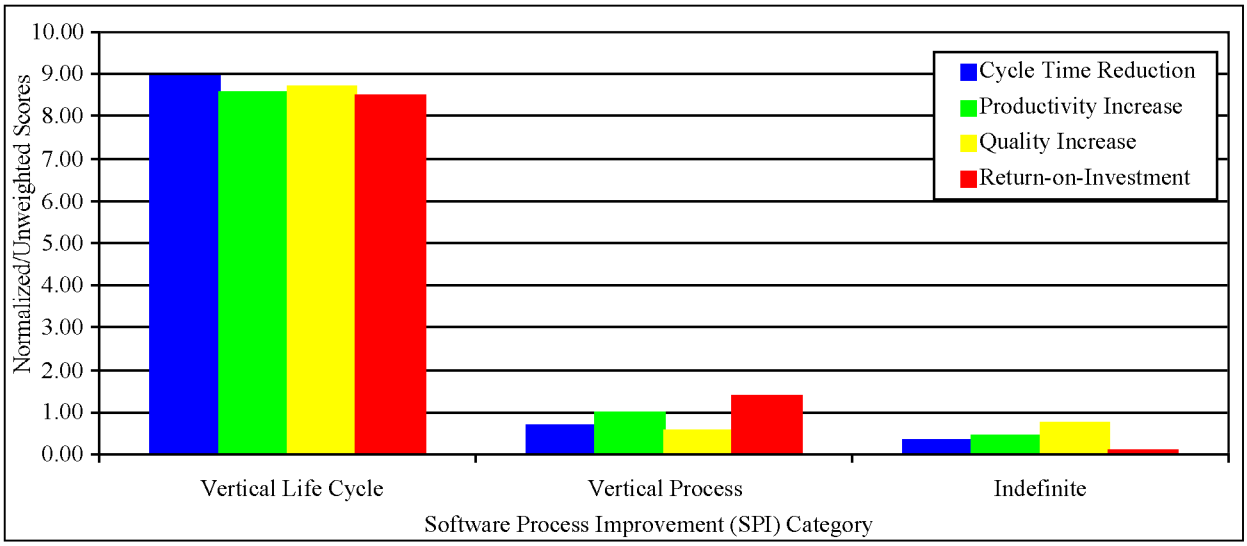


Figure 56. Normalized Benefits of Categories

Figure 56 emphasizes the vast difference in benefits between Vertical Life Cycle SPI strategies, and Vertical Process and Indefinite SPI strategies. This analysis reveals that there is much less parity and equality between the SPI categories than previously implied by Figure 55. This chasm between the benefits of Vertical Life Cycle SPI strategies and the others was not anticipated (as shown in Figure 57).

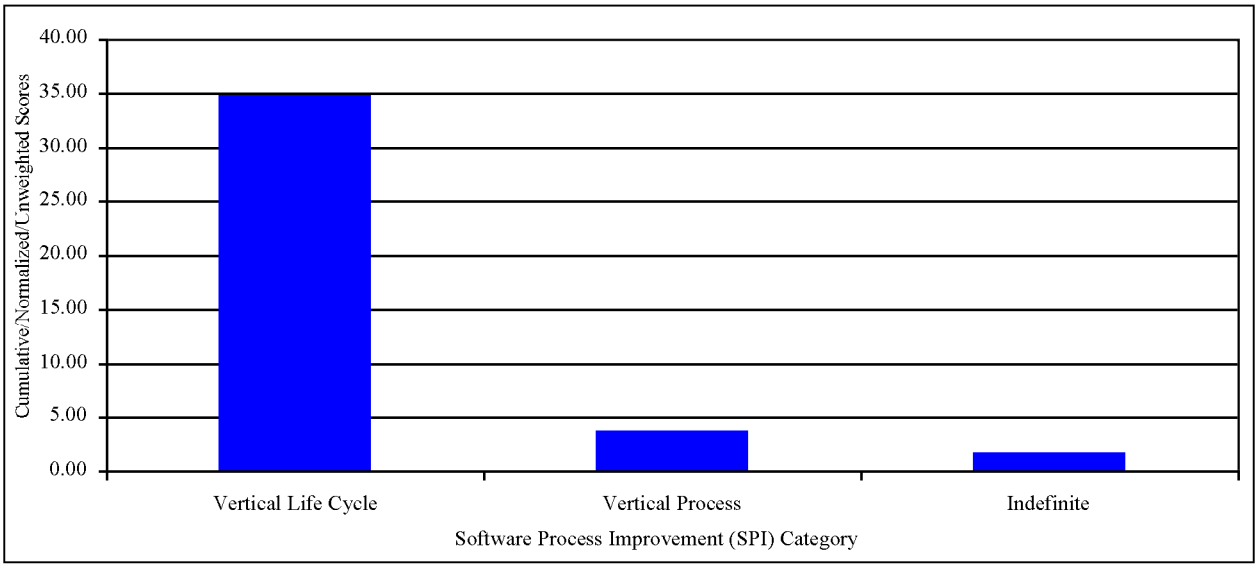


Figure 57. Average Benefits of Categories

The composite benefits of the Vertical Life Cycle SPI category tower over the others. The average benefits of the Vertical Process and Indefinite SPI categories look almost uninteresting. But this is deceiving as will be later revealed.

Once again, the overwhelming benefits of the Vertical Life Cycle SPI category weren't anticipated at the outset of this study. But, even more surprising was the reasonably good benefit performance of the Indefinite SPI category, and the surprisingly even performance between the Vertical Process and Indefinite SPI categories.

The remainder of the analysis will focus on comparing the benefits of the Vertical Process and Indefinite SPI categories. Further analysis will prove interesting and valuable.

Table 107: Normalized Benefits of Worst Categories (Part I)

	Vertical Process	Indefinite
Cycle Time Reduction	6.82	3.18
Productivity Increase	6.90	3.10
Quality Increase	4.34	5.66
Return-on-Investment	9.38	0.62
	27.44	1 2.56

There is definitely greater differentiation between the benefits of Vertical Process and Indefinite SPI categories than revealed by Table 106, Figure 56, and Figure 57 (as shown in Table 107). The advantages for the Vertical Process over the Indefinite category include 2.14X for Cycle Time Reduction, 2.23X for Productivity Increase, and 15.13X for Return-on-Investment. Very surprisingly, the Indefinite category did have one advantage over the Vertical Process category, a 1.3X for Quality Increase. This was probably due to a single questionable quality value reported for ISO 9000. Overall, the Vertical Process Category has a 2.18X advantage over the Indefinite category (as illustrated in Figure 58).

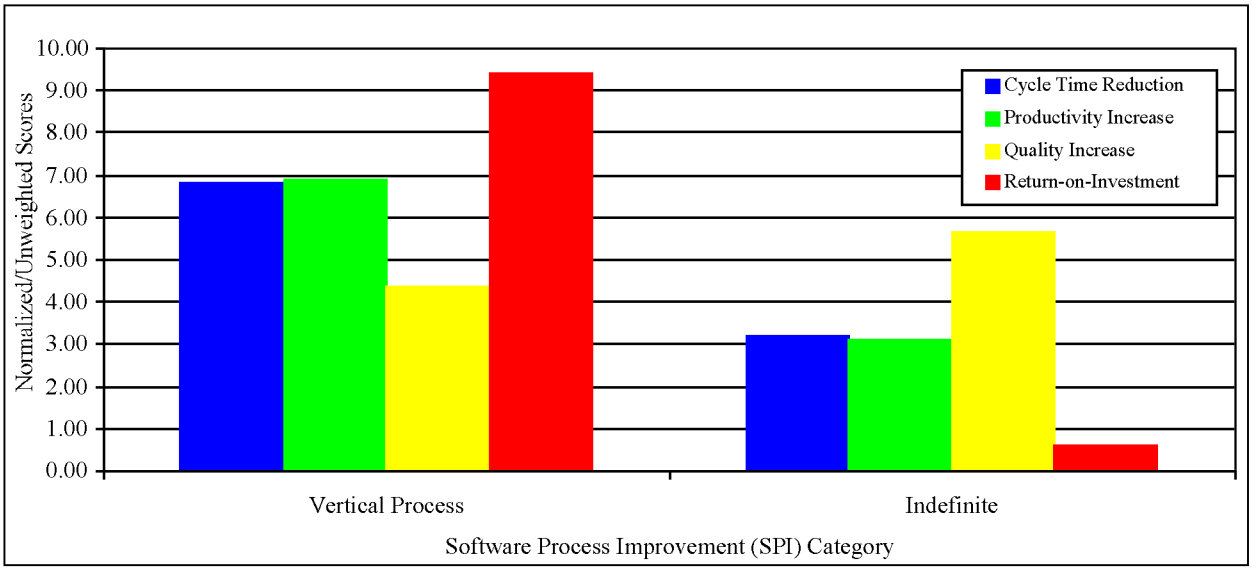


Figure 58. Normalized Benefits of Worst Categories (Part I)

A composite average of the benefits for Vertical Process and Indefinite SPI categories does reveal a strong advantage for the Vertical Process category (as shown in Figure 59).

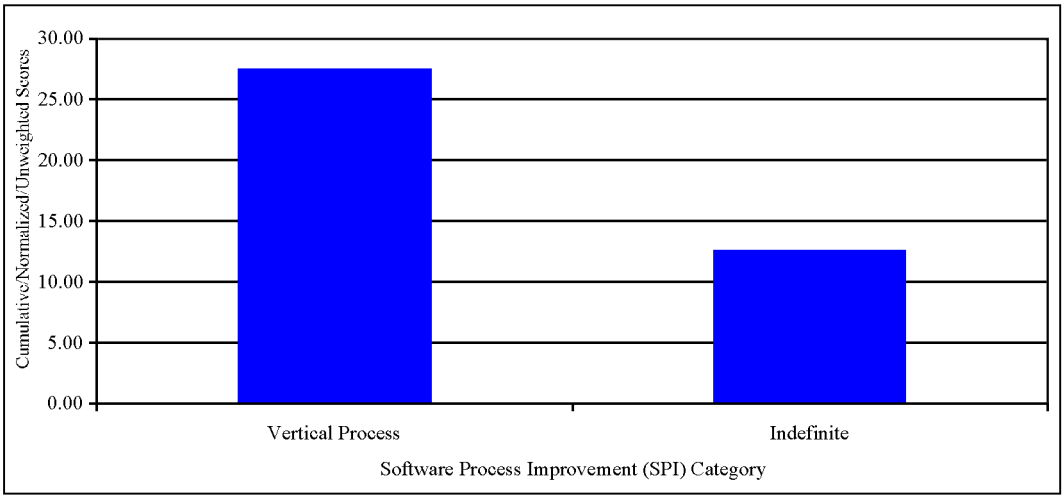


Figure 59. Average Benefits of Worst Categories (Part I)

Once again, Quality Increase data for the Vertical Process category was very strong and authoritative, ensuring a valid result in this area. However, ISO 9000 actually had sparse quantitative data available, and there is little confidence in the Quality Increase value reported for the Indefinite category. Return-on-Investment results seem to skew the final evaluation, demanding segregation of this data element for final evaluation. Therefore a final analysis without Return-on-Investment data was designed in order to support full evaluation of the benefits involving Vertical Process versus Indefinite SPI categories (as shown in Table 108).

Table 108: Normalized Benefits of Worst Categories (Part II)

	Vertical Process	Indefinite
Cycle Time Reduction	6.82	3.18
Productivity Increase	6.90	3.10
Quality Increase	4.34	5.66
	1 8.06	1 1.94

Table 108 still exhibits a substantial advantage for the Vertical Process SPI category over the Indefinite SPI category, even without Return-on-Investment. The Vertical Process SPI category still holds a 2.18X advantage over the Indefinite SPI category for Cycle Time Reduction and Productivity Increase (as shown in Figure 60).

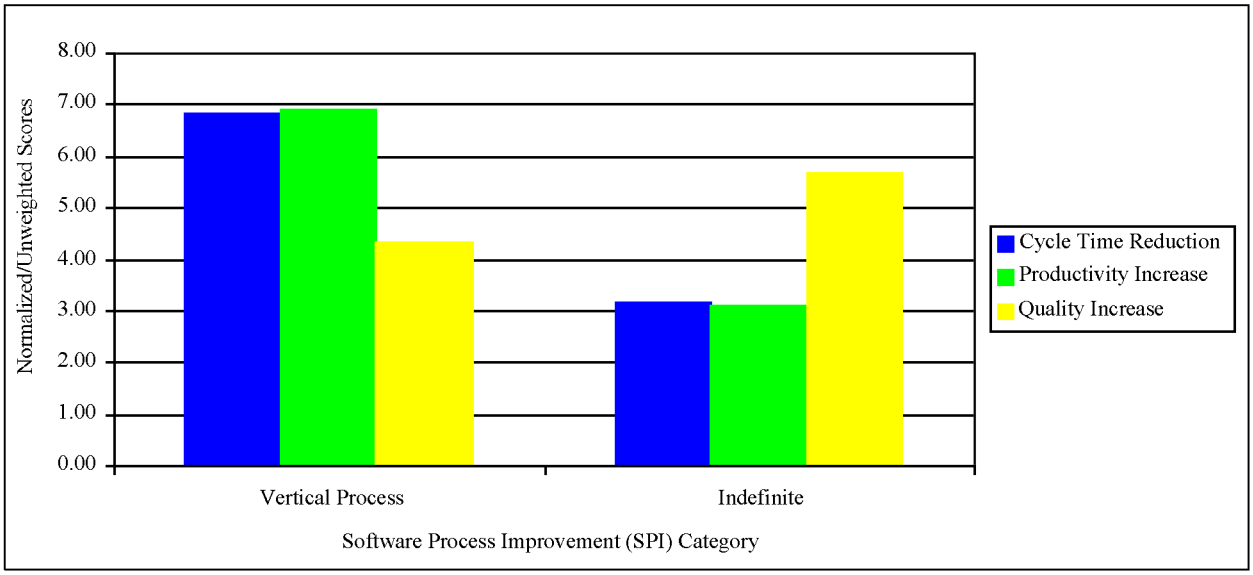


Figure 60. Normalized Benefits of Worst Categories (Part II)

And, finally, the composite average for Vertical Process and Indefinite SPI categories concludes the Data Analysis for this study (as illustrated in Figure 61).

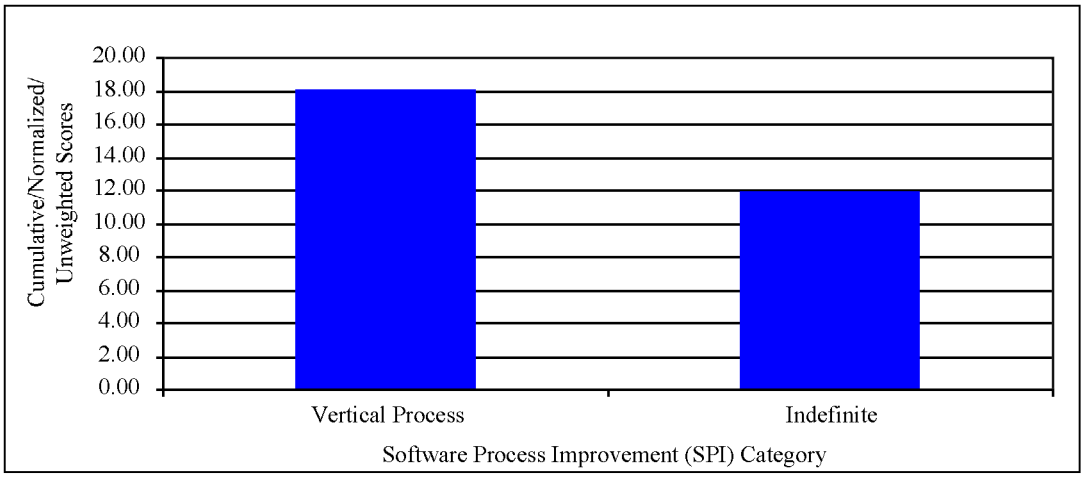


Figure 61. Average Benefits of Worst Categories (Part II)

Conclusion

As stated in the title, this study involved "Using Cost Benefit Analyses to Develop a Pluralistic Methodology for Selecting from Multiple Prescriptive Software Process Improvement (SPI) Strategies." Rather simply, this study identified as many step-by-step SPI strategies that could be conclusively analyzed based on cost and benefit data, in order to help software managers and engineers in choosing SPI strategies, or at least understanding the behavioral economics of the SPI strategies that they currently employ.

While, it was hoped that more SPI strategies could be conclusively analyzed, such as the Team Software Process (TSP), Orthogonal Defect Classification (ODC), Software Process Improvement and Capability dEtermination (SPICE), IEEE 12207, Configuration Management (CM), or Malcolm Baldrige National Quality Award (MBQNA), we are satisfied with what was accomplished. In fact, eight well-known SPI strategies were quite impressively analyzed, Personal Software Process (PSP), Clean Room, Reuse, Defect Prevention, Inspection, Test, Capability Maturity Model (CMM), and ISO 9000. Not only are we sufficiently satisfied that an authoritative base of SPI strategies were identified and analyzed, but that this study accomplished a uniquely quantitative study of this magnitude for the first time (as known by this author). While the SPI strategies, data, models, conclusions, and fidelity were less than perfect, it is believed that this study substantially forwards the state-of-the-art in SPI strategy economic analyses, especially with respect to the Personal Software Process (PSP).

An exhaustive Literature Review was attempted for several reasons, identify an authoritative body of SPI strategies, metrics and models for evaluating SPI strategies, SPI strategy costs and benefits for later analyses, and most importantly, a suitable methodology for evaluating the economics of SPI strategies. While, the Literature Review accomplished all of these goals and objectives, it is believed that a primary accomplishment is the design of the Methodology, which can continue to be populated with SPI strategy costs and benefits.

As mentioned before, the Literature Survey was instrumental in identifying Clean Room and Reuse costs and benefits, thus making the decision to include these SPI strategies in this study. The other six SPI strategies, PSP, Defect Prevention, Inspection, Test, CMM, and ISO 9000 were already selected in advance for economic analyses. More SPI strategies that would have been valuable would have included Experience Factory, Goal Question Metric (GQM), Statistical Process Control (SPC), Product Line Management, Initiating, Diagnosing, Establishing, Acting & Learning (IDEAL), or the plethora of the SEI's CMM variations. Even CMM-Based Assessments for Internal Process Improvement (CBA-IPIs) and Software Capability Evaluations (SCEs) are considered SPI strategies by some. What about BOOTSTRAP, Trillium, SPRM, and a virtual constellation of various proprietary methods? Yes, it would really be something if there were quantitative costs and benefits available and associated with every SPI strategy mentioned here.

There were several major contributions made by this study, an extensible framework and Methodology that can be populated with higher fidelity economic data, and some rather suprising economic results for SPI strategies such as PSP, Inspection, and Test. The PSP was initially only considered to be a minor player that would be overshadowed by SPI strategy legends such as Clean Room, Defect Prevention, and Inspection. However, the economic advantages of PSP proved to be far too overwhelming against the seven classical SPI strategies selected for comparative analysis, Clean Room, Reuse, Defect Prevention, Inspection, Test, CMM, and ISO 9000. In addition, this study continued to advance the tri-fold theoretical taxonomy and classification of SPI strategies, Vertical Life Cycle, Vertical Process, and Indefinite.

Results of Data Analysis

See the Methodology and Data Analysis for detailed economic analyses of the costs and benefits of the eight SPI strategies, PSP, Clean Room, Reuse, Defect Prevention, Inspection, Test, CMM, and ISO 9000, as well as the three SPI categories, Vertical Life Cycle, Vertical Process, and Indefinite. This section will attempt to directly translate the economic and data analyses into the conceptual terms Good, Average, and Poor. The technique for making this conceptual translation was to divide the range of values into three parts, and assign the term Poor if the value fell in the first third, Average if the value fell in the second third, and Good if the value fell in the last third. This conceptual translation was based directly upon normalized economic values and was not arbitrarily or qualitatively assigned.

Table 109: Comparative Summary of Eight Strategies

	PSP	Cleanroom	Reuse	Prevent	Inspect	Test	CMM	ISO
Breakeven Hours	Good	Good	Good	Good	Good	Good	Average	Good
Training Hours/Person	Good	Good	Poor	Good	Good	Good	Good	Good
Training Cost/Person	Good	Good	Poor	Good	Good	Good	Good	Good
Effort (Hours)	Good	Good	Good	Good	Good	Good	Average	Good
Cycle Time Reduction	Good	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Productivity Increase	Good	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Quality Increase	Good	Poor	Poor	Poor	Poor	Poor	Poor	Poor
Return-on-Investment	Good	Poor	Poor	Poor	Poor	Poor	Poor	Poor

Table 109 illustrates that the normalized economic values for the PSP fell into the upper third of ranges when compared to the other seven SPI strategies. Clean Room's costs also fell into the upper third of ranges, but its benefits fell into the lower third of ranges when compared to the PSP. Reuse, Defect Prevention, Inspection, Test, CMM, and ISO 9000 faired similarly to Clean Room when compared to the PSP. This graph indicates relative parity among the costs, but a minimum 3:1 advantage for PSP benefits over the benefits of the other seven SPI strategies.

Since relative parity exists among the costs of the eight SPI strategies, cost data were factored out for further analysis and summarization. The PSP benefits overshadowed the benefits of the other seven SPI strategies, reducing and eliminating differentiation among them. Therefore, PSP data were also factored out for further analysis and summarization. Table 110 illustrates the benefits of the seven worst performing SPI strategies, Clean Room, Reuse, Defect Prevention, Inspection, Test, CMM, and ISO 9000.

Table 110: Comparative Summary of Strategies (Part I)

	Cleanroom	Reuse	Prevent	Inspect	Test	CMM	ISO
Cycle Time Reduction	Poor	Poor	Poor	Average	Average	Poor	Poor
Productivity Increase	Average	Poor	Poor	Average	Average	Poor	Poor
Quality Increase	Good	Poor	Poor	Poor	Poor	Poor	Poor
Return-on-Investment	Poor	Poor	Average	Good	Poor	Poor	Poor

In this analysis, Clean Room yields an average Productivity Increase and a good Quality Increase when compared to the other six worst performing SPI strategies. Reuse yields poor Cycle Time Reduction, Productivity Increase, Quality Increase, and Return-on-Investment when compared against this same set. Defect Prevention only seems to yield an average result for Return-on-Investment, one of the only SPI strategies to do so in this set. Inspection yields average results for Cycle Time Reduction and Productivity Increase, surprisingly yields poor for Quality Increase, and yields the highest value for Return-on-Investment in this set. Test also surprisingly yields average results for Cycle Time Reduction and Productivity Increase. CMM and ISO 9000 yield only poor results among the seven worst performing SPI strategies. Once again, the Clean Room and Inspection results overshadow the results of the other five SPI strategies, necessitating further analysis of the poorest performing SPI strategies, Reuse, Defect Prevention, Test, CMM, and ISO 9000 (as shown in Table 111).

Table 111: Comparative Summary of Strategies (Part II)

	Reuse	Prevent	Test	CMM	ISO
Cycle Time Reduction	Poor	Poor	Average	Poor	Poor
Productivity Increase	Poor	Poor	Average	Poor	Poor
Quality Increase	Poor	Poor	Poor	Poor	Average
Return-on-Investment	Poor	Good	Poor	Poor	Poor

Unfortunately, since the conceptual terms of Poor, Average, and Good were based on the total range of values, Defect Prevention scored very high for Return-on-Investment, pushing the results for the five poorest performing SPI strategies downward. Reuse scored poorly for all criterion in this analysis. Defect Prevention scored poor for three out of four criterion values. Test continued to score average for Cycle Time Reduction and Productivity Increase. CMM, like Reuse, score poor for all criterion. And, ISO 9000 scored average for Quality Increase, and poor against the other three criteria, when compared to the five poorest SPI strategies.

Table 112: Comparative Summary of Categories

	Vertical Life Cycle	Vertical Process	Indefinite
Breakeven Hours	Good	Good	Poor
Training Hours/Person	Average	Good	Good
Training Cost/Person	Average	Good	Good
Effort (Hours)	Good	Good	Poor
Cycle Time Reduction	Good	Poor	Poor
Productivity Increase	Good	Poor	Poor
Quality Increase	Good	Average	Average
Return-on-Investment	Good	Average	Average

Finally, the Vertical Life Cycle SPI category yields good and average results for all criteria. The Vertical Process SPI category yields good and average for all criteria, except Quality Increase and Productivity Increase. And, the Indefinite SPI category yields good and average for training costs, as well as Quality Increase and Return-on-Investment.

Outcome of Hypotheses

While, this study doesn't necessarily employ a hypothesis-based methodology and approach, it is none-the-less interesting to qualitatively evaluate the strategic hypotheses established in the Introduction. The first two strategic hypotheses deal with qualitative perceptions associated with the SPI field. The third, fourth, and fifth strategic hypotheses deal qualitatively with the notion that multiple SPI strategies and categories actually exist, attempting to point out the simple notion that there is more than one approach to SPI. The last hypothesis dealt with the identification of criteria for evaluating SPI strategies.

The first hypothesis (emerging definition of SPI)

SPI is a discipline of defining, measuring, and changing software management and development processes and operations in order to increase productivity, increase quality, reduce cycle times, reduce costs, increase profitability, and increase market competitiveness. Table 1 indicates that SPI includes perfecting processes, adding value, adding quality, increasing productivity, increasing speed, increasing efficiency, reducing cost, providing advantages, profiting, increasing flexibility, downsizing, substituting better processes, using methods, defining processes, measuring processes, simplifying processes, adding processes, and incremental change.

The second hypothesis (existence of multiple SPI strategies)

Prevalent SPI strategies such as the PSP, Clean Room, Reuse, Defect Prevention, Inspection, Test, CMM, and ISO 9000 exist and are widely in use. Other mainstream SPI strategies include TSP, ODC, SPICE, IEEE 12207, CM, MBQNA, Experience Factory, GQM, SPC, Product Line Management, IDEAL, other CMM variations, CBA-IPI, SCE, BOOTSTRAP, Trillium, and SPRM.

The third hypothesis (SPI strategies exhibit favorable costs and benefits)

SPI strategies such as the PSP, Clean Room, Reuse, Defect Prevention, Inspection, Test, CMM, and ISO 9000 yield quantitatively favorable results such as increased productivity, increased quality, reduced cycle time, and favorable return-on-investment. The eight SPI strategies analyzed in this study yield Cycle Time Reductions of 23.58X, Productivity Increases of 16.75X, Quality Increases of 42.09X, and Return-on-Investments of 193:1.

The fourth hypothesis (existence of multiple SPI categories)

SPI categories exist such as Vertical Life Cycle (PSP, Clean Room, and Reuse), Vertical Process (Defect Prevention, Inspection, and Test), and Indefinite (CMM and ISO 9000). Other Vertical Life Cycle SPI strategies include TSP, IEEE 12207, and Product Line Management. Other Vertical Process SPI strategies include ODC, CM, and SPC. And, other Indefinite SPI strategies include SPICE, MBQNA, Experience Factory, GQM, IDEAL, other CMM variations, CBA-IPI, SCE, BOOTSTRAP, Trillium, and SPRM.

The fifth hypothesis (SPI categories exhibit distinct costs and benefits)

Vertical Life Cycle SPI strategies are 1.36X better than Vertical Process and 2.15X better than Indefinite. Vertical Process SPI strategies are 1.58X better than Indefinite. Cycle Time Reduction, Productivity Increase, Quality Increase, and Return-on-Investment are 57X, 39X, 100X, and 440:1 for Vertical Life Cycle, 4X, 5X, 7X, and 72:1 for Vertical Process, and 2X, 2X, 9X, and 5:1 for Indefinite.

The sixth hypothesis (existence of criteria for evaluating SPI strategies)

Criteria for evaluating SPI strategies include Breakeven Hours, Training Hours/Person, Training Cost/Person, Effort (Hours), Cycle Time Reduction, Productivity Increase, Quality Increase, and Return-on-Investment. 72 scholarly surveys identified by this study organized 487 individual software metrics into 14 broad metrics classes such as Productivity, Design, Quality, Effort, Cycle Time, Size, Cost, Change, Customer, Performance, ROI, and Reuse.

Reliability and Validity

According to Kan (1995), reliability deals with the predictive accuracy of a metric, model, or method, and validity deals with whether the predicted value is correct. Reliability and validity became of paramount concern as the Methodology was being designed and constructed. This study addresses a very serious issue, cost and benefits associated with software management and development. The software industry is a critically and strategically important as the world moves into the 21st century. Therefore, reliability and validity of the metrics, models, methods, and results of this study have to be dealt with responsibly. We will attempt to do so here, though reliability and validity were summarily dealt with throughout the Methodology, as necessary.

First, let's address the design of the Methodology. Kan (1995) firmly asserts that the Defect Removal Model is good for software quality management, but not accurate for predicting reliability. Many of the costs and benefits throughout this study were based on empirical relationships established by the Defect Removal Model. Therefore, the predictive nature of the Methodology should not be taken for granted. The bottom line results of this study were for gross analytical purposes, and are probably not good for concisely predicting the costs and benefits associated with any one application of the aforementioned SPI strategies. In other words, don't create an operational budget from the results of this study. The Cost and Benefit Data used to drive the final analyses were not always related and correlated to one another, therefore, not exhibiting a direct cause and effect relationship. In other words, applying a specified amount of cost used in this study may not yield the associated benefit. The Return-on-Investment Model, while employing valid mathematical methods and relationships, only took training costs into account, ignoring the much reported high-costs of organizational and cultural change. In other words, it may take more than a few hours of training to employ and institutionalize the SPI strategies analyzed by this study. The Break Even Point Model, like the Return-on-Investment Model doesn't account for the high-costs of organizational and cultural change. Ironically, the Clean Room and Reuse sources, which had unusually high costs may have actually done so. The Costs and Benefits of Alternatives should also be used and interpreted with caution. While some of the data is believed to be very authoritative, particularly for PSP and Inspections, some data is very questionable, especially for CMM and ISO 9000. This isn't to say that the PSP analysis is highly reliable, as there are intermittent sources reporting the high cost of organizational and cultural change associated with this SPI strategy.

As alluded to here and throughout the Methodology, the cost of training, implementation, and institutionalization seems to be the least understood, or at least analyzed, element in this study. While, SPI strategy training and implementation costs may make an excellent topic for future research and analysis, these costs may be a large suspect source of reliability and validity associated with this study. As reported earlier, Return-on-Investment and Breakeven Hours were based on authoritative costs to train a single individual, not an entire organization. When using this study to aid in software organizational design and SPI strategy rollout, carefully analyze and estimate the cost to train all strategic personnel, and then reapply the ROI and break even models suggested by this study. Doing so will yield a more realistic estimate, which once again, should only be used as a guideline, not an absolute. The Methodology used a sample software defect population size associated with medium to large-scale software development. Modern website development tends to deal with small software product sizes and extremely small defect populations, which would require careful reinterpretation of ROI and Breakeven Hours. However, if your Internet strategy involves small numbers of engineers, this study may actually prove very useful for cost and benefit analysis, but not necessarily cost prediction.

Future Research

This study has revealed several areas for future research, developing a dynamically scaleable Return-on-Investment Model, continuing to populate the models in the Methodology with more authoritative and accurate cost and benefit data, accurately modeling training and implementation costs, and including exciting new SPI strategies.

Scaleable Return-on-Investment Model

Two interrelated items for future research in this area include automating the Methodology, so that cost and benefit data may be automatically entered and reports generated, and allowing the user to input a variety of factors such as organizational size, product size, efficiencies, and time-scales.

Continuing Cost and Benefit Data Population

Now that our awareness has been heightened to strategic cost and benefit factors associated with SPI strategies and a highly structured framework has been designed to capture, classify, and analyze them, increasingly frequent reports of cost and benefit data should be input into the models.

Accurately Modeling Training and Implementation Costs

Perhaps, additional criteria need to be added, such as the costs associated with not only training employees in the various SPI strategies, but the costs associated with organizational and cultural adaptation, change, and penetration.

Analyzing Emerging Strategies

This will probably be one of the most fruitful areas for future research. Quantitative benefits for the TSP are rapidly emerging and should've been included in this study as a Vertical Life Cycle. In addition, ODC is reported to be orders of magnitude more effective than Defect Prevention, and should've been included in this study as a Vertical Process. More and more data is emerging associated with using the CMM, CBA-IPIs, SCEs, and SPICE. The methodology should include these methods as Indefinite SPI strategies.

Recommendations

The recommendations are primarily three-fold, and were not anticipated in advance of initiating this study, carefully consider the Personal Software Process (PSP), Software Inspection Process, and Software Test Process, as critically strategic Software Process Improvement (SPI) strategies. The reason these recommendations weren't expected to be the final results, was because the PSP wasn't expected to perform so well, Inspections were perceived to be obsolete, and Testing was believed to be far too inefficient.

Personal Software Process (PSP)

The PSP yields phenomenal results for Cycle Time Reduction, Productivity Increase, Quality Increase, and especially Return-on-Investment, such as 164X, 110X, 254X, and 1,290:1. Cost and benefit data for the PSP are by far the most plentiful, robust, and detailed than for any SPI strategy identified by this study.

Software Inspection Process

Inspections yield excellent results for Cycle Time Reduction, Productivity Increase, Quality Increase, and once again especially Return-on-Investment, such as 6X, 6X, 9X, and 133:1. Inspections are widely known and respected techniques that will continue to prove viable in the 21st century. Cost and benefit data for Inspection is plentiful and very authoritative.

Software Test Process

Test yields respectable results for Cycle Time Reduction, Productivity Increase, Quality Increase, and Return-on-Investment, such as 6X, 6X, 6X, and 9:1. Reluctantly speaking, Test may be a fruitful area for focus and improvement, as Test is a traditional and widely employed technique in use throughout the world. While, admittedly Test processes are rather immature, or at least they are in use, they may be excellent candidates for immediate improvement. PSP and Inspections would require substantially more cultural change and commitment than Test.

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