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2004 U. S. Government’s Top 5 Programs

The annual Top 5 contest to award quality software development has a new name, and its scope has expanded to include total program performance.

Project Management

Software Project Management Practices: Failure Versus Success

This author’s analysis of successful large software projects versus those that ran late, were over budget, or cancelled reveals six common problems associated with project management rather than with technical personnel.

by Capers Jones

Catastrophe Disentanglement: Getting Software Projects Back on Track

Most software calamities were troubled projects that went on for too long. This article proposes a 10-step process to effectively deal with an out-of-control project and get it back on track.

by E.M. Bennatan

Understanding Causal Systems

This article describes a model and a supporting set of terms that facilitate reasoning about and planning for causal systems and designing process experiments, all of which is based on practical experience.

by David N. Card

Software Engineering Technology

Requirements Engineering So Things Don’t Get Ugly

Even if you know exactly what you want, requirements engineering is a tough task that requires understanding different points of view. This author discusses how processes in the Capability Maturity Model Integration provide a good foundation to accomplish this.

by Deb Jacobs

Open Forum

Independent Estimates at Completion – Another Method

This article reviews the most frequently used Earned Value Management formulas for calculating the Independent Estimate at Completion (IEAC), and proposes an alternative method of calculating IEAC that shows promise.

by Walt Lipke
CROSSTALK Welcomes New Sponsors

I am pleased to announce that the three U.S. Air Force Air Logistics Centers’ (ALC) Software Divisions have joined together to become CROSSTALK’s new co-sponsors. The three maintenance directorate divisions are commonly referred to by their office symbol, MAS, and are located at Ogden ALC, Hill Air Force Base, Utah; Oklahoma City ALC, Tinker Air Force Base, Oklahoma; and Warner Robins ALC, Robins Air Force Base, Georgia. Well known for high-quality software development and sustainment capabilities, the divisions are currently under the chief leadership of Randy Hill, Kevin Stamey, and Tom Christian, respectively. You will see little change to CROSSTALK as the journal’s mission remains the same:

To encourage the engineering development of software in order to improve the reliability, sustainability, and responsiveness of our war fighting capability and to inform and educate readers on up-to-date policy decisions and new software engineering technologies.

Also, the Air Force Software Technology Support Center will continue in its role as the publisher as it has since CROSSTALK’s inception in 1988.

We proudly begin this issue by announcing the fourth annual U.S. Government’s Top 5 Programs contest, formerly called the Top 5 Quality Software Projects. The National Defense Industrial Association will facilitate the award process this year. You can submit your 2004 nomination at <www.ndia.org>.

This month we highlight project management and begin with an article from a longtime CROSSTALK supporter, Capers Jones. In his special report to CROSSTALK, Software Project Management Practices: Failure Versus Success, Jones looked at 250 large software projects. He found six common problem areas: project planning, cost estimating, measurements, milestone tracking, change control, and quality control. Learn how project managers focusing on these six areas can increase their project’s chance of success.

Next, Catastrophe Disentanglement: Getting Software Projects Back on Track by E.M. Bennatan is featured in our theme section. This article describes how a project catastrophe can be determined through budget, schedule, or quality aspects and presents a 10-step process to aid a project manager and his or her team in turning around their project before it’s too late.

As organizations continue to journey to high process maturity levels, teams may find themselves faced with applying causal analysis to identify defects or problems and their associated symptoms, causes, and corrective actions. In our final theme article Understanding Causal Systems by David N. Card, the basic concepts and terminology of causal systems are defined along with a model to facilitate reasoning.

In our first supporting article, Requirements Engineering So Things Don’t Get Ugly by Deb Jacobs, we are reminded of the importance of customers and development teams working together to communicate, understand, and define effective requirements throughout a project lifecycle. This author discusses the basics of requirements engineering and defines key steps that a project manager can take to ensure requirements are defined, analyzed, and managed properly.

Our issue wraps up with Independent Estimates at Completion – Another Method by Oklahoma’s MAS Deputy Chief Walt Lipke. Used to predict the final cost of a project, an Independent Estimate at Completion (IEAC) is a method often used by cost analysts and project managers. In this article, Lipke reviews several common calculations for IEAC and offers insights into why optimistic and questionable results may occur and thus proposes alternative calculations.

As we begin a new fiscal year at CROSSTALK, I welcome our new co-sponsors and look forward to their insights into the many lessons learned gained by their individual software divisions. Through this new partnership, we strengthen our commitment to disseminate information aimed at helping the defense software community acquire, develop, and sustain software better.

Tracy L. Stauder
Publisher
MEMORANDUM FOR ALL GOVERNMENT PROGRAM OFFICES

SUBJECT: 2004 U.S. GOVERNMENT’S TOP 5 PROGRAMS AWARDS

As the Department of Defense’s Executive Agent for Systems Engineering and sponsor for activities aimed at improving acquisition, I am pleased to announce the search for the 2004 U.S. Government’s Top 5 Programs, formerly the Top 5 Software Quality Projects.

Many organizations are employing processes and practices that result in the successful delivery of programs with significant software content to the United States government. Looking at past winners of this award, it is apparent that successful programs have used well-defined and proven processes and practices to develop, manage, and integrate software into deliverable systems. Beginning in 2004, this award intends to identify successful programs and highlight their efforts.

One significant change to the award structure this year, beyond extending the criteria from just software quality performance to total program performance, is the recognition of both the U.S. government project office and the industry prime contractor that participated in the system development, in recognition that successful programs are indeed government/industry team efforts. To facilitate the joint award process, we now have a co-sponsor of this prestigious award, the National Defense Industrial Association Systems Engineering Division.

CrossTalk will announce the Top 5 government and industry winners in the May 2005 issue, and winners will receive their awards at the 2005 Systems & Software Technology Conference. The winning projects will then be highlighted in a series of articles in CrossTalk’s July 2005 issue.

Nomination forms and additional information on the U. S. Government’s Top 5 Programs awards can be found at:

http://www.ndia.org, click on Divisions, then Systems Engineering.

Access to articles discussing previous winners can be found at:

http://www.stsc.hill.af.mil/top5projects

David R. Castellano
Deputy Director, Systems Engineering
Defense Systems
(Assessments and Support)
Software Project Management Practices: Failure Versus Success

An analysis of approximately 250 large software projects between 1995 and 2004 shows an interesting pattern. When comparing large projects that successfully achieved their cost and schedule estimates against those that ran late, were over budget, or were cancelled without completion, six common problems were observed: poor project planning, poor cost estimating, poor measurements, poor milestone tracking, poor change control, and poor quality control. By contrast, successful software projects tended to be better than average in all six of these areas. Perhaps the most interesting aspect of these six problem areas is that all are associated with project management rather than with technical personnel. Two working hypotheses emerged: 1) poor quality control is the largest contributor to cost and schedule overruns, and 2) poor project management is the most likely cause of inadequate quality control.

This article is derived from analysis of about 250 large software projects at or above 10,000 function points in size that were examined by the author's company between 1995 and 2004. (Note that 10,000 function points are roughly equivalent to 1,250,000 statements in the C programming language.)

It is difficult during analysis to pick out successful or unsuccessful methods from projects that are more or less average. However when polar opposites are examined, some very interesting differences stand out. The phrase polar opposites refers to projects at opposite ends of the spectrum in terms of achieving cost, schedule, and quality targets. When projects that were late by more than 35 percent, or overran their budgets by more than 35 percent, or experienced serious quality problems after delivery are compared to projects without such issues, some interesting patterns can be seen.

Of the 250 projects analyzed, about 25 were deemed successful in that they achieved their schedule, cost, and quality objectives. About 50 had delays or overruns below 35 percent, while about 175 experienced major delays and overruns, or were terminated without completion. The projects included systems software, information systems, outsourced projects, and defense applications. This distribution of results shows that large system development is a very hazardous undertaking. Indeed, some of the failing projects were examined by the author while working as an expert witness in breach-of-contract litigation involving the failed projects.

These large applications included both systems software and information systems. Both corporations and government agencies were included. In terms of development methods, both waterfall development cycles and spiral development were included. The newer agile methods were not included because such methods are seldom if ever utilized on applications larger than about 1,000 function points.

Table 1 shows six major factors noted at opposite ends of the spectrum in terms of failure versus success as they were revealed in the study analysis.

The author and his colleagues were commissioned by clients to examine the software development practices, tools utilized, quality, and productivity results of various projects. Thus, this article may be biased toward the topics examined. We were not commissioned to examine other kinds of issues such as poor training, staff inexperience, or poor personnel practices. There are, of course, many other influential factors besides these six is this report. Indeed, several prior books by the author cited more than 100 factors [1, 2]. But these six key factors occur so frequently that they stand out from factors that occur only now and then. For additional studies on recent project failures other than the author’s, see [3, 4, 5, 6].

Before dealing with the patterns observed on the successful and failing projects, it is desirable to discuss some of the differences between project planning and project estimating since these are the key factors associated with both success and failure.

The phrase project management tools has been applied to a large family of tools whose primary purpose is sophisticated scheduling for projects with hundreds or even thousands of overlapping and partially interdependent tasks. These tools are able to drop down to very detailed task levels, and can even handle the schedules of individual workers. A few examples of tools within the project management class include Artemis Views, Microsoft Project, Primavera, and Project Manager’s Workbench.

However, the family of project management tools is general purpose in nature and does not include specialized software sizing and estimating capabilities as do the software cost estimating tools. Neither do these general project management tools deal with quality issues such as defect removal efficiency. Project management tools are useful, but software requires additional capabilities to be under full management control.

The software cost estimation industry and the project management tool industry originated as separate businesses with project management tools appearing in the 1960s, around 10 years before software cost estimating tools. Although the two were originally separate businesses,
they are now starting to join together technically.


Project management tools are an automated form of several techniques developed by the Navy for controlling large and complex weapons systems. For example, the program evaluation and review technique (PERT) originated in the 1950s for handling complex military projects such as building warships. Other capabilities of project management tools include critical path analysis, resource leveling, and production of Gantt or timeline charts. There are many commercial project management tools available such as Artemis Views, Microsoft Project, Primavera, Project Manager’s Workbench, and more.

Project management tools did not originate for software, but rather for handling very complex scheduling situations where hundreds or even thousands of tasks need to be determined and sequenced, and where dependencies such as the completion of a task might affect the start of subsequent tasks.

Project management tools have no built-in expertise regarding software as do the commercial software cost estimating tools. For example, if you wish to explore the quality and cost impact of an object-oriented programming language such as Smalltalk, a standard project management tool is not the right choice.

By contrast, many software cost estimating tools have built-in tables of programming languages and will automatically adjust the estimate based on which language is selected for the application.

Since software cost estimating tools originated about 10 years after commercial project management tools, the developers of software cost estimating tools seldom tried to replicate project management functions such as construction of detailed PERT diagrams or critical path analysis. Instead, the cost estimation tools would export data to a project management tool. Thus, interfaces between software cost estimating tools and project management tools are now standard features in the commercial estimation market.

Let us now turn to applying project planning and project estimating tools to large software applications.

Successful and Unsuccessful Project Planning

The phrase project planning encompasses creating work breakdown structures, and then apportioning tasks to staff members over time. Project planning includes creation of various timelines and critical paths including Gantt charts, PERT charts, or the like.

Effective project planning for large projects in large corporations involves both planning specialists and automated planning tools. Successful planning for large software projects circa 2004 involves the following:

- Using automated planning tools such as Artemis Views or Microsoft Project.
- Developing complete work breakdown structures.
- Conducting critical path analysis of project development activities.
- Considering staff hiring and turnover during the project.
- Considering subcontractors and international teams.
- Factoring in time for requirements gathering and analysis.
- Factoring in time for handling changing requirements.
- Factoring in time for a full suite of quality control activities.
- Considering multiple releases if requirements growth is significant.

Successful projects do planning very well indeed. Delayed or cancelled projects, however, almost always have planning failures. The most common planning failures include (1) not dealing effectively with changing requirements; (2) not anticipating staff hiring and turnover during the project; (3) not allotting time for detailed requirements analysis; and (4) not allotting sufficient time for inspections, testing, and defect repairs.

Successful project planning tends to be highly automated. There are at least 50 commercial project-planning tools on the market, and successful projects all use at least one of these. Not only are the initial plans automated, but also any changes in requirements scope or external events will trigger updated plans to match the new assumptions. Such updates cannot be easily accomplished via manual methods; planning tools are a necessity for large software projects.

Successful and Unsuccessful Project Cost Estimating

Software cost estimating for large software projects is far too complex to be performed manually. This observation is supported by the presence of at least 75 commercial software cost estimating tools, including such well-known tools as COCOMO II, CostXpert, KnowledgePlan, PRICE-S, SEER-SEM, SLIM, and the like [7]. Successful projects all use at least one such tool, and usage of two or more is not uncommon. Estimates produced by trained estimating specialists are also noted on many successful large projects, but not on failing projects. Successful cost estimating for large systems involves using the following:

- Software estimating tools (COCOMO II, CostXpert, KnowledgePLAN, PRICE-S, SEER-SEM, SLIM, etc.).
- Formal sizing approaches for major deliverables based on function points.
- Comparison of estimates to historical data from similar projects.
- Availability of trained estimating specialists or project managers.
- Inclusion of new and changing requirements in the estimate.
- Inclusion of quality estimation as well as schedule and cost estimation.

By contrast, large failing projects may not utilize any of the commercial software estimating tools. However, manual estimates are never sufficient for projects in the 10,000-function point range.

Failing projects tend to underestimate the size of the work to be accomplished due to inadequate sizing approaches. Failing projects also omit quality estimates, which are a major omission since excessive defect levels slow down testing to a standstill. Overestimating productivity rates or assuming that productivity on a large system will be equal to productivity on small projects are other common reasons for cost and schedule overruns. The main problem with estimates for projects in the 10,000-function point size range is that they err on the side of excessive optimism.

Project planning tools and project estimating tools overlap in functionality, and are usually marketed separately. Normally, the project planning and cost estimating tools pass information back and forth. The software cost estimating tool would be used for overall project sizing, resource estimating, and quality estimating. The project-planning tool would be used for critical path analysis, detailed scheduling, and for work breakdown structures.

Successful and Unsuccessful Project Measurements

Successful large projects are most often found in companies that have software measurement programs for capturing productivity and quality historical data [8,
Thus any new project can be compared against similar projects to judge the validity of schedules, costs, quality, and other important factors. The most useful measurements for projects in the 10,000-function point domain include measures of the following:

- Accumulated effort.
- Accumulated costs.
- Development productivity.
- Volume and rate of requirements changes.
- Defects by origin.
- Defect removal efficiency.

Measures of effort should be granular enough to support work breakdown structures. Cost measures should be complete and include development costs, contract costs, and costs associated with purchasing or leasing packages. There is one area of ambiguity even for top companies and successful projects: The overhead or burden rates established by companies vary widely. These variances can distort comparisons between companies, industries, and countries, and make benchmarking difficult. Of course, within a single company this is not an issue.

Function points are now the most commonly used metric in both the United States and Europe for software projects, and are rapidly growing in usage throughout the world. Development productivity measurements normally use function points in two fashions: function points per staff month and/or work hours per function point [10, 11, 12]. For additional information on functional metrics, refer to the Web site of the non-profit International Function Point Users Group at <www.ifpug.org>.

The federal government, some military projects, and the defense industry still perform measurements using the older lines-of-code metric. This metric is hazardous because it cannot be used for measuring many important activities such as requirements, design, documentation, project management, quality assurance, and the like. There are also programming languages such as Visual Basic that have no effective rules for counting lines of code. About one third of the large software projects examined utilized several programming languages concurrently, and one large application included 12 different programming languages.

Measures of quality are powerful indicators of top-ranked software producers and are almost universal on successful projects. Projects that are likely to fail, or have failed, almost never measure quality. Quality measures include defect volumes by origin (i.e., requirements, design, code, bad fixes) and severity level, defect severity levels, and defect repair rates.

Really sophisticated companies and projects also measure defect removal efficiency. This requires accumulating all defects found during development and also after release to customers for a predetermined time period. For example, if a project finds 900 defects during development and the users find 100 defects in the first three months of use, then it can be stated that the project achieved a 90 percent defect removal efficiency level. Of course, any defect found after the first three months lowers the defect removal value.

It is interesting that successful projects are almost always better than 95 percent in defect removal efficiency, which is about 10 percent better than the U.S. average of 85 percent [13].

It is not possible to measure defect removal efficiency for cancelled projects since there is no customer usage. However, for projects that finally get started on time, although delivered late—defect removal efficiency seldom tops 80 percent, or about 5 percent below U.S. averages and 15 percent below successful projects. This statement is based on only about a dozen large systems because almost universally, projects that are delayed or over budget do not have effective quality measurements in place.

Since the bulk of schedule delays and cost overruns tends to occur during testing and is caused by excessive defect volumes, it can be hypothesized that lack of effective quality control on large systems is a major contributor to both cost and schedule overruns.

Successful and Unsuccessful Milestone Tracking

The phrase milestone tracking is ambiguous in the software world. It sometimes refers to the start of an activity, sometimes to the completion of an activity, and sometimes to nothing more than a calendar date. In this article, the phrase refers to the point of formal completion of key deliverables or a key activity. Normally, a completion milestone is the direct result of some kind of review or inspection of the deliverable. A milestone is not an arbitrary calendar date.

Project management is responsible for establishing milestones, monitoring their completion, and reporting truthfully on whether the milestones were successfully completed or encountered problems. When serious problems are encountered, it is necessary to correct the problems before reporting that the milestone has been completed.

A typical set of project milestones for successful software applications in the nominal 10,000-function point size range would include completion of the following:

- Requirements review.
- Project plan review.
- Cost and quality estimate review.
- External design reviews.
- Database design reviews.
- Internal design reviews.
- Quality plan and test plan reviews.
- Documentation plan review.
- Deployment plan review.
- Training plan review.
- Code inspections.
- Each development test stage.
- Customer acceptance test.

Failing or delayed projects usually lack serious milestone tracking. Activities might be reported as finished while work was still ongoing. Milestones might be simple dates on a calendar rather than completion and review of actual deliverables. Some kinds of reviews may be so skimpy as to be ineffective.

Successful projects, on the other hand, regard milestone tracking as an important activity and try to do it well. There is no glossing over of missed milestones, or pretending that unfinished work is done. Delivering documents or code segments that are incomplete, contain errors, and cannot support downstream development work is not the way milestones occur on successful projects.

Another aspect of milestone tracking on successful projects is what happens when problems are reported or delays occur. The reaction is strong and immediate: corrective actions are planned, task forces assigned, and corrections occur as rapidly as possible. Among lagging projects, on the other hand, problem reports may be ignored and very seldom do corrective actions occur.
Successful and Unsuccessful Change Management
Applications in the nominal 10,000-function point size range run from 1 percent to 3 percent per month in new or changed requirements during the analysis and design phases [8]. This fact was discovered by measuring the initial function point totals at the requirements stage and comparing them to the function point total after design. If the initial function point total is 10,000 function points and the post-design total is 12,000 function points, then the overall growth is 20 percent. If the schedule for analysis and design took 10 calendar months, then the monthly growth rate was 2 percent per month.

The total accumulated volume of changing requirements can top 50 percent of the initial requirements when function point totals at the requirements phase are compared to those at deployment. Therefore, successful software projects in the nominal 10,000-function point size range must use state-of-the-art methods and tools to ensure that changes do not get out of control.

Successful change control for applications in the 10,000-function point size range include the following:
• A joint client/development change control board or designated domain experts.
• Using joint application design (JAD) to minimize downstream changes.
• Using formal prototypes to minimize downstream changes.
• Planned usage of iterative development to accommodate changes.
• Formal review of all change requests.
• Revised cost and schedule estimates for all changes greater than 10 function points.
• Prioritizing change requests in terms of business impact.
• Formal assignment of change requests to specific releases.
• Using automated change control tools with cross-reference capabilities.

One of the observed byproducts of using formal JAD sessions is a reduction in downstream requirements changes. Rather than having unplanned requirements surface at a rate of 1 percent to 3 percent per month, studies of JAD by IBM and other companies have indicated that unplanned requirements changes often drop below 1 percent per month due to the effectiveness of the JAD technique.

Prototypes are also helpful in reducing the rates of downstream requirements changes. Normally key screens, inputs, and outputs are prototyped so users have some hands-on experience with what the completed application will look like.

However, changes will always occur for large systems. It is not possible to freeze the requirements of any real-world application, and it is naïve to think this can occur. Therefore, leading companies are ready and able to deal with changes, and do not let them become impediments to progress. Therefore, some form of iterative development is a logical necessity.

Successful and Unsuccessful Quality Control
Effective software quality control is the most important single factor that separates successful projects from delays and disasters. The reason for this is because finding and fixing bugs is the most expensive cost element for large systems and takes more time than any other activity.

Successful quality control involves both defect prevention and defect removal activities. The phrase defect prevention includes all activities that minimize the probability of creating an error or defect in the first place. Examples of defect prevention activities include JAD for gathering requirements, using formal design methods, using structured coding techniques, and using libraries of proven reusable material. The phrase defect removal includes all activities that can find errors or defects in any kind of deliverable. Examples of defect removal activities include requirements inspections, design inspections, document inspections, code inspections, and all kinds of testing.

Some activities benefit both defect prevention and defect removal simultaneously. For example, participation in design and code inspections is very effective in terms of defect removal, and also benefits defect prevention. The reason why defect prevention is aided is because inspection participants learn to avoid the kinds of errors that inspections detect. Successful quality control activities for 10,000-function point projects include the following:

Defect Prevention
• JAD for gathering requirements.
• Formal design methods.
• Structured coding methods.
• Formal test plans.
• Formal test case construction.

Defect Removal
• Requirements inspections.
• Design inspections.
• Document inspections.
• Code inspections.
• Test-plan and test-case inspections.
• Defect repair inspections.
• Software quality assurance reviews.
• Unit testing.
• Component testing.
• New function testing.
• Regression testing.
• Performance testing.
• System testing.
• Acceptance testing.

The combination of defect prevention and defect removal activities leads to some very significant differences in the overall numbers of software defects compared between successful and unsuccessful projects. For projects in the 10,000-function point range, the successful ones accumulate development totals of around 4.0 defects per function point and remove about 95 percent of them before customer delivery. In other words, the number of delivered defects is about 0.2 defects per function point or 2,000 total latent defects. Of these, about 10 percent or 200 would be fairly serious defects. The rest would be minor or cosmetic defects.

By contrast, the unsuccessful projects accumulate development totals of around 7.0 defects per function point and remove only about 80 percent of them before delivery. The number of delivered defects is about 1.4 defects per function point or 14,000 total latent defects. Of these about 20 percent or 2,800 would be fairly serious defects. This large number of latent defects after delivery is very troubling for users.

One of the reasons why successful projects have such high defect removal efficiency compared to unsuccessful projects is the usage of design and code inspections [14, 15]. Formal design and code inspections average about 65 percent efficiency in finding defects. They also improve testing efficiency by providing better source materials for constructing test cases.

Unsuccessful projects typically omit design and code inspections and depend purely on testing. The omission of upfront inspections causes three serious problems: (1) the large number of defects still present when testing slows the project to a standstill, (2) the bad fix injection rate for projects without inspections is alarmingly high, and (3) the overall defect removal efficiency associated with only testing is not sufficient to achieve defect removal rates higher than about 80 percent.

(Note: The term bad fix refers to secondary defects accidentally injected by means of a patch or defect repair that is
itself flawed. The industry average is about 7 percent, but for unsuccessful projects the number of bad fixes can approach 20 percent; i.e., one out of every five defect repairs introduced fresh defects [13]. Successful projects, on the other hand, can have bad-fix injection rates of only 2 percent or less.)

Conclusions
There are many ways to make large software systems fail. There are only a few ways of making them succeed. It is interesting that project management is the factor that tends to push projects along either the path to success or the path to failure.

Large software projects that are inept in quality control and skimpy in project management tasks are usually doomed to either outright failure or massive overruns.

Among the most important software development practices leading to success are those of planning and estimating before the project starts, absorbing changing requirements during the project, and successfully minimizing bugs or defects.

Successful projects always excel in these critical activities: planning, estimating, change control, and quality control. By contrast, projects that run late or fail typically had flawed or optimistic plans, had estimates that did not anticipate changes or handle change well, and failed to control quality.

References

About the Author
Capers Jones is founder and chief scientist of Software Productivity Research LLC. He is an international consultant on software management topics, a speaker, a seminar leader, and author. Jones was formerly at the ITT Programming Technology Center in Stratford, Conn., where he was assistant director of Programming Technology. Prior to joining ITT, he was at IBM for a 12-year period in both research and managerial positions. He received the IBM General Product Division’s outstanding contribution award for his work in software quality and productivity improvement methods. Jones has published 12 books on software project management topics and more than 200 journal articles. He has given seminars on software project management in more than 20 countries to more than 150 major corporations, government agencies, and military services.

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Catastrophe Disentanglement: Getting Software Projects Back on Track®

E.M. Bennatan
Advanced Project Solutions, Inc.

If you are responsible for a late and over-budget software project, you are not alone—software project overruns are all too common. But if serious problems have existed for quite a while and the situation is getting worse, not better, you may have a project catastrophe on your hands. At this point, there is no established rescue process to follow. Dealing effectively with an out-of-control project is as much an emotional challenge as it is a managerial and technical one. This article describes a 10-step process to disentangle a software project catastrophe and get it back on track.

In Spencer Johnson’s “Who Moved My Cheese?” [1], the little people keep coming back to where the cheese used to be even though it is not there anymore. It is a natural tendency to continue doing what we have always done even when, to an outside observer, it no longer makes sense. This behavior is quite common when projects get into trouble. We keep plodding away at the project hoping that the problems will go away and the cheese will miraculously reappear. In all too many cases, it does not.

Just as the smart thing to do when a ball of twine seems hopelessly entangled is to stop whatever we are doing (otherwise the tangle gets worse), so it often is with a disastrous project: The longer we keep at it, the worse it gets. At some point, we need to halt all activity and reassess what we are doing.

Disastrous software projects, or catastrophes, are projects that are completely out of control in one or more of the following aspects: schedule, budget, or quality. They are by no means rare—44 percent of surveyed development organizations report that they have had software projects cancelled or abandoned due to significant overruns, and 15 percent say that it has happened to more than 10 percent of their projects (see Figure 1).

But, obviously, not every overrun or quality problem means a project is out of control, so at which point should we define a software project as a catastrophe? What are the criteria for taking the drastic step of halting all activities, and how do we go about reassessing the project? Most importantly, how do we get the project moving again? The answers to these questions are the essence of the concept of catastrophe disentanglement.

When Is a Project a Catastrophe?
Organizations and projects vary to such an extent that there can be no universal crite-
ria for branding a software project a catastrophe. The expectations from mission-critical, life support, or banking software are significantly different than from most consumer- or Internet-based software applications. But experience shows that in virtually all cases, projects are in deep trouble if serious problems have existed for quite a while and the situation is getting worse, not better. How is this reflected in terms of schedule, budget, and quality?

Schedule
Software projects rarely or never strictly follow their schedule; delays often grow and shrink like an accordion. It is a sad reality that software project delays are an excessively common occurrence (see Figure 2). But we are not looking at just any delay; the issue here is to identify those projects where the delay is growing uncontrollably.

To determine if the delay is out of control, divide the total development schedule into 12 phases, and look at each of the last three. Has the delay steadily grown in each phase? Is the total delay now greater than three phases (i.e., 25 percent of the total project schedule)?

On a one-year schedule, for example, look at the last three months and ask the following questions:
1. Was the delay significant two months ago?
2. Was the delay even greater one month ago?
3. This month, has the delay grown again?
4. Has the delay growth been steady (that is, not two small delays and one major delay caused by an identifiable event)?
5. Is the total delay now greater than three months?

If the answer to these questions is yes, it is probably a good idea to halt the project and reassess it.

Budget
A project is a budget catastrophe if its remaining projected cost far exceeds what the development organization is willing to pay for it. In software projects, major budget overruns are often the result of schedule overruns or of attempts to reduce schedule overruns (e.g., by adding staff). The following are points to consider:
1. Does the project schedule appear to be a catastrophe? If so, project cost projections have little value at this time.
2. If the project schedule appears to be under control, then extrapolate budget overruns for the past three phases up to the end of the most current project schedule (assume that every future phase will continue to exceed the budget at a similar rate). Is this a cost your organization can bear?
3. Do you have current feedback from the project’s customers and users? Do you have updated market research data? Is the original cost/value analysis for this project still valid?

Quality
A software project is a quality catastrophe if (a) the list of serious quality problems has been substantial for three periods and is not decreasing, or if (b) customers/users who have evaluated the software that is being developed are exceptionally critical of it.

The project problem list is a good indicator of how serious the problems are. The list is commonly divided into (a) critical, (b) serious, and (c) minor problems. The following are points to consider:
1. Is the critical problem list growing? Are problems being resolved? How fast are new problems being added?
2. The second level of serious quality problems can also indicate the gravity of the situation if the list is particularly long and not getting any shorter.
3. Another indicator to monitor is how well the quality problem lists are being maintained. Are problems being categorized correctly? Are problems being removed prematurely from the list? Are new problems being withheld from the list?
Severe quality problems (those that are either critical or most serious) are often difficult, if not impossible, to see in the early stages of a project. In fact, many severe quality problems emerge only toward the end of a project (and sometimes only after its release). Even the last-three-phases technique can be ineffective during the first half of a project because too often problem lists have not yet been compiled or well maintained.

But project quality issues can be monitored from the outset if there is someone whose job it is to do so. This means assigning an independent software quality assurance (SQA) professional to every project team as soon as the project is launched. For small development teams, one SQA professional can be responsible for two or three projects, though large projects should have their own indigenous SQA team.

Customer and user feedback is the best source for evaluating project quality. Unfortunately, it is sometimes difficult to get feedback until a project is close to release. For large projects, it is often worth investing in prototypes and pre-releases, thus getting preliminary versions of the software into the users’ hands for early evaluation and feedback. This investment is like an insurance policy: It reduces the risk of major product quality issues – but at a cost.

The Project Is a Catastrophe – Now What?
The following 10 steps describe the process for disentangling a failing software project and getting it back on track. Because these steps intrude on the responsibilities of the team members – most especially the project manager – the process should be confined to getting the project back on track and nothing more. Ultimately, the new project plan must gain the unreserved support of the development team members, and the details should be left up to them.

1. **Stop**
Once you have determined that a software project is unlikely to be completed with any reasonable degree of success, the next step is painful but clear: Stop all activities immediately. This is a difficult decision because it will always be open to harsh criticism from some circles. It is also a tough decision because, as we have seen, there is really no airtight algorithm for determining that a project is a catastrophe. Ultimately, the decision is a combination of data analysis and management experience.

Stopping a project should never leave a team idle. There is much to do in preparing the project for assessment, including the following:

- Collecting and updating project documentation and data.
- Preparing status reports for each team member and each team.
- Bringing the project software to the nearest point (backward, not forward) for demonstration. This means that except for minor exceptions, no new code should be written and no new features should be added or integrated (otherwise there is a risk that the demonstration will take too long to prepare).
- Assisting the project evaluator.

In addition, other activities should be prepared and held in reserve such as training and assistance to other projects.

2. **Assign An Evaluator**
Virtually all software projects in trouble have strong emotional and political hallmarks that often produce passionate advocates and opponents. Therefore, the importance of using an external project evaluator cannot be overstated. This will increase the likelihood of getting an unbiased and unemotional evaluation.

In choosing an evaluator, you should assign a reliable, pragmatic, experienced, and successful project evaluator who (a) understands the project technology, (b) has good social skills, and (c) can reprioritize other responsibilities to allow sufficient time for the evaluation. For very large projects, use an evaluation team of two or more evaluators but...
Evaluating a team is a sensitive activity that
should be handled both resolutely and
tactfully. This step is purely part of the
evaluation process and does not, at this
point, result in any restructuring of the
team. The following are questions to be
considered:

1. Reduce tension by involving the
   project team in your evaluation and by
   being completely open (no secrecy or
   mysterious behind-closed-doors
discussions).
2. Consider only observable facts (e.g.,
   not, “This feature used to work well
but something has gone wrong.”)
3. Consider accomplishments, not effort.
4. For almost completed tasks, apply the
   90-50 rule. (It takes 50 percent of the
time to do 90 percent of the work and another
50 percent to do the remaining 10 percent.)
5. Present your evaluation to the team
   before finalizing it and consider their
   responses (look for details and facts
   that you overlooked or misunderstood,
   while resisting undue pressure to
   amend your findings).

4. Evaluate the Team
Evaluating a team is a sensitive activity that
should be handled both resolutely and
tactfully. This step is purely part of the
evaluation process and does not, at this
point, result in any restructuring of the
team. The following are questions to be
considered:

1. Does the project team have the neces-
sary skill set and experience to success-
fully deliver the project?
2. Do the team leaders have the leader-
ship, technical skills, and the personali-
ty necessary to lead their team?
3. Does the project manager have the
   required leadership, technical skills, and
   personality necessary to lead the project
team, and does he or she command the
   respect of the team members?
4. Are there any internal team conflicts or
tensions that could disrupt the project?
5. What is the level of team spirit and
   morale? If low, then why? (Are there rea-
sons beyond the failing of the project?)

5. Define Minimum Goals
The emphasis here is on the word mini-
mum; the project should be reduced to the
smallest size that achieves only the most
good essential goals. This resetting of goals and
objectives can only be performed with the
active involvement of senior (executive) manage-
ment and the customer. Divide all
project requirements into three sets:

- **Set One:** Essential requirements with-
  out which the project has no value.
- **Set Two:** Important requirements that
greatly improve the project but are not
essential.
- **Set Three:** Nice-to-have requirements
  that add to the project, but are not
especially important.

Now, start by retaining the require-
ments from set one, and initially eliminat-
ing sets two, and three. This will often cre-
ate tremendous opposition, but remember
- we are dealing with a project that was
totally out of control and may otherwise
be cancelled. Occasionally, some elements
from set two can be added, but this should
be rare. All remaining requirements (from
sets two and three) should be targeted for
subsequent releases of the software.

Here is a word of caution: Be prepared
to forestall the ploy by some stakeholders
to second-guess the whole evaluation
process by their insistence on listing all (or
most) requirements in set one.

6. Can Minimum Goals Be Achieved?
The main challenge here is to determine
whether the requirements in set one can
reasonably be achieved. The questions to
be addressed are the following:

- Is set one a genuine and significant
  reduction of the project scope?
- Is there a single requirement in set one
  that adds an order of magnitude to the
  complexity of the project? If so, are
  members of management aware of this
  and will they reconsider its inclusion?
- Are the new project goals now achiev-
able? Is there now a reasonable chance
  that the team will be able to deliver the
  requirements in an acceptable time-
frame, within a reasonable budget, and
  with an acceptable quality level?
- How genuinely confident are the team
  members (and especially the project
  manager) in their ability to achieve the
  new set of goals?
- If the minimum goals appear unachiev-
able (and they are truly minimal),
a recommendation to cancel the project
may be the only remaining realistic course
of action.

7. Rebuild the Team
Based on the evaluation of the team (see
step four) it may be necessary to restruk-
ture and even partly re-staff the team to
handle the new set of goals.

A halted software project can mean a
team that is demotivated and demoralized.
But in all probability, if the project was in
deep trouble before it was halted, then the
low morale did not start with the decision
to halt the project. However, the issue of
team morale should be a major considera-
tion in rebuilding the project team (this
will be further discussed later).

In rebuilding the team, consider the
following points:

- **Team Structure.** Is the project team
  structured optimally for the success of
  the project?
- **Team Functions.** Are the necessary
team functions staffed?
- **Team Members.** Are there team
  members who should be replaced?
- **Team Leaders.** Are there team leaders
  who should be replaced?
- **Project Manager.** Is the project man-
ger the right person to lead this
  project?

8. Risk Analysis
In all phases of a software development
project, risk analysis is virtually an indis-
pensable tool – this is particularly true of a
failing project trying to get back on track.
The process identifies risk events, mitiga-
tion steps and contingency plans, and
assigns tracking responsibilities.

High-level risk analysis (i.e., anticipat-
ing the most serious potential problems)
should be performed as part of the project
evaluation process. The analysis will not
only help evaluate the chances of success
in restarting the project, it will also help
restore a level of confidence within the
project team.

9. New Estimates and Schedule
Based on the minimal goals and the rebuilt
team, new reasonable high-level estimates
and a new schedule need to be prepared
and the cost-effectiveness of the renewed
project plan should be established. If the
schedule is firm, ensure that budget,
staffing level, and feature set are not also
all fixed (or another catastrophe will
ensue).

In many cases, it may be prudent to
focus primarily on the schedule and fea-
ture set (the other parameters, such as bud-
get and staffing levels, can initially be side-
lined). This means that if the minimal fea-
ture set is firm, then calculate the project
delivery date and vice versa. Remember
that even a generous budget and an unre-
stricted staffing level may not be enough to
resolve the problem of a fixed feature set
with an uncompromising delivery date.

Here is a note on cost effectiveness: In
analyzing the cost of completing a soft-
ware project, only future costs (not costs
already expended) should be considered.
The cost of project completion should
then be compared to the value of the
completed project.
10. Establish Clear Project Review Milestones

Put in place an early warning system to ensure that the project does not slip back into catastrophe mode. Such a system should include the following:

- The introduction of an efficient and reliable project data collection and analysis system.
- Clear project evaluation criteria for management.
- A schedule of frequent project reviews with well-defined measurable milestones.

After successful completion of these project evaluation steps, and after determining that the renewed project plan is achievable and cost effective, the project can be restarted.

Case Study

A failing project is often like a hand in a cookie jar: to get some cookies out, you first have to let some go. Such was the case at Motorola with the software for a wireless telephony control and maintenance center (CMC) that we delivered several years ago as part of a 200,000-subscriber project to one of the emerging Eastern European countries (see [5]). The specially tailored CMC was a last minute add-on to the wireless telephony contract and was consequently not well defined.

The CMC was developed with a subcontractor team, based on an existing control system. The first phase of the project was devoted to producing a voluminous set of requirements, none of which could be omitted (according to the customer). The schedule was dictated – 16 months, which was set as close as possible to the date the subscriber telephony system was to become operational. Needless to say, every month was critical.

Five months into the project, key dates were already being missed. Seven months into the project, doubts began arising among senior management about whether the project would be ready on time. Nine months into the project, senior management was trying to calculate how much the project does not slip back into catastrophe mode. Such a system should include the following:

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- Clear project evaluation criteria for management.
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The Customer Perspective

Some software organizations’ attitude toward customers is reminiscent of the librarian who disliked readers removing books from the library shelves because they disrupted the tidy placement of the books on the shelves. The librarian had confused means (the library) with goals (reading books). In software development, we also sometimes tend to confuse means (the project) with goals (customer satisfaction). There is justification for a project only as long as there are willing customers for its product. Hence, it is wise for both management and the project team to keep an ever-watchful eye on the customers: their needs, their expectations, and their opinion of the software being developed. After all, the continued development of a product that no longer has a willing customer (or user) is the ultimate project catastrophe.

Post-Project Reviews

Getting a failed software project back on track is an admirable accomplishment, but an even greater one is not having it go off track in the first place. Therefore, part of the catastrophe disentanglement procedure is preventing future recurrences of similar catastrophes. This is achieved through a special review process held after the project has ended (successfully or otherwise).

The post-project review is a process intended to facilitate an understanding of why a project evolved the way it did. What was done right? What was done wrong? What can be done better next time? The review is a structured process that is not intended to find the guilty or to lay any blame, and is best done with a trained facilitator.

The output of the review includes a list of operational, procedural, and organizational changes and actions to ensure that mistakes are not repeated and successes are. In fact, the U.S. Army recommends that 50 percent of the review be devoted to discussions on how to do better in the future; the remaining time is devoted to what happened (25 percent), and why (25 percent) [7].

The Human Factor

The process of disentangling catastrophes is traumatic not just for the project team, but for the organization itself. Clearly, halting a project does not add to the motivation of a project team. Similarly, declaring a project to be a catastrophe does not add to the prestige of a development organization – though the courage to make such a decision often deserves praise.

While a highly motivated team is certainly one of the primary factors for project success, the fear of demotivating a team or tarnishing an organization’s image...
should never be a reason to allow a team to continue in the wrong direction. Catastrophe disentanglement should be viewed like corrective surgery: just as the body undergoes trauma in order to heal, so does the development organization.

One of the problems with the rather drastic measures of catastrophe disentanglement is that the knowledge that an organization will take such measures can inhibit the flow of accurate information (particularly bad news) to senior management. But successful corrective action, just like successful surgery, depends on the flow of truthful and accurate information even, in fact especially, when the news is bad.

The ability to bring bad tidings and make unpopular decisions is a desirable, if not entirely common, part of an organization’s culture. Former Intel Chief Executive Officer Andy Grove said:

… If you are a middle manager you [may] face … the fear that when you bring bad tidings you will be punished, the fear that management will not want to hear the bad news from the periphery. Fear that might keep you from voicing your real thoughts is poison. Almost nothing could be more detrimental to the well-being of the company. [8]

Grove’s point is that effective corrective action requires accurate information—a reality not unfamiliar to those of us who drive a car: We cannot effectively steer a vehicle on the road if we cannot get accurate data. Thus, an organization that wants to be able to effectively evaluate its activities with processes such as the one described here, needs to promote the flow of accurate information by ensuring the following:

• The process is open and fair (not secretive).
• The staff is briefed about the process and the reason it is being adopted.
• The organization promotes a mistake-tolerant culture. Blame and punishment need to be eliminated from the evaluation process (mistakes should be addressed in normal performance reviews alongside successes and achievements).

Conclusion

Most software catastrophes were troubled projects that went on for too long. Part of the trauma of dealing with them is the realization that “this shouldn’t have happened,” or “we should have seen it coming.” Realizing this, the call to action is: “Something has to change around here.” Returning to Johnson’s “Who Moved My Cheese?” the tale continues:

The little people were outraged, shocked, scared, and befuddled when the cheese disappeared. In their comfort, they didn’t notice the cheese supply had been dwindling, nor that it had become old and smelly. They had become complacent. [1]

How better to describe the failing of a software project?

References


Notes

1. To be statistically accurate, the results may have included some projects that were finished early, but we risked the speculation that such cases (if any) would only represent a small fraction of the results.
2. The term customer here refers to the entity that requested the project or that will use its product, or more generally, for whom the project is being developed.
3. Fred Brooks [3] tells the story of a senior naval officer’s last minute requirement after many months of negotiating features, schedule, and cost for a new navy helicopter. “It must be able to fly across the Atlantic,” he stated. Only after laboriously explaining to him the enormous complexity that it added to the project was the officer willing to drop the requirement.
4. For an overview of basic software project risk analysis, see [4].
5. Telephony here refers to the provision of telephone-related services.
6. Yes, profitability is usually a good goal, too.
7. A useful overview of a generic, after-action review process, which can be easily adapted for software projects, is given in [6].
8. For an interesting discussion of a mistake-tolerant business culture, see [9].

About the Author

E.M. Bennatan is president of Advanced Project Solutions, Inc., where he assists development companies in software project catastrophe disentanglement, introduction of orderly process into ad-hoc organizations, organizational structure, simplification of existing processes, and management of multinational development. Bennatan spent many years as senior director at Motorola leading multinational design centers and developing wireless access systems. He was also responsible for program management of Motorola’s High Availability Systems corporate-wide initiative. Before Motorola, Bennatan spent several years developing defense and aerospace systems in the U.S. and overseas. Bennatan has authored several articles and books, including “On Time Within Budget: Software Project Management Practices and Techniques,” and is a senior member of the Institute of Electrical and Electronics Engineers and a member of the Association for Computing Machinery.

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Understanding Causal Systems

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This article describes a model and a supporting set of terms that facilitate reasoning about causal systems, planning for causal analysis, and designing process experiments. This perspective is based on practical experience in implementing causal analysis in industry. The implementation of effective causal analysis methods has become increasingly important as more software organizations transition to higher levels of process maturity where causal analysis is a required – as well as an appropriate – behavior.

A causal system is an interacting set of events and conditions that produces recognizable consequences. Causal analysis is the systematic investigation of a causal system in order to identify actions that influence a causal system, usually to minimize undesirable consequences. Causal analysis may sometimes be referred to as root cause analysis or defect prevention. Searching for the cause of a problem (laying the blame) is a common human behavior that would not seem to require much formalism. However, causal investigations often go wrong, beginning with the definition of a cause.

Causal analysis focuses on understanding cause-effect relationships. Three conditions must be established to demonstrate a causal relationship:
• First, there must be a correlation or association between the hypothesized cause and effect.
• Second, the cause must precede the effect in time.
• Third, the mechanism linking the cause to the effect must be identified.

The first condition implies that when the cause occurs, the effect is also likely to be observed. Often, this is demonstrated through statistical correlation and regression. While the second condition seems obvious, a common mistake in the practice of causal analysis is to hypothesize cause-effect relationships between factors that occur simultaneously. This is an over-interpretation of the correlational analysis.

Figure 1 shows a scatter diagram of two variables measuring inspection (or peer review) performance. These two variables frequently demonstrate significant correlations. This diagram and a correlation coefficient computed from the data often are taken as evidence that preparation causes detection.

However, most inspection defects are discovered during preparation. Both meters are running simultaneously. Thus, preparation performance cannot substantially influence detection performance. They are measures of the same activity. Rather, the correlation suggests that some other factor affects both preparation and detection.

Issuing a mandate (as a corrective action) to spend more time in preparation may result in more time being charged to inspections, but it is not likely to increase the defect detection rate. The underlying cause of low preparation and detection rates may be a lack of understanding of how to prepare, schedule pressure, or other factors that affect both measures. That underlying cause must be addressed to increase both the preparation rate and detection rate. Recognition of the correlational relationship helps to narrow the set of potential causes to things that affect both preparation and detection performance.

The relationship between the height and weight of adult human beings provides a good analogy to the situation described in Figure 1. Taller people tend to weigh more than shorter people. (Obviously other factors intervene as well.) While this is a necessary relationship, it is not a causal relationship. It would be a mistake to assume that increasing someone’s weight would also increase his/her height. Both variables are determined by other causes (chiefly genetics and childhood nutrition). Those underlying causes are the ones that need to be identified and manipulated in any causal system.

Some of the responsibility for this kind of misinterpretation can be attributed to statisticians. The horizontal and vertical axes of Figure 1 are typically referred to as the independent and dependent variables respectively. While these terms are simple labels, not intended to imply a causal relationship, they are often misunderstood.

Satisfying the third condition of a causal relationship requires investigating the causal system. Many good examples of causal analysis efforts in software engineering have been published [1, 2, 3, 4]. However, these efforts have adopted different terminology and approaches. In particular, the elements of a causal system have not been defined in a consistent way. The differences between the analysis procedures obscure the commonality in the subject matter to which the procedures are applied. Further complicating the situation are substantial differences in the

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Figure 1: Example of Correlation Between Variables

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notion of causal analysis defined in the Capability Maturity Model® (CMM®) [5] and CMM IntegrationSM [6] (described later).

One of the consequences of a poor understanding of the nature of causal systems and causal analysis is that causal analysis sessions become superficial exercises that do not look deeply enough to find the important causes and potential actions that offer real leverage in changing performance. This reduces the cost benefit of the investment in causal analysis expected of mature software organizations. This article describes a model of causal analysis and a set of supporting terms that have evolved from extensive experience with the software industry. Some of these experiences with causal analysis were summarized in [7]. This experience encompasses scientific data-processing software, configuration management, and other software-related processes.

Elements of a Causal System

A cause-effect relationship may be one link in a potentially infinite network of causes and effects. A richer vocabulary than just causes and effects is needed to help us determine appropriate starting and stopping points for causal analysis. The model and terminology described in this section facilitate reasoning about causal systems and planning for causal analysis. Figure 2 describes the key elements of a causal system. Most of the approaches to causal analysis previously cited do not explicitly address all these elements of a causal system.

As indicated in the figure, causal systems include three classes of elements:

- **Objectives.** Our purposes in investigating the causal system.

- **Observations.** The events and conditions that comprise the causal system.

- **Actions.** Our efforts to influence the behavior of the causal system.

Observations are events and conditions that may be detected. Building an understanding of a causal system requires identifying these events and conditions, as well as discovering the relationships among them. Observations include the following:

- **Symptom.** These are undesirable consequences of the problem. Treating them does not make the problem go away, but may minimize the damage.

- **Problem.** This is the specific situation that, if corrected, results in the disappearance of further symptoms.

- **Cause.** These are the events and conditions that contribute to the occurrence of the problem. Addressing them helps prevent future similar problems.

Note that both problems and symptoms are effects of one or more underlying causes. Once a causal system is understood, action can be taken to change its behavior and/or impact on the organization. Actions may be of three types:

- **Preventive.** Reducing the chances that similar problems will occur again.

- **Corrective.** Fixing problems directly.

- **Mitigating.** Countering the adverse consequences (symptoms) of problems.

The corrective type usually includes actions to detect problems earlier so that they can be corrected before they produce symptoms. The optimum mix of preventive, corrective, and mitigating actions to be applied to a causal system depends on the cost of taking the actions as well as the magnitude of symptoms produced. Attacking the cause itself may not be the course of action that produces the maximum cost benefit in all situations. Potential symptoms and mitigations may be addressed as part of a risk-management activity.

Three objectives or motivations for undertaking causal analysis are common:

- **Improvement.** Triggered by recognition of an opportunity.

- **Control.** Triggered by an outlier or usual result relative to past performance.

- **Management.** Triggered by a departure from plans or targets.

Regardless of the motivation for causal analysis, all elements of the causal
system (as described earlier) should be considered. Most real causal systems are more complex than Figure 2 suggests. That is, a specific problem may produce multiple symptoms. Moreover, many causes may contribute to the problem. Consequently, many different actions of all types may be possible. The Ishikawa diagram [8] is a popular tool for describing and reasoning about causal systems.

These general concepts of causal systems can be applied to the investigation of any undesirable situation, not just to the investigation of defects. Figure 3 shows an example of a causal system explaining a cost problem.

In the hypothetical example of Figure 3, a project has exceeded its budget for the work accomplished to date. This is a symptom of an underlying problem. It might be overcome through management action by reducing the functionality of the software to be delivered, thus reducing the remaining work.

A causal analysis of the situation might reveal that the adoption of a new tool suite without preparation by the project had reduced productivity. That is the problem. Providing training might increase the efficiency and effectiveness of the team, returning productivity to its normal state.

Preventing future occurrences of such problems might be accomplished by establishing a formal process for deploying new technology that assures appropriate training is provided. Whether or not such an action is taken to prevent this cause, correct the problem, or mitigate the symptoms depends on their costs and expected benefits.

For example, if the project has already passed through the phase where the tool suite was expected to have the greatest impact, then providing training to this project team may not be cost-effective, although preventing future occurrences and mitigating the impact of the current problem may still be helpful.

**CMM/CMMI Views of Causal Analysis**

While the software community’s interest in causal analysis predates the publication of the CMM [5], the pursuit of process maturity has become a primary motivation for the adoption of causal analysis practices today. Both the CMM and CMMI [6] contain process areas describing causal analysis activities. These are Defect Prevention (DP) and Causal Analysis and Resolution (CAR), respectively. These two views of causal analysis differ in three important respects:

1. Required practices (activities).
2. Focus on prevention of defects.
3. Scope of triggering anomaly.

These differences are summarized below. The principal activities of the DP key process area of the CMM [5] are as follows:

- A DP plan is developed.
- Task kick-off meetings are held.
- Causal analysis meetings are held.
- Teams meet to coordinate actions.
- Defect prevention data is documented.
- Organizational process is revised.
- Project process is revised.
- Feedback is provided to staff.

Using the terminology described earlier, DP views defects as problems to be corrected. Failures are the consequences or symptoms of these problems that may have to be mitigated with workarounds, etc.

**“One of the consequences of a poor understanding of the nature of causal systems and causal analysis is that causal analysis sessions become superficial exercises that do not look deeply enough to find the important causes and potential actions that offer real leverage in changing performance.”**

The conditions that lead to the creation of defects are the causes to be prevented.

The specific practices of the CAR process area of CMMI [6] are as follows:

- Select defect data for analysis.
- Analyze causes.
- Implement the action proposal.
- Evaluate the effect of changes.
- Record data.

Note that DP requires some additional activities, not obvious in CAR. In particular, developing a DP plan and conducting task (usually phase) kick-off meetings exceed the explicit requirements of CAR. DP is triggered by the recognition of an opportunity for improvement, e.g., a large number of defects associated with a particular activity.

DP focuses on developing preventive actions, rather than corrective or mitigating actions. Moreover, DP focuses on defects and their causes, not problems in general. Actions to detect defects earlier usually are considered preventive actions, although the case can be made that they really are corrective actions.

CAR is more general than DP. CAR defines a defect to include a broad range of problems. Any anomaly, outlier, or opportunity (as described in the preceding section) may trigger CAR, and result in any of the three types of actions identified earlier. It does not focus on prevention and early detection.

The generality of CAR makes it easy to come up with an example of investigating something to identify some kind of action, and thus claim satisfaction of the CAR requirements. On the other hand, systematic causal analysis does not need to be limited to the prevention of defects, as implied by DP. An understanding of the nature of causal systems helps to overcome the generality of CAR and ensure that each potential trigger for causal analysis is handled appropriately.

**Summary**

A good understanding of the basic concepts and terminology of causal systems helps to overcome the difficulties inherent in implementing a practice that seems obvious. The differences between the perspectives of CAR and DP has led to some problems as organizations either 1) try to facilitate the transition to CMMI by building a CMM Level 5 process that incorporates CMMI guidance into its initial design, or 2) transition an established CMM Level 5 organization to CMMI.

A causal analysis process based on CAR usually does not satisfy the CMM requirements for DP. A causal analysis process based on DP usually does not satisfy CMMI requirements for CAR. Understanding and applying the basic concepts of causal analysis underlying both process areas makes it possible to design a process that satisfies both sets of requirements.

Effective causal analysis is becoming even more important to the software industry as process maturity increases and new forces, such as Six Sigma [9] focus increasing attention on quality improvement. Academic researchers, especially those conducting empirical studies, also may benefit from thinking a little more
systematically about causal systems. Application of the concepts and terminology presented here helps ensure that causal systems get fully investigated and effective actions are taken.

References
It was a cold, gloomy night in October. Outside the fog was so thick you could not see your hand in front of your face. Inside was even worse. Joe walked out of the conference room in a daze. He tried to remember what had happened but it all seemed like such a blur. The throbbing in his head grew even stronger. He hurried down the hall to the men’s room. His thoughts were spinning. He asked himself, “What am I going to do?”

Joe had just learned the project he was working on would require more overtime. He kept thinking of how his wife had threatened to leave him just last week if he could not spend more time with her and the kids; in fact, he had not seen his kids in weeks. By the time he got home, they were in bed. Even when he did see them, he was so tired and frustrated he did not enjoy them. In fact, he had not really enjoyed life in a long time. It had actually started about a year ago when he had begun working on this project.

All of a sudden, the meeting came back to him. Voices screamed out in his head: “What do you mean that’s not what you want? That’s what the requirements say.”

“That’s not what we meant though. Don’t you people understand anything?”

“We understand what you wrote down in the statement of work.”

“But did you even bother to ask what we meant?”

“Well, we thought it was pretty clear.”

“You missed the basic functionality we were looking for; in fact, this is so bad we’re going to have to start completely over. And, by the way, we can’t give you any slack on the schedule either.”

For Joe, things were definitely getting ugly! This scenario may sound familiar to many of you. It happens time after time on project after project. So, how does it get like this?

How Does a Project Get Like This?

Sadly, for the information technology (IT) industry as well as their customers, studies show that the majority of systems are delivered with only about 42 percent to 67 percent of requirements. The Standish Group has found that even though projects are being delivered on time and within budget, the statistics for delivering requirements and meeting customer expectations are decreasing significantly [1].

Figure 1 shows a summary of The Standish Group’s reports concerning project success as well as the top 10 most important elements for successful projects. The Standish Group stated,

Figure 1: Standish Group Findings Summary

We find that on average only 54 percent, down from 67 percent in 2001, of the originally defined features of a project are delivered. Even more troubling is the realization that of those features that are delivered – a full 45 percent are NEVER used. [4]

This article does not contain any new or eye-opening information; much of the information discussed is well known to requirements engineering experts. Best practices in requirements engineering have been honed since about 1968, and people have been writing about and teaching requirements engineering for several years; however, statistics continue to show that many IT practitioners and project managers still are not listening or have not been exposed to good requirements engineering.

In my positions over the last 20-plus years as project manager, software/technical project manager, software developer, systems engineer, process improvement engineer, new business proposal manager, and IT instructor, I have had the opportunity to be both the requirements giver and the requirements receiver. I have seen some very good examples of require-
If Architects Had to Work Like Programmers

Dear Mr. Architect:

Please design and build me a house. I am not quite sure what I need, so you should use your discretion.

My house should have between two and 45 bedrooms. Just make sure the plans are such that the bedrooms can be easily added or deleted. When you bring the blueprints to me, I will make the final decision of what I want. Also, bring me the cost breakdown for each configuration so that I can arbitrarily pick one.

Keep in mind that the house I ultimately choose must cost less than the one I am currently living in. Make sure, however, that you correct all the deficiencies that exist in my current house (the floor of my kitchen vibrates when I walk across it, and the walls do not have nearly enough insulation in them).

As you design, also keep in mind that I want to keep yearly maintenance costs as low as possible. This should mean incorporating extra-cost features like aluminum, vinyl, or composite siding. (If you choose not to specify aluminum, be prepared to explain your decision in detail.) Please take care that modern design practices and the latest materials are used in constructing the house, as I want it to be a showplace for the most up-to-date ideas and methods. Be alerted, however, that the kitchen should be designed to accommodate, among other things, my 1952 Gibson refrigerator.

To ensure that you are building the correct house for our entire family, make certain that you contact each of our children, and also our in-laws. My mother-in-law will have very strong feelings about how the house should be designed, since she visits us at least once a year. Make sure that you weigh all of these options carefully and come to the right decision. I, however, retain the right to overrule any choices that you make.

Please do not bother me with small details right now. Your job is to develop the overall plans for the house: Get the big picture. At this time, for example, it is not appropriate to be choosing the color of the carpet. However, keep in mind that my wife likes blue.

Also, do not worry at this time about acquiring the resources to build the house itself. Your first priority is to develop detailed plans and specifications. Once I approve these plans, however, I would expect the house to be under roof within 48 hours.

While you are designing this house specifically for me, keep in mind that sooner or later I will have to sell it to someone else. It therefore should have appeal to a wide variety of potential buyers. Please make sure before you finalize the plans that there is a consensus of the population in my area that they like the features this house has.

I advise you to run up and look at my neighbor's house he constructed last year. We like it a great deal. It has many features that we would also like in our new home, particularly the 75-foot swimming pool. With careful engineering, I believe that you can design this into our new house without impacting the final cost.

Please prepare a complete set of blueprints. It is not necessary at this time to do the real design since it will be used only for construction bids. Be advised, however, that you will be held accountable for any increase of construction costs as a result of later design changes.

To be able to use the latest techniques and materials and to be given such freedom in your designs is something that cannot happen too often. Contact me as soon as possible with your complete ideas and plans.

Respectfully,

J.P. Anonymous

P.S.

My wife has just told me that she disagrees with many of the instructions I have given you in this letter. It is your responsibility as the architect to resolve these differences. I have tried in the past and have been unable to accomplish this. If you cannot handle this responsibility, I will have to find another architect.

P.P.S.

Perhaps what I need is not a house at all, but a travel trailer. Please advise me as soon as possible if this is the case.

Whose Responsibility Is Understanding Requirements?

To correct this prevalent problem, the IT industry as a group has to depart from the them-and-us attitude that permeates the industry: it must be just as. The finger pointing must stop, and we must start...
working as a team, both the requirements receivers and requirements givers. The current trend toward agile/eXtreme programming (XP) [6] consists of several practices that lend themselves to accomplishing better requirements engineering. One significant aspect of agile/XP is working closely with the client throughout the development process, which is called Active Stakeholder Participation.

The following are some ideas that have worked well for others:
- Bill of rights or stakeholder contract.
- Approval process for all requirements.
- Win-win negotiations meetings that negotiate requirements based on technology, environment, time, effort, and budget constraints.
- Requirements team training; i.e., same training for all team members.

It is the development team’s responsibility to learn to balance the stakeholder needs and expectations. The needs are the identified requirements and the expectations are the unidentified requirements. Sometimes the expectations drive the full understanding of the identified requirements. If you understand what the customer is looking for in terms of their expectations, you gain insight into what they have identified as the real requirements. It is the customer’s responsibility to articulate their expectations so that the development team fully understands what they are looking for in the resulting product.

For both the development team and the customer, there must be a clear understanding of who are the decision makers or final authorities for requirements. This includes someone who can do the following:
- Add or approve a new requirement.
- Change an existing requirement.
- Accept changes to requirements.
- Direct the developer or their manager.
- Determine if a requirement has or has not been met.
- Accept requirements as met or not met.

A graphical depiction can help immensely in defining and keeping track of who’s who. These should be approved by the appropriate managers and distributed to the entire team. If a project has a communications plan, this is a good place to include these diagrams.

Why Is Requirements Engineering So Important?
We, as an industry, cannot afford the consequences of not doing requirements engineering effectively. The cost of incorrect, misunderstood, and not agreed upon requirements affects all of us in terms of time, money, and lost opportunities. The results can be confusion, distrust, misdirection, frustration, lack of quality, higher cost, overtime, a general lack of understanding, and incapability due to being ill-equipped to handle issues.

Requirements engineering is a means of providing the functions and related characteristics of systems by providing the tools, concepts, and methods that mediate between the providers of information technology services and products, and the users or markets for the services and products. It is a means of providing the necessary communications to define needed products. Misunderstood, wrong, or even slightly skewed requirements propagate as the project moves forward until you get to the testing phase and scenarios like those discussed earlier occur.

Like dominoes, once problems start, they proliferate throughout the project – requirements problems at the beginning proliferate through design, development, and, finally, into test. Many times it gets to the point where starting over takes less time than trying to fix what you have already done. The sidebar “If Architects Had to Work Like Programmers” illustrates this point very well.

What Are Requirements?
Requirements tell the development team what the customer is contracting the team to build. As a whole, they provide a means of determining the functionality and attributes of the resulting product. The Institute of Electrical and Electronics Engineers [7] defines a requirement as the following: (1) a condition or capability needed by a user to solve a problem or achieve an objective; (2) a condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed documents; and (3) a documented representation of a condition or capability as in (1) or (2).

Proven Requirements Engineering Process
CMMI provides a good foundation for requirements engineering. It describes what should be included in an effective requirements engineering process. CMMI is based on best practices and lessons learned from the IT community, including both government-related and private industry. There are, in fact, several good taxonomies and methodologies that have been defined for requirements engineering. The requirements engineering process illustrated in Figure 2 and described in this article has proven effective on numerous successful projects and includes these basic best practices.

There are two major phases that are essential in defining and controlling requirements: Requirements Definition and Analysis, and Requirements Management.

Requirements Definition and Analysis
Requirements Definition and Analysis sets the stage for all subsequent tasks in devel-
Developing the resulting product. Getting this right is key to the success of the overall project. A domino effect will begin here due to wrong, misunderstood, or slightly skewed requirements. The rule of thumb I have learned during my career is approximately 15 percent of project time should be spent on identifying, defining, and clarifying the requirements. This will vary depending upon the life-cycle methodology selected but it works well for most projects.

The following list includes some examples of typical inputs to the Requirements Definition and Analysis task. The inputs will depend upon an organization’s processes, customer’s processes, and whether the system being developed is an upgrade, major refurbishing of an existing system, or a new system.

- **Functional and performance requirements.** This information can be obtained using many methods but could simply be a list or a verbal exchange.

- **Statement of work.** Typically provided by the customer to the development team. Can be a key document for the customer and development team.

- **Plans.** Projects produce numerous plans that may drive some requirements such as the project plan, configuration management plan, logistics plan, communications plan, development plan, or engineering plans.

- **Customer information.** Various customer information can be derived that drives requirements such as customer standards, including user interface standards and security standards.

- **Problem reports.** Many times problem reports drive major system upgrades or refurbishment. The original problem report contains a good deal of information pertinent to understanding requirements.

- **Schedule.** The schedule may contain some information needed to understand what the customer is looking for and the complexity expected, especially if the customer provides the overall schedule.

- **Work Breakdown Structure (WBS).** This provides information concerning the breakdown of requirements if it is developed using a WBS method that breaks the project down by product functionality.

- **Architecture (physical and functional).** For existing systems, this can be key to understanding requirements such as communications protocols, existing functionality, interfaces, etc. For new systems, the customer may provide this information in a statement of work and existing system documentation may help understand interfacing systems and data.

- **Engineering analysis.** Many times one or more trade studies or prototypes are developed that will help in understanding requirements.

- **Constraints.** There are many forms that constraints can take, including time, cost, and technical.

- **Assumptions.** Development team assumptions will drive the requirements and understanding of requirements. These should always be documented and discussed with the customer. Conversely, customers have assumptions that also must be communicated.

- **Existing system documentation.** Existing system documentation even when not up to date can provide invaluable information for understanding requirements.

### Table 1: Requirements Identification Techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Brief Description</th>
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<tr>
<td>Interviews (structured and unstructured)</td>
<td>Meetings can be structured, unstructured, or a combination of both.</td>
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<tr>
<td>Group Brainstorming</td>
<td>These are informal meetings that generate discussion of requirements.</td>
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<td>Observation</td>
<td>When upgrading systems, it is extremely helpful to observe a system in its operational environment. When the automated system is not available, observing the manual functions helps understanding.</td>
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<tr>
<td>Analysis of Existing Documentation</td>
<td>When upgrading systems, it is extremely helpful to analyze existing documentation (development and user documents). When the automated system is not available, some documentation may be available describing the functionality.</td>
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<tr>
<td>Questionnaires and/or Surveys</td>
<td>Questionnaires and surveys can give the development team insight into expectations (a word of caution: appropriate customer representative should always approve each requirement and derived requirement).</td>
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<tr>
<td>Prototyping</td>
<td>Prototyping is a great tool to use to simulate the final product especially for large systems by providing a visualization of the system or parts of a system. It is very effective in exposing any misunderstandings, risks, or missing functionality, clarifying confusing functionality; defining derived requirements; and avoiding being trapped in loops of refinement during design and coding. The two types of prototypes include discovery (aka throw-away) and production (aka evolutionary).</td>
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<tr>
<td>Conceptualization/Modeling</td>
<td>Conceptualization/modeling helps to clarify and prove requirements, weed requirements, clarify gaps in requirements, generate derived requirements, discover rules and procedures and functions/algorithms needed, ferret out data needs, and ensure correctness of the defined requirements. Effective in meetings (interviews and brainstorming) to describe how a system will behave, to describe interfaces (internal and external), and to discuss the consequences of each requirement using a whiteboard or paper.</td>
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<tr>
<td>Cognitive</td>
<td>Examining usability of requirements based upon cognitive characteristics of user interaction. This technique incorporates the human factors into requirements definition. Some methods include protocol analysis, laddering, card sorting, and repertory grids.</td>
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Requirements Identification/Elicitation

The Requirements Identification/Elicitation step provides an in-depth description of the desired resulting product. Some of the techniques used to identify and analyze requirements include those shown in Table 1.

I always recommend that one or more of these techniques be used to fully understand and communicate requirements throughout the project. The better the requirements are understood, the more likely the resulting system will be effective for the customer. During Requirements Identification/Elicitation, several questions need to be addressed that are shown in Table 2.

There is no simple formula for writing good, useable requirements; however, sources for writing good, useable requirements can be found on the Internet.
The categories should be based upon the cause, impact and priority, timing, exception handling, and performance criteria. Function is the most prevalent and understandable categorization method.

Prioritization should be given to each requirement to understand its importance. Prioritization will help determine the sequence of tasking as well as weed out the essential versus the desirable versus the optional requirements.

Each requirement should be examined to determine any technical, cost, or schedule implications or risks. Any risks associated with each requirement should be recorded and tracked using the project’s risk management process. The impact and the potential for occurrence will be key factors in managing risk.

Any impractical and excessive requirements should be weeded out since they drive cost and schedule. Multiple requirements pertaining to the same functional/performance feature should be examined to ensure they are coherent and consistent. Finally, requirements should be allocated to system components for assignment. This can be done using a WBS if it has been designed using that method.

Requirements Traceability Matrix Generation
A very useful tool in managing requirements is a Requirements Traceability Matrix that is generated with the complete set of requirements. The matrix provides an authorized record of the requirements. The tool selected for the matrix will depend upon the size and scope of the project. A database is the optimal method for managing requirements but a simple spreadsheet can also be very effective. Several very good commercial tools are available; see <www.incosec.org/tools/tooltax/reqtrace_tools.html> [8].

Creation of a homegrown requirements database will give users exactly what they are looking for if the expertise and time are available. Requirements tools have many advantages over a simple listing, including easy search, smooth requirements management, requirements change control, requirements metrics collection with minimal effort, and any needed documentation. The key to selecting the right tool is to ensure that you are getting the bang for the buck.

In [4], The Standish Group states, “Only 5 percent of new and changing applications will use a requirements management tool.” That could be why we have many of our requirements problems.

Requirements Management
The requirements management phase consists of monitoring and controlling the requirements throughout the remaining development life cycle. Monitoring and controlling requirements ensures that the resulting system has all of the agreed upon or authorized requirements. It helps to avoid the widespread requirements epidemic known as requirements creep.

Requirements creep can drive both cost and schedule significantly. When a new or upgraded requirement is identified, the development team must go through the same process as defined for the Requirements Definition and Analysis phase with the appropriate decision makers.

New Requirement Identification/Update Requirements
As new requirements are identified or existing requirements change, they must be updated in the requirements baseline. Requirements should be maintained and baselined using the same type of configuration management controls as software such as the four elements of configuration management: identification, change management (the key), status accounting, and verification and audit.

Some configuration management tools have built-in requirements management features. This ensures the integrity of the requirements.

<table>
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<th>Table 2: Requirements Engineering Process</th>
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requirements. As requirements change—and they will—the changes must be controlled.

Requirements Change Control
Either formal or informal change control methods can be used. Formal change mechanisms include using a Configuration Change Board and appropriate formal authorizations. Less formal methods can also be effective, especially for smaller projects.

Whether a formal or informal change control method is selected, it is important that the identified decision makers finalize and authorize all requirements changes. This includes management of even the smallest detail since even a slight change can alter elements of the product. The changes must be coordinated with all stakeholders since they may have an impact on the tasks they are assigned either directly or indirectly.

Recycle Definition and Analysis
Once the new or upgraded requirements are approved, they must undergo the same process as the initial requirements.
- Requirements Translation/Decomposition.
- Requirements Collation.
- Requirements Traceability Matrix Generation/Update.

It is important to ensure that changes to requirements do not impact other requirements. Many times even simple changes will have a ripple effect on other requirements. The development team must be prepared to handle these changes. The Requirements Traceability Matrix should always reflect the current requirements as they are at any point in the project. They will be the authorized record for the resulting product.

Requirements Volatility Metric
Several metrics will help determine the status of a project but a key metric is requirements volatility, which is considered a key project success indicator. It indicates the stability of the baseline requirements.

How much change is too much and at what stage of the development cycle will it have a significant impact? There are some rules of thumb for how much requirements change is too much. “A Gentle Introduction to Software Engineering” indicates,

The accepted requirements volatility metric is 1 percent of requirements per month. If it is much less, one should ask oneself if the system would be desirable to its intended audience. If it is much more than 2 percent a month, development chaos is all but assured. [9]

Other sources also use that rule of thumb; however, a study accomplished at the Colorado State University, Department of Computer Science concluded the following:

All the results show that changes have more influence on defect density when they occur closer to the end of the testing effort. This temporal dependence is generally exponential. Changes made very early can be relatively inconsequential, but those occurring later can raise defect density quite significantly. [10]

I have found in my experience that frequent changes to requirements are expected during the early stages of the project; however, a high volume of changes late in the development life cycle can have a significant impact to functionality, interfaces, cost, and schedule. The amount of acceptable changes can then depend upon many factors, including the project phase, development team, requirements complexity, system complexity, system size, customer expectations, schedule, technology, methodologies, tools, etc.

If frequent changes are expected, it may be beneficial to use either an iterative build life cycle such as the spiral or incremental build or an agile/XP approach. There is an upside and a downside to all methods; the key is to select the method that is right for that development team, the customer, the system being developed, and the environment.

The Bottom Line
Time after time, projects experience nightmare scenarios similar to the one described at the beginning of this article. It is key to a project’s success in delivering the customer’s needed functionality that development teams and customers work as a team to develop effective requirements in order to develop effective products. If we look at things from each other’s vantage point, the chance of success grows by leaps and bounds. We all look at things differently based on our background, education, experience, and simply from where we are standing at the moment. Open communications and respect for each other’s position is crucial.

There is enough to panic about when developing a system without the added stress of misunderstandings. Products must be delivered with better numbers than 42 percent to 67 percent of the required functionality. Nobody can afford the consequences of wrong, misunderstood, or even slightly skewed requirements.

The bottom line is this: Always remember that what you see is relative to where you are standing. We must all work as a team and select the best methodologies, techniques, and tools that keep things simple so things do not get ugly.

References

Additional Reading


### About the Author

Deb Jacobs is a professional consultant for Focal Point Associates specializing in process improvement and project management. She provides support to organizations in training, process improvement consulting, project management consulting, software engineering consulting, and proposal development. Jacobs has more than 25 years experience in system/software engineering, project management, process improvement, and proposal development. Her notable successes include leading a successful Capability Maturity Model® (CMM®) Level 3 effort in one year, successfully reorganizing struggling projects, mentoring new managers, and gaining new business for companies through proposal development.

She is former SPINOUT editor/originator; former Computer Emergency Response Team conference chairperson, infotec deputy Software Tracks chair, and a Software Engineering Institute CMM IntegrationSM contributor. She is currently working on a book to help organizations successfully achieve process maturity at minimal costs. Jacobs has a Bachelor of Science in computer science.

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### Web Sites

**Project Management Institute**

[www.pmi.org](http://www.pmi.org)

The Project Management Institute (PMI) is a not-for-profit, project-management professional association with more than 100,000 members in 125 countries. PMI publishes “A Guide to the Project Management Body of Knowledge,” offers Project Management Professional certification, and maintains ISO 9001 certification in Quality Management Systems.

**Software Program Managers Network**

[www.spmn.com](http://www.spmn.com)

The Software Program Managers Network (SPMN) is sponsored by the deputy under secretary of defense for Science and Technology, Software Intensive Systems Directorate. It seeks out proven industry and government software best practices and conveys them to managers of large-scale Department of Defense software-intensive acquisition programs. The SPMN provides consulting, on-site program assessments, project risk assessments, software tools, guidebooks, and hands-on training.

**NASA Independent Verification and Validation Facility**

[www.ivv.nasa.gov](http://www.ivv.nasa.gov)

The NASA Independent Verification and Validation (IV&V) Facility was established in 1993 to provide the highest achievable levels of safety and cost-effectiveness for mission critical software. The IV&V Facility’s efforts have contributed to the improved safety record of NASA since its inception. The IV&V Facility houses more than 150 full-time employees and more than 20 in-house partners and contractors.

**Practical Software and Systems Measurement**

[www.psmsc.com](http://www.psmsc.com)

Practical Software and Systems Measurement (PSM) is sponsored by the Department of Defense and the U.S. Army. PSM is an information-driven measurement process that addresses the unique technical and business goals of an organization by providing objective information needed to successfully meet cost, schedule, and technical objectives.

**International Society of Parametric Analysts**

[www.ispa-cost.org](http://www.ispa-cost.org)

The International Society of Parametric Analysts (ISPA) is a professional society dedicated to the improvement and promotion of parametric cost modeling techniques and methodologies and the related fields of risk analysis, econometrics, design-to-cost, technology forecasting, and management. ISPA provides a forum that encourages the professional development of its members through the interchange of ideas and perspectives. ISPA members represent government agencies, universities, and nearly 200 organizations in 12 countries.
Independent Estimates at Completion – Another Method

Walt Lipke
Tinker Air Force Base

This article reviews the most frequently used Earned Value Management formulas for calculating the Independent Estimate at Completion (IEAC). The formulas are examined and discussed with reference to the findings from several studies. Some formulas appear to be inconsistent with the determinations from the studies of the Cost Performance Index (CPI). An alternative method of calculating IEAC is proposed, which is in agreement with the generalizations and conclusions from the IEAC and the CPI studies. This method shows promise.

The calculation of the Independent Estimate at Completion (IEAC) is significant to project management. It is a quick method facilitated by using Earned Value Management to predict the final project cost. Project managers (PM) and cost analysts often use IEAC to validate the bottoms-up forecast made by contract sources. When the IEAC result is substantially different from the contractor’s estimate, more than likely the PM will question the discrepancy. The PMs also use the IEAC to justify continuation of the project to upper management. Thus, you can see IEAC has far reaching implications.

During the last 10 years, primarily due to the interest generated from the cancellation of the Navy’s A-12 Avenger acquisition program, studies of the predictive accuracy of the various methods for calculating IEAC have been made. These studies considered and included several IEAC formulas and regression calculation methods. In general, no single specific method has been shown to be superior.

Although no particular method provided accurate results for all periods or phases of a project, some fundamental characteristics were observed. With the establishment of these characteristics, the application of some of the IEAC formulas and calculation methods appears to be questionable. However, these fundamentals have provided inspiration for proposing new IEAC methods in this article.

Studies of IEAC and Cost Performance Index

There are several popular formulas for calculating IEAC. In general, the equations use the cost to date added to the forecast cost for the work remaining. For the formulas identified here, the Cost Performance Index (CPI) and Schedule Performance Index (SPI) are the cumulative values unless otherwise noted. The following are the IEAC formulas most often seen and used:

- \( \text{IEAC}_1 = \text{ACWP} + \frac{\text{BAC} - \text{BCWP}}{\text{CPI}} \)
- \( \text{IEAC}_2 = \text{ACWP} + \frac{\text{BAC} - \text{BCWP}}{\text{SPI}} \)
- \( \text{IEAC}_3 = \text{ACWP} + \frac{\text{BAC} - \text{BCWP}}{(\text{SPI} \times \text{CPI})} \)
- \( \text{IEAC}_4 = \text{ACWP} + \frac{\text{BAC} - \text{BCWP}}{(\text{wt}_1 \times \text{SPI} + \text{wt}_2 \times \text{CPI})} \)
- \( \text{IEAC}_5 = \text{ACWP} + \frac{\text{BAC} - \text{BCWP}}{\text{CPI}} \)

The abbreviations \( \text{wt}_1 \) and \( \text{wt}_2 \) of IEAC 4 provide insight regarding the study results, regardless of type and stage, is IEAC.

A second set of studies was performed that examined the behavior of the CPI throughout the life of a contract [3, 4, 5]. Two of the studies are very recent – spring and winter 2002 – and performed the analysis using statistical hypothesis testing. The three studies provided the following to PMs for assessing the validity of estimates at completion:
1. The result from IEAC is a reasonable estimate of the lower bound of the final cost.
2. The cumulative value of the CPI stabilizes by the time the project is 20 percent complete. Stability is defined to mean that the final CPI does not vary by more than 0.10 from the value at 20 percent complete.
3. The value of the CPI tends only to worsen from the point of stability until project completion.

Commentary

The understanding of the behavior of the CPI, over the life of the project, provides insight regarding the study results for the IEAC equations. For IEAC,

For IEAC, the product, SPI * CPI, is sometimes identified in literature as SCI. The abbreviations \( \text{wt}_1 \) and \( \text{wt}_2 \) of IEAC are numbers between 0.0 and 1.0 used to weight the influence of the two indexes; the sum of \( \text{wt}_1 \) and \( \text{wt}_2 \) is equal to 1.0. The CPIx in IEAC is the cumulative value of the last \( x \) performance periods.

Two studies were performed in the 1990s that examined the prediction capability of the various formulas and regression methods [1, 2]. The generalizations and conclusions reached by these studies of IEAC are as follows:
1. The accuracy of regression-based forecasting has not been established. A recommendation was made to further study the method.
2. The accuracy of index-based formulas depends upon the system in development, and the stage and phase of the project. The formula most frequently appearing in the tabulated results, regardless of type and stage, is IEAC.
3. The index-based formulas, including SPI are better applied early in the project. For projects behind schedule, SPI falsely improves as percent complete increases. Thus, the influence of SPI on the computation is not in agreement with actual schedule performance.
4. The accuracy of IEAC with \( \text{wt}_1 = 0.2 \) and \( \text{wt}_2 = 0.8 \) is not supported.
5. The accuracy of IEAC is better for middle and late stages of the project.

"Using the range of outcomes for the CPI from the statistical method and IEAC, a range for the estimates at completion can be calculated. The range may be computed for any statistical confidence level desired ..."
the statistical method and IEAC, a range
the range of outcomes for the CPI from
a prior publication [6]. Using
provide reasonable results, even when
IEAC, as we know it must be. Regarding IEAC, it makes sense that this
equation is a reasonably good predictor
because the CPI, is constructed from
recent data. However, the limited amount
of data used for creating the CPI, causes
IEAC to oftentimes exhibit erratic
behavior.

From these correlations, there appears
to be insufficient reason to continue to
use IEAC equations two through five. We
know from the winter 2002 study [5] that
the calculated result from IEAC is a
good estimate of the lower bound for the
final cost. Also, it is known with 95
percent confidence that the absolute value of the
difference between the CPI at 20 percent
complete (CPI) and the CPI at project
completion (CPI) will not be
greater than 0.10 [4]. Thus the result from
IEAC, when using the projected extreme
values for the CPI, is expected to yield the
upper and lower bounds for the final
cost. Only the IEAC equation is needed
to predict the range of project cost outcomes
with 90 percent confidence (A 90
percent confidence for the estimate at completion
(IEAC) range is equivalent to 95 percent
confidence that | CPI - CPI | ≤ 0.1.)

**Alternative Calculation Methods**

An alternative to the presently employed
IEAC calculation methods (the five
formulas cited previously) is to compute the
statistical range of outcomes for the CPI.
I have described and illustrated this
method in a prior publication [6]. Using
the range of outcomes for the CPI from
the statistical method and IEAC, a range
for the estimates at completion can be
calculated. The range may be computed for
any statistical confidence level desired; in
my article referenced above, the range is ±
three standard deviations, but it just as
well could be 90 percent.

If the CPI for each performance period
of the project behaves independently
from when it occurs, then this method
should yield very good results. Without
proof, I believe that the method will still
provide reasonable results, even when
there is an underlying relationship
between the cumulative value of the CPI
and the period of performance in which it
occurs. The reason for my assertion is the
value of the CPI is updated each period;
therefore, it is moving toward its final
value. And, the standard deviation of the
periodic values is likely large enough to
encompass the value for the CPI at project
completion. Therefore, it is very likely the
actual final cost will be within the 90 percent
confidence range calculated using
IEAC. For this method, the predicted
estimate at completion will always be optimistically biased; i.e., it is likely the
computed nominal value will be less than the
final actual cost.

A second IEAC alternative calculation
method is similar to the first, but it should
reduce the optimistic bias. The characteristic
of the CPI worsens from the point of
stability until completion, reported in the
1993 study [3], indicates there may be a
mathematical relationship between
cumulative CPI and the percentage of project
completion. Beginning at 20 percent complete, the CPI is regarded as stable and proceeds to

decrease as percent complete increases, but does not
fall more than 0.10 from its stable value.

Understanding the stability and inefficiency characteristics, a mathematical
model of the CPI decreasing as the project
moves toward completion can be created.
With the proposed equation, it should be understood that the model only
deals with the two characteristics and thus has little theoretical substantiation.
The mathematical form chosen, after some experimentation, is the following:

\[
\ln(CPI) = A + B \times (X^3)
\]

where,

A and B are unknown parameters, X is the
percentage completion of the project, and
ln is the natural logarithm.

The calculated result from the equation
is considered to be valid when the
project is within the range of 20 percent
to 100 percent complete. An advantage of
the model’s mathematical form is that it
has only two unknown parameters: A and
B. Parameter A can be either positive or
negative; however, B can only be negative.
By constraining B to be negative, the tendency
of the CPI to worsen from the point of stability to project completion is
imposed in the model [4]. The rate of
decrease of the CPI is dependent upon B
and the power to which X (percent complete)
is raised. After some trials, I chose the
power 3. It seems reasonable that
noticeable efficiency roll-off should begin
to occur when X equals 0.5; the power
equal to 3 provides this behavior.

Using this model with curve-fitting
software, statistical prediction is easily
accomplished. The software produces the
nominal values for A and B along with
their corresponding 90 percent confidence limits. When applying the curve
fitting software, the variables A and B are
constrained such that the CPI is within
0.1 of the CPI. As mentioned previously,
the variable B is further restricted to have
only negative values. The constrained values
for A and B are computed for each
paired data values of the CPI and percent
complete using the following equations:

\[
A_{con}=\ln(CPI_{2n} + 0.1) - B_{max} \\
B_{con}=\ln(CPI_{2n} - 0.1) - A_{min}
\]

where,

A and B are the constraint values for the
variables A and B; A and B (= 0) are
the minimum and maximum values of
A and B, respectively; and the CPI is the
value occurring at the first percent com-

“ ... I believe that the
method will still provide
reasonable results, even
when there is an
underlying relationship
between the cumulative
value of the CPI and the
period of performance in
which it occurs.”
The confidence limits produced from the software assume that the data population is infinite. However for our application, project data is finite. For example, the project may execute for two years; if earned value status is taken monthly, the project has 24 data points. Because projects are finite, the confidence limits for ln CPI can be computed. Of course, by applying the antilog the upper and lower CPI values are determined. These quantities are then used in IEAC5 to calculate the 90 percent confidence limits of the EAC. The calculation may yield a confidence limit outside of the upper and lower bounds for EAC, especially when percent complete is less than 0.5. In agreement with the studies cited earlier, the lower bound is estimated by dividing the CPI by plus 0.1 into BAC, while the upper bound is BAC divided by CPI minus 0.10.

Example Application

To provide an example of the proposed IEAC calculation method, notional data has been created for percent complete and the cumulative CPI. The data is shown in Table 1.

Beginning with \(X \geq 0.2\), the nominal values of \(A\) and \(B\), and their 90 percent confidence limits, are repeatedly obtained from the curve-fit as each new data point is included in the data set. A minimum of three data points is required to determine \(A\) and \(B\) and their limits. The high and the low values for ln CPI, calculated from the model’s formula, are determined by pairing the high values of \(A\) and \(B\), and the low values, respectively. The high and low ln CPI limits are then modified by the finite project adjustment factor, as described in the previous section. These adjusted limits are the 90 percent confidence limits for ln CPI.

The antilogarithms of the nominal, and the adjusted high and low values, of ln CPI are used in the IEAC5 equation to calculate estimate at completion. The calculation produces the most likely value for EAC along with its 90 percent confidence limits. For the Budget at Completion (BAC) equal to $100,000, the result of the curve fit for our IEAC model (IEAC5(m)) is shown in Figure 1.

As can be observed, the model rapidly converges and accurately predicts ($102,817) the final cost ($102,788), after only a few data points are included in the curve fit. Likewise, it is seen that the 90 percent confidence limits, IEAC5(m) Hi and IEAC5(m) Lo, converge and eventually fall within the high and low boundaries for EAC. For reference, the high and low bounds for EAC are shown in the figure as Hi Bound and Lo Bound. The value for the high bound is $104,209, while the low bound is $86,236. Thus, it can be said that the results from the IEAC model are well behaved with respect to the predicted extremes of the estimate at completion.

To further illustrate the model’s performance, the results from computing IEAC5 and IEAC5 are compared to our model. Recall that IEAC5 uses CPI, which is the cumulative value of the CPI from the last three periodic observations. Figure 2 graphically depicts the percent difference from the final cost for each of the calculation methods. IEAC5 and IEAC5 are calculated using the equations cited earlier, while IEAC5(m) and IEAC5(m) Lo are the nominal and low confidence limit values from Figure 1.

As seen from Figure 2, the three methods produce comparably poor results for percent complete equal to 20 percent through 30 percent. Beginning at 40 percent there is a marked departure; the model's prediction of final cost becomes
significantly improved and is better than the other estimates. Beginning at 50 percent and continuing through project completion, the method used to calculate IEAC(m) produces cost estimates that have very small differences with the actual final cost. It is also noticeable that IEAC1 provides optimistic results as it should if, indeed, the CPI tends to worsen as percent complete increases [3, 4]. Likewise, IEAC5 produces optimistic results as percent complete increases, again, due to the tendency of the CPI to worsen. While not observed in the example, the CPI model can produce either optimistic or pessimistic results for IEAC(m).

The final observation for Figure 2 is the comparison of IEAC1 to IEAC1(m) Lo. Recall from the earlier discussion in the studies section of this article that IEAC1 was postulated to provide a good running estimate for the lowest value for final cost. The figure shows the two lines closely tracking beginning at percent complete equal to 0.40. Thus if the hypothesis concerning IEAC1 is valid, there is added credence to the nominal and high confidence limit values produced by the IEAC(m) calculation method.

Although the graphical result appears wonderful, the method is unproven. The data created conforms to the model itself; thus, the result should be good. Even so, what has been shown is significant. The model presented for the CPI behaves in accordance with the behavior characteristics determined by previous studies [3, 4, 5]:
1. The CPI stabilizes when project reaches 20 percent complete, CPI20.
2. The CPI tends only to worsen from the point of stability until project completion.
3. With 95 percent confidence, the CPI at project completion will not be more than 0.10 from CPI20.

If these characteristics are indeed true, then our example indicates the proposed model may provide good prediction capability for estimate at completion.

**Prototype Application**

To further illustrate the curve fit model approach to calculating IEAC, results from prototyping actual project data are shown. The application is in progress. As can be seen, the results from the real data correlate well with the notional data presented earlier. Figure 3 is an output from the curve fit software. In agreement with the studies of the CPI, the ln CPI is seen worsening as percent complete increases. As discussed earlier, the model accounts for degradation of cost performance as the project nears completion. Figure 4 illustrates the model’s rapid convergence to the predicted final cost. Observed in Figure 5 (see page 30), both IEAC1 and IEAC5 are predicting a more optimistic final cost than is the model. Lastly, the close tracking of IEAC(m) Lo IEAC1 is strikingly similar to the observation made for the notional data.

**Summary**

From several previous studies, it can be inferred that the behavior of the CPI, from its point of stability to project completion...
For a more in-depth explanation of earned value and its indicators, reference Quentin Fleming’s book [7].

2. The Confidence Interval is the region surrounding the computed nominal value within which the true value lies with a specified level of confidence. The end points of the interval are the Confidence Limits. The equation for the Confidence Limits is:

\[
<x> \pm z \left( \frac{\sigma}{\sqrt{n}} \right)
\]

where,

- \(<x>\) is the nominal value of \(x\), while \(z\) is from the standard unit normal distribution and corresponds to the area selected (for this application, \(z = 1.6449\) at 90 percent of the distribution area), \(\sigma\) is the standard deviation of the observations of \(x\), and \(n\) is the number of observations [8].

### About the Author

Walt Lipke is the deputy chief of the Software Division at the Oklahoma City Air Logistics Center. He has 30 years of experience in the development, maintenance, and management of software for automated testing of avionics. In 1993 with his guidance, the Test Program Set and Industrial Automation (TPS and IA) functions of the division became the first Air Force activity to achieve Level 2 of the Software Engineering Institute’s Capability Maturity Model® (CMM®). In 1996, these functions became the first software activity in federal service to achieve CMM Level 4 distinction. Under Lipke’s direction, the TPS and IA functions became ISO 9001/TickIT registered in 1998. These same functions were honored in 1999 with the Institute of Electrical and Electronics Engineers’ Computer Society Award for Software Process Achievement. Lipke is a professional engineer with a master’s degree in physics.

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A little Learning is a dang'rous Thing; Drink deep, or taste not the Pierian Spring. 

— Alexander Pope

While many people are familiar with metadata, which is information about information, and widely used to manage content in cyberspace, few understand the realm of pseudo-knowledge, where a little learning is not only not a dangerous thing, but in fact constitutes the most effective form of just-in-time transfer of intellectual property ever devised. Consider the pseudo-knowledge for the Capability Maturity Model® (CMM®) that was carefully crafted by its authors nearly two decades ago (whether they knew it or not), supporting countless presentations to senior managers in which software engineering process group chairs want to familiarize them with the CMM, but don’t want them to know enough to be dangerous:

1. The CMM has five maturity levels (so you can count them on one hand, boss).
2. Those five maturity levels have 18 key process areas (just like the 18 holes on the golf course you’re going to play this afternoon with that potential client).
3. Those 18 key process areas have 52 goals to achieve (just as there are 52 cards in the deck you’ll use to play poker at the 19th hole, after your 18-hole round of golf).
4. Those 52 goals are satisfied through the implementation of 316 key practices (which is almost 317, or if presented as 3/17 would be recognized as March 17th, which as we all know is St. Patrick’s Day, and a fine representative for the beer to be consumed at the 19th hole while you play poker with a deck of 52 cards after finishing the 18 holes of golf and shaking hands with your now new client with that firm senior manager handshake using all five fingers! However, since we only have 316 key practices, we’ll just have to remember St. Patrick’s Day eve, which would then of course be March 16th, or 3/16).

Thus, through effective presentation of pseudo-knowledge, your senior manager has information relevant to the CMM with which he or she can amuse his or her peers, family, and friends at cocktail parties without being dangerous to you, the process improvement lead!

Now, however, with the transition to the CMM IntegrationSM (CMMI®), this treasure trove of pseudo-knowledge is soon to be rendered obsolete! Useless! Pointless! The question of the hour is this: What shall be the pseudo-knowledge associated with the CMMI? How is a poor process lead to portray relevant but useless information about the CMMI to management, friends, family, and neighbors? Where do you start? Staged, continuous, or constageduous? Software only? Software and systems engineering? How about Integrated Product and Process Development (IPPD) and supplier sourcing? Six capability levels or five maturity levels? Where to begin? While it is true that each representation has 25 process areas and 55 specific goals, just what do you do with all those generic goals and practices? And how do you account for the difference in specific practices (189 vs. 185)? Do you even attempt to address the bodies of knowledge incorporated, the different dimensions, or the categories of process areas? Inquiring minds want to know!

Earlier this year, Pat O’Toole calculated that there are 4.7 x 10^18 possible capability level profiles across all 24 process areas in the CMMI for Systems Engineering, Software Engineering and IPPD Vers. 1.1 since each may be performed at any one of the six possible capability levels. How exactly do you think we’ll capture that little tidbit in pseudo-knowledge?

To this end, I hope the process improvement community will accept the challenge to identify the new pseudo-knowledge for the CMMI. How should we represent this fascinating tool in all its glory and splendor without sharing anything of real meaning or value? How shall we endeavor to entertain and amuse without compromising our positions as organizational leaders of process improvement? Put on your pseudo-thinking caps and send me your best! We’ll select the finalists from all entries submitted to me by Oct. 29, and let the community pick the winners at the CMMI conference in Denver, Colo., Nov. 15-18.

— Barry Schrimsher
barry@glentalon.com

3. Adapted with permission from a tale shared by Pat O’Toole of Process Assessment, Consulting, & Training, LLC.
The Software Technology Support Center (STSC) helps you improve your processes by identifying root causes of your problems; constructing simple, practical solutions; and creating ownership of the solution. In other words, we help determine what to change, what to change to, and how to cause the change. But how do you get started? Call us. The STSC can help plan process improvement at any level. Once you decide what you need, we are the group to help implement the solution, whether it’s implementing the Capability Maturity Model®, setting up a Management Steering Group, or designing a Software Engineering Process Group infrastructure. We help you understand how to implement process improvement. Don’t start your process improvement without a STSC mentor.

We have been in the trenches and have the scars to prove it. Call us first. Whether your organization is big or small, just starting a project or embattled in difficulties, we can help. We bring hands-on experience.

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