Chapter 12: Project Execution and Control of the Core Processes

The Why, What and How of Project Execution and Control

Chapter 12

12

Sabrina Stevens, project manager for the Internet development project, comes running into the office of Jack Jones, the project sponsor. "Jack!! Your not thinking of changing the requirements on the e-commerce web site are you—I heard a rumor!! You know we talked about this at the beginning of the project when we wrote up the requirements. We told you we would freeze the requirements after the conceptualization and definition stage because to change the requirements means that we have to go back and change everything—the requirements document, the project budget and plan, and because we've started execution, the functional specification, the design document, even some of the web modules. Sooooo, I'm hoping this rumor is wrong, Jack, because if it isn't you'd better be ready to shell out the big bucks."

"Sabrina, when we wrote those requirements, eleven months ago, our structural dynamics practice wasn't growing like it is now. You know it has been growing at the rate of 15% a month! For us not to have an e-commerce connection for that part of our business is to totally misrepresent what our firm is evolving into. I know it's going to be expensive to fix; I know you basically have to re-write all the documents beginning with the requirements document. At this point, we have two choices—either we effect this change now, or I cancel the project and hire an outside IT firm to re-build our web site!"

"Jack, you've got to be kidding!! You know we promised corporate we'd have this site up by the middle of the year. You know we're already behind schedule without this change. And, have you looked at the budget lately? We have just barely enough to finish out at this point and that's assuming everything goes well here as we approach testing and going live with the new site. Wouldn't it be better to deliver on what we originally conceived and defined and then effect the changes you're proposing in a second follow-on project?? Like I say, hope you've got lots of money."

"Sabrina, as I said, you agree to do this now or I'm canceling your project and going outside with the whole thing—the choice is yours!!"

Finally, we have arrived at the point where execution of the project can begin. In actuality, the lifecycle we have been describing is a kind of meta or super project methodology. One purpose of this lifecycle is to get to this point with a well-defined concept or product for the project and a well-developed plan and budget for execution of the project. With the deliverables of stages one and two in hand, stage three of the lifecycle can begin. And in doing so the steps determined in stage two are started and executed in sequence.

Critical to the success of this stage will be performance assessment. Performance assessment provides a measure of the progress and success of a project. Performance reporting is also the history of the project and, as a famous cliché states, those who do not study and record history are doomed to repeat it. This is definitely true in projects. If you do not measure and report the performance of a project, you will not only lack the knowledge of the current status of your project, but you will also be unable to learn from your past mistakes or successes.

Processes Involved

The following processes are entailed in this the third stage of the meta-project—Execution and Control.

KNOWLEDGE AREA – subordinate process

SCOPE MANAGEMENT – Scope change control
TIME MANAGEMENT – Schedule control
COST MANAGEMENT – Cost control
QUALITY MANAGEMENT – Quality control
HUMAN RESOURCE MANAGEMENT – Team development
COMMUNICATION MANAGEMENT – Performance reporting
RISK MANAGEMENT – Risk response control
PROCUREMENT MANAGEMENT – Contract administration

Each of the above processes possesses, inputs, outputs and tools and technologies as depicted in Figure 12.1 below for integrated change control.

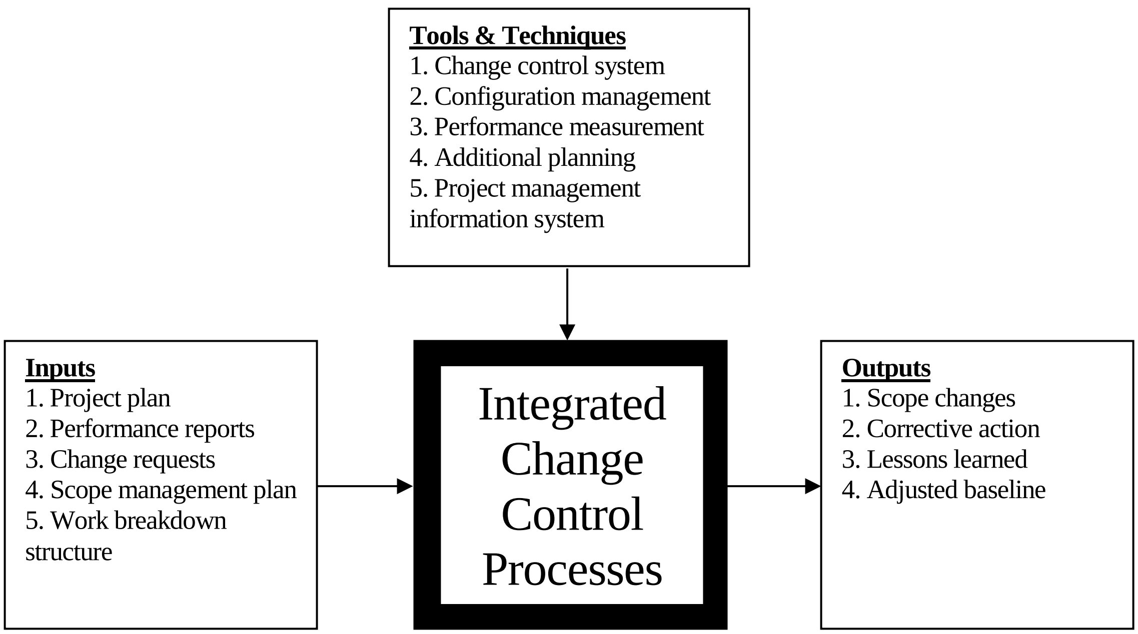


Figure 12.1: Inputs, Outputs, Tools & Techniques for the Change Control Process (PMBOK, 2000)

To Freeze or not to Freeze, that is the Question

The point of the opening scenario was to bring home, once again, the effects of changing requirements in this, the execution and control stage. Ideally, most project managers[1] would prefer frozen requirements. Previous to execution of this stage, the project stakeholders along with the project

[1] If the project manager is external to the firm, he or she may actually solicit changes, knowing full well that the customer must pay extra for them. Typically, the external contractor has a fixed price contract to deliver a specific product. Further, the external contractor usually wins this contract by being the lowest bidder. The contractor doesn't expect to make any money on the actual contract but on the changes requested by the customer. So, when customers request changes, they can expect to pay dearly for them. In this kind of environment, THE CUSTOMER IS ALWAYS RIGHT!! But the project is never completed on time or within budget. From the contractor's point of view, that wasn't the money-making plan anyway.

manager have determined if the project is to have frozen requirements or if the project will permit some kind of change control system or process to assess what changes will be allowed. All such deliberations must be contemplated in the context of a variety of considerations: 1) the contractual arrangements, 2) the need to get some functionality out as soon as possible, 3) the need to create a product with competitive or superior functionality vis-à-vis competitive products, and 4) the fact that everybody wants changes toward the end of the project.

It has been said that frozen requirements are akin to the proverbial abominable snowman—both are myths and both are melt when enough heat is applied to them. The more modern approach to changing requirements (which constitute changes in scope) is to utilize a change control system. The policies governing such a system are the following: late breaking changes in the scope are always costly and nearly always result in cost and schedule overruns. In many cases it is better to hold off on the change and wait for a follow-on project to deliver the next version of the product. There are exceptions—when the product being produced is a commercial one and new commercial products have appeared in the market space with much more functionality. In such cases, without competitive functionality, the project might as well be terminated as the product will be inferior and may not sell. Another case might be when the organization's requirements change due to external influences coming from the competition, the customer, or changing technology. Wallace (2002) stated "Scope change is a good thing, not a bad thing. It is wrong to resist all scope change. Where a scope change generates improved benefit, it should be proposed to the project's decision making body." Thus, by controlling scope change effectively, a project manager will be able to maximize the value of a project.

The use of a change control system belongs to a relatively new discipline known as **change management**. A simple "best practice" within this system is to use a change control board to litigate all proposed changes, which are written up on a standard-template proposed-change form.

Forces Pushing for Late-Project Requirements Change

There are many scenarios that lead to late-breaking changes in the requirements for a software system. Here are just a few examples. The competition introduces a new version of a competitive product with unanticipated KILLER features. The development team has no choice but to endeavor to replicate these features even though they were not in the original requirements specification. Another "event" that tends to unfreeze requirements is new work that is undiscovered late in the project. Again, this work must be done, even though it was not in the original requirements. Yet another reason for why changes are made to the requirements is that a "Wouldn't It be Great if…" scenario happens. End-users want changes because they now know more about their requirements than they did 18 months ago. Developers want changes because they have a great emotional and intellectual investment in all of the system's details. Frequently, the technology changes so rapidly that the current system being developed is obsolete even before it gets finished, which means that its requirements must be changed or that the project must be killed or that the deliverable must be completed even though it will be technologically inferior.

The successful project manager has learned that rigorous scope control is essential to deliver projects on time and on budget. The prime focus for the project manager should not be to deliver the agreed scope on time and on budget, but to optimize the benefit generated by the project. If that means allowing the scope to change then this scope change is a good thing, not a bad thing. It is wrong to resist all scope change. When a scope change generates improved benefit, it should be proposed to the project's decision-making body. Make clear the positive and negative impacts of allowing the change. Make sure the impact is fully reflected in the project's definition and performance criteria. All participants should understand that the later in the project that a change is addressed, the greater the affect in terms of costs, risks, and timescale. It is wise to surface potential changes as early as possible. The change control process should make it easy to do so.

Project Execution

Execution is the missing link between aspirations and results. In the past firms got away with poor execution by pleading for patience. Today, a company can win or lose serious market share before it even realizes what has hit it. Today, a firm that is publicly held can see its stock price cut in half because of poor execution. As in sports, execution in business makes the difference between winning or losing.

Execution is a discipline (Bossidy & Charan, 2002). Additionally, Bossidy and Charan assert that execution is a major job of the business leader (viz. project leader, project manager). And execution must be a core element of a company's culture. Leadership figures significantly in successful execution. Leadership involves setting clear goals and priorities, articulating ground truth reality and using the creative tension between these as motivation to improve performance. Leadership also involved knowing your people and your business and follow-through. Leadership, according to Bossidy and Charan (2002), also involves rewarding the doers, expanding people's capabilities through coaching, and knowing yourself.

The big story in execution is focus. It is focus that gets work done on-time and with the required functionality and quality. Distractions from focus are the enemies of success in project management. In that regard, multitasking as defined and discussed in Chapter 8 is considered an enemy of good execution because it destroys focus, delays the completion of projects and often results in increased costs. Student syndrome[2] also is an enemy of focus because it reminds us of the college roommate who waited until the night before to begin work on his term paper.

Project Scope Change Control

Scope change control is change management by any other name and often involves configuration management as well. Changes made to the requirements or to the processes planned to create the required product will usually involve additional costs and delays in the completion of the product, so acceptance of these changes should be a decision taken with great care as to consequences. In most cases, it may be better to finish the required existing project and undertake the proposed changes in a follow-on project.

An efficient scope change control process should be defined. There needs to be a balance between flexibility and control. If the process is too onerous, either valuable changes will be lost or the participants will ignore the rules - leading to uncontrolled scope and configuration. If the process is too easy, then many changes may be applied with insufficient thought given to their merits and consequences.

The following flow chart describes a typical change control process.

[2] By any other name, "procrastination."

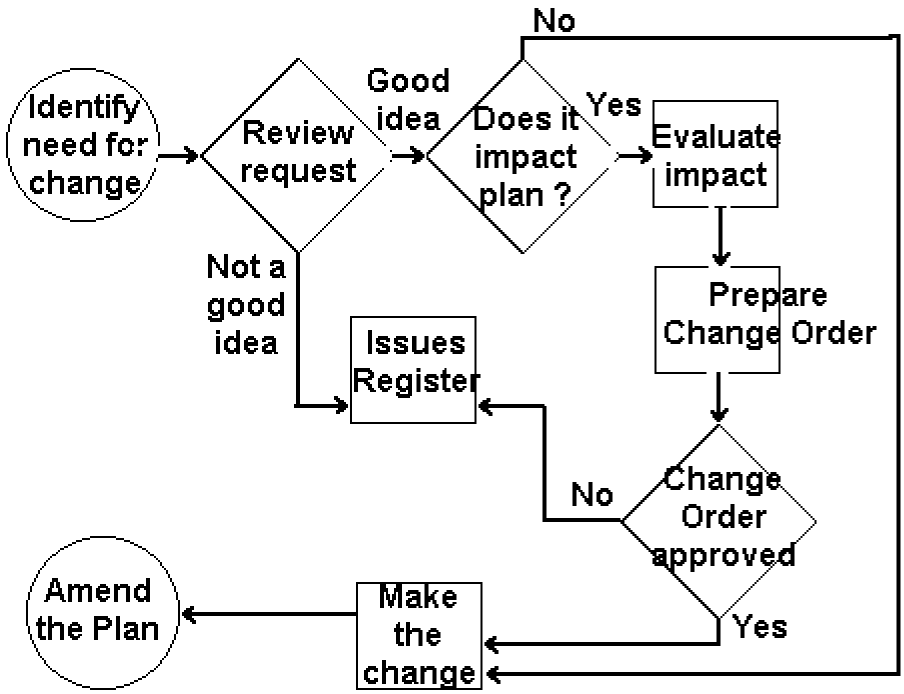


Figure 12.2: A Change Control Process

To start with, a potential change in the project scope is identified. This potential change is reviewed. If it is not considered beneficial to the success of the project but will impact the project result if left unattended, an issue is recorded in the Issues Register. If it is considered, the change is then evaluated. If there is no impact on the project deliverables, budget, or schedule, the change is made and documented. Otherwise, the calculations are made and the Change Order Form is completed. The customer and/or the Change Control Board review the Change Order Form. If the change is approved, it is implemented and then documented. If the change is not approved, something remains unresolved, so an Issue is raised and resolved through that process.

The change control process will involve a combination of procedures, responsibilities, and systems. The key to success is to have a well-controlled but efficient process defined in possibly the project charter. Stakeholders must define and agree on the membership of the change control board(s), the detailed procedures, forms, etc, protocols for levels of authority, e.g., what types of change can be approved without reference to the project's business owners, linkage to other management procedures, e.g., the issue management process, configuration management, which tools will be used to support and manage the process, how to communicate and promote the process and its importance to all participants.

Figure 12.3 exhibits the scope change control process in terms of inputs, outputs, tools and techniques as adapted from PMBOK.

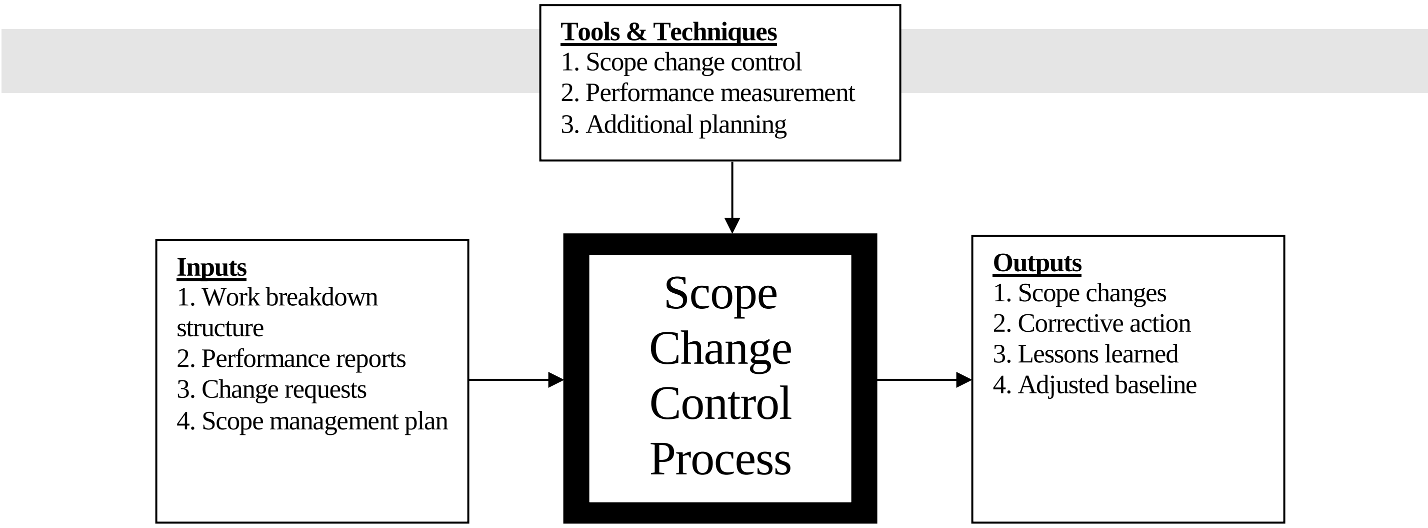


Figure 12.3: Inputs, Outputs, Tools & Techniques for the Scope Change Control Process (PMBOK, 200x)

Project Schedule Control

Unlike construction and aerospace projects, knowledge and IT projects have a visibility problem. With construction projects, it is apparent by merely looking at the structure to see the progress. With knowledge and IT projects, the progress is a lot less apparent because it is hidden within the memory of the desktop computer. One purpose for regularly scheduled meeting is to have each project player demonstrate his or her progress on the task assigned. At the end of the chapter a "best practice" created by Microsoft years ago is that of the Daily Build and Smoke Test. With this exercise the software product being developed is compiled, linked, executed and high-level tested. As a result, increases in visibility become more readily apparent.

In his book *Critical Chain* (1997), Goldratt makes a number of excellent suggestions regarding execution of projects. In Chapter 8, we discussed the issues of safety, multitasking and student syndrome from a planning and estimation perspective. Here, we want to revisit those and other issues from an execution perspective.

Execution of projects has been likened to that of a car race. It ought to be according to plan and it ought to be with expediency and focus. In his novel, *Critical Chain*, Goldratt makes a substantial case for focus. Project managers should stay focused on the critical path. Initiatives should be taken so that only one path is critical and no other path can become critical. Project players should stay focused on their assigned work that they have currently under way. In his 1997 novel, Goldratt suggests that when a team member's critical task[3] is coming into view, he or she should be advised a week ahead of time that the contribution he or she will make is coming soon. When that team member receives his or her "deliverable" and begins to add value to it, he or she is expected to drop everything and do nothing but work on just that task until it is complete, then pass it on immediately to the next resource person on the critical path, even if it is completed early. There should not be any multitasking[4] in conjunction with critical tasks, nor should there be any student syndrome[5].

[3] A critical task is a task that is on the critical path.
[4] Multitasking is doing several tasks concurrently.
[5] Student syndrome is Goldratt's term for procrastination.

Multitasking, Student Syndrome, Safety

As described above, multitasking and student syndrome are the enemies of focus and therefore can cause serious delays in the completion of projects. Multitasking, as everyone knows is doing several things at once, whereas student syndrome is postponing until near the due date work that should have been accomplished sooner. Safety is the excess time over and above the time required to complete a task by a certain due date with .5 probability. These are all concepts that were extensively discussed in Chapter 8.

Project Cost Control

Project cost control includes monitoring cost performance, ensuring that only appropriate project changes are included in a revised cost baseline, informing project stakeholders of authorized changes to the project that will affect costs, and using earned value analysis as a tool for cost control. The cost management overview diagram suggested by PMBOK is exhibited in Figure 12.4.

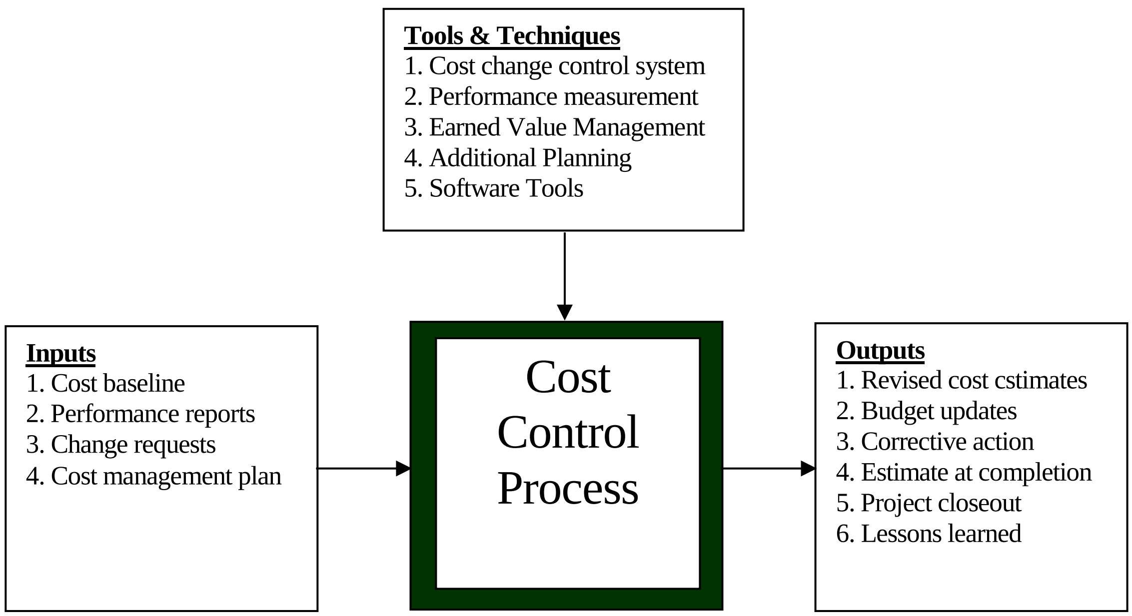


Figure 12.4: Inputs, Outputs, Tools & Techniques for the Cost Control Process (PMBOK, 2000)

Project cost control is an important issue that is not always handled well in project management. Cost control today is more important than ever due to the ever-increasing complexity and size of modern projects, and the risks involved. The problem of controlling costs in project management has been recurring throughout history. As the book *Project Cost Control in Action* mentions, the Bible takes us back 2000 years in history mentioning the function of project cost control quite explicitly (3). We read: "But don't begin until you count the cost. For who would begin construction of a building without first getting estimates and then checking to see if he has enough money to pay the bills? Otherwise he might complete only the foundation before running out of funds. And then how everyone would laugh!" (Luke 14:28, 29, The Holy Bible, The Living Bible Translation) This verse not only implies cost control, but also budgeting and resource planning. The keys to understanding project cost control are the general basics of cost control, who controls cost, establishing targets, and warning signs. Also, understanding what the main roles of the cost engineer and project manager are will enable a more thorough understanding of cost control.

Basics and General Explanation of Cost Control

Many things can change during a project to alter the expected rate and amount of spending. According to Dennis Lock, author of *Project Management*, the change is usually an increase (Lock, 1996, p. 459). He says that the change may be unexpected, but the fault will probably lie somewhere within the organization. "The principal purpose of cost control is to ensure that no preventable wastage of money or unauthorized increase in costs is allowed to happen," says Lock (p. 459). The mistake of confusing cost reporting with cost control tends to be quite common. Accurate and timely cost reporting is essential but, alone, is not cost control because by the time overspending is reported, the damage is already done (p. 459).

There are two vital factors that must never be forgotten when discussing cost control: 1) simple controls applied early and 2) sophisticated controls applied late (Kharbanda Stallworthy and Williams, 1981, p. 18). An aspect of sophisticated controls is that they are always applied late, because they are too complex to set up early. *Project Cost Control in Action* (Kharbanda Stallworthy and Williams, 1981, p. 18) states that it is much better to act early on fairly incomplete and inaccurate information than to act late on more precise information.

The three dimensions of cost control are cost, time, and quality. These factors are interrelated and interdependent. They can all be described in monetary terms. Shorter completion times and improvements in quality will lead to higher cost (Kharbanda Stallworthy and Williams, 1981, p. 18). More recent studies tend to suggest just the opposite—faster completion times lead to lower cost and sometimes better quality as well (McConnell, Steve, 1996, p. 126).

According to *Project Cost Control in Action*, certain basic principles are self-evident, but must be studied and accompanied by the realization that the ability to have any influence at all on cost diminishes rapidly as the project progresses (Kharbanda Stallworthy and Williams, 1981, p. 44). Those principles are:

1) real cost control will only be achieved by sound management of the project;
2) the accountant, and others directly concerned with costs, cannot control them; however, their reports will assist the project team to do so;
3) constant and continuous effort to control cost is required, throughout the life of the project;
4) all members of the project team must be *cost conscious*;
5) initial cost targets set should be seen as a challenge to be beaten;
6) control is far too late, if it is initiated once excessive costs start coming in (Kharbanda Stallworthy and Williams, 1981, p. 44).

A small project can be run extremely efficiently without recourse to detailed documentation and sophisticated control techniques. However, the basic features of project cost control must always be constantly in mind (Kharbanda Stallworthy and Williams, 1981, p. 47). Those basic features are:

1) start control early, before design begins;
2) plan meticulously, before construction starts;
3) watch out for the early warning signals.

Who Controls Cost?

Although some may try to ignore it, cost is inevitably everybody's business (Kharbanda Stallworthy and Williams, 1981, p. 20). It is easy to conclude that costs are higher or lower depending upon workers' diligence and skills applied to the project. Management must have convictions: they must have faith in project cost control and trust it (Kharbanda Stallworthy and Williams, 1981, p. 20). This is because only after a manager has made a complete commitment to the principles of cost control can a project manager and his/her team be expected to apply and implement correct cost control procedures (Kharbanda Stallworthy and Williams, 1981, p. 20).

The project manager's role is very important in the cost control process, because he/she is a focal point for many reports, decisions, and data (Kharbanda Stallworthy and Williams, 1981, p. 20).

He/She will have the best “feel” for the project, and therefore will know which direction to guide the project. The project manager will also have the major job of guaranteeing speedy and constant communication between the members of his/her team, and between owner and contractor.

Warning Signs

The most meaningful of all the information that can become available in relation to cost is the trend--where are we going (Kharbanda Stallworthy and Williams, 1981, p. 135). The book goes on to explain that management would always rather know ahead of time if the project budget will be exceeded. The data that contributes to the early assessment of the cost trend is very valuable as it can provide an “early warning system” to management in relation to the estimates of both time and cost.

The first major purchasing exercise of a project is the writing of the requisitions and the placing on order of all the major plant and equipment (Kharbanda Stallworthy and Williams, p. 137). This process occurs quite rapidly, and all the equipment is placed on order by 30% completion of the total project life (Kharbanda Stallworthy and Williams, 1981, p. 137). This enables us to ascertain the validity of our total cost target at the 30% completion point.

The progress of value of work done is also a potential early warning signal. This is because it gives a very clear picture of the potential situation to the project manager. The project manager will be able to make use of this early warning signal in his/her report to management.

Dynamic data, as used by the project manager, will provide more “yardsticks” that will assist the project manager to “see into the future” with a certain degree of confidence. In the context of project management the most meaningful of all the information that can become available is the trend–where are we going.

Major Cost Initiatives of the Project Manager

The major cost initiatives of the project manager are to establish cost targets, maintain a control estimate throughout the life of the project, monitor performance relative to the targets, and to predict the final cost of all materials and services provided (Kharbanda Stallworthy and Williams, 1981, p. 181).

If the estimate that was prepared by the project manager is adequately detailed, it would be taken as the project control estimate. Then the control estimate is issued to all key personnel working on the project, so that all knowledge on potential cost is available before those who are starting work on the project (Kharbanda Stallworthy and Williams, 1981, p. 181). The estimate serves to control all subsequent purchasing and construction activities. As revised estimates are prepared when more information becomes available, they become the target for the cost control engineer when making forecasts and assessing trends.

Estimate updating is the next major task of the cost control engineer. The costs in the control estimate, amended where needed, and detailed per cost code, are reported in the project cost report as the “estimated final cost.”

Earned Value Analysis

Earned Value Analysis (EVA) is a “way to measure a project’s progress, forecast its completion date and final cost, and provide schedule and budget variances along the way.” Earned Value Analysis is required in cost and schedule control because cost variance is unknown until schedule variance is known. For example, if you compare actual expenditures to date with budgeted expenditures to date, you may observe that you have spent less than was budgeted to be spent by a certain date. Can you conclude that the project is under budget? Not necessarily. What if the project is behind schedule?

Earned Value Analysis was invented by the federal government in the 1970's to get a handle on all of this. It was originally called Schedule and Cost Control System or SCCS.

Figure 12.5 is an example of a graph demonstrating the difference between the actual cost and the budgeted cost of a project. It shows how the actual cost of the project to date is less than the predicted budget of the project to date.

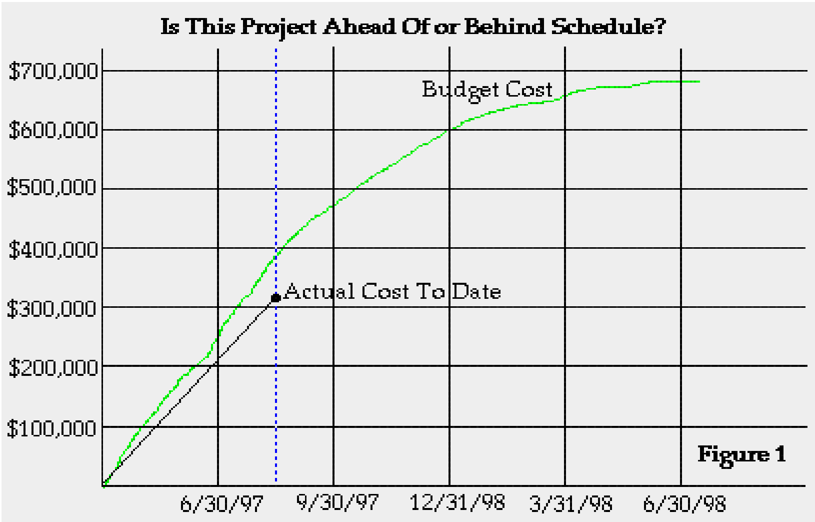


Figure 12.5: Plots of Actual Cost and Budgeted Cost over Time

In order for EVA to be effective, the detailed tasks and requirements of the project must be completely planned prior to the start of the project. An effective set of technical criteria to measure the performance of the project must also be established before the start of the project. An effective EVA must also have a predetermined completion date and final cost of the project, and must maintain control of the performance measurement baseline. Some additional objectives for EVA to be effective are to analyze the schedule status and projections and the expenditure of funds according to the work accomplished, not the work scheduled. EVA must also be able to isolate problems and take corrective action in order to fix the problems of the project. Every EVA must meet certain criteria in order to be effective and reliable. Organizational planning and budgeting, accounting considerations, analysis and management reports and revisions and data maintenance are the outlines of the criteria that an effective EVA should contain.

Earned Value Analysis requires three quantities to be computed for each activity or summary activity within a project's Work Breakdown Structure. They are Budgeted Cost of Work Scheduled (BCWS) or **planned value (PV)**, Budgeted Cost of Work Performed (BCWP) or **earned value (EV)**, and Actual Cost of Work Performed (ACWP) or **actual cost (AC)** of accomplished work. The units used in conjunction with each of these measures is "dollars" and each measure tends to be date sensitive. Change the "current" date and you get a different value for each, generally. Hence, each is a function of time. Let's look at each of these three terms more closely.

Budgeted Cost of Work Scheduled (BCWS) or Planned Value (PV): For the entire project, this is the sum of the budgets of each work package that comprise the complete project up to a certain date, expressed in dollars. Let's consider, for simplicity just a single task. If that single task has $10,000 budgeted for it and it is ten days in duration, and is scheduled to begin at some date in the future, then its BCWS is zero. If that same task should already have been completed by now (that is, its completion date is in the past), then its BCWS is $10,000. If the task started on time three days ago, then it should be 30% complete and its BCWS is $3,000.

Obvious analogous statements can be made for an entire project consisting of a collection of tasks. Suppose that a project has three tasks that are supposed to be complete at this point in time, for which $10,000 was budgeted for each. Then the BCWS for the entire project is $30,000. Note that the BCWS has nothing to do with whether the tasks are actually complete or not. The BCWS only tells us what should have been spent up to a particular date. Note that the BCWS is date sensitive. Choose a different date and you get a different BCWS, generally. As mentioned earlier, we also refer to BCWS as the "planned value" or PV.

Budgeted Cost of Work Performed (BCWP) or Earned Value (EV): For the entire project, this is the sum of budgets for completed work packages and completed portions of open work packages that have been partially worked on. Or to be more precise, BCWP is the percentage of work actually completed multiplied by the planned cost of that work package.

If $10,000 has been budgeted for a work package and it is estimated to be 30% complete by its assigned resource, then the BCWP for the work package is $3,000.

Actual Cost of Work Performed (ACWP) or Actual Cost (CV): For the entire project, this is the sum of actual costs for completed work packages and completed portions of work packages during a given time period. The actual cost is not bound, but is compared to the timescale and budget of the Work Breakdown Structure.

There are other formulas that contribute to the Earned Value Analysis. More terms are necessary to record cost and schedule performance and program budget. They include the following.

Cost Variance (CV): This is the difference between the Budgeted Cost of Work Performed and the Actual Cost of Work Performed (the difference between earned value and actual cost). Units employed are "dollars." CV is a measure of the difference between the estimated cost of an activity and the actual cost of that activity. For the project in total, CV would describe whether the project is out of spec and by how much. A negative cost variance indicates a task, activity or project that is over budget, that cost more than planned. A positive CV indicates just the opposite, that the cost was under budget or less than planned. The actual formula for CV follows: CV = BCWP – ACWP = EV – AC.

Cost Variance Percent (CV%): This is similar to the previous definition, but is expressed as a percentage between what has actually been earned to date and what should have been earned (CV% = BCWP*100/ACWP = EV*100/AC).

Schedule Variance (SV): This is the difference between the Budgeted Cost of Work Performed and the Budgeted Cost of Work Scheduled (the difference between earned value and planned value). This difference, if indicated by a negative number, shows a project that is over budget or behind schedule, or possibly both. (SV = BCWP – BCWS = EV – PV).

Schedule Variance Percent (SV%): This is similar to the Schedule Variance but, is expressed as a percentage, between what has actually been earned by what should have been earned. (SV% = BCWP*100/BCWS = EV*100/PV).

Using the above measurements and the base measurements we can also calculate completion figures as follows:

Cost Performance Index (CPI): This is the ratio of work performed to actual costs. CPI can also be used to calculate how much it will cost to complete the project. A CPI of one shows a project that costs exactly as much as predicted. If the number calculated is negative or less than 100% the project is over budget. Similarly, if the number is greater than 1 or 100% then the project has cost less than projected. (CPI = BCWP/ACWP = EV/AC)

Schedule Performance Index (SPI): This is the ratio of work performed to work scheduled. SPI can also be used to calculate how much time it will take to finish a project. A SPI of one indicates a project that took exactly as much time as it was planned to take. A SPI less than one or less than 100% shows a project that is behind schedule. Likewise, if the SPI is greater than 1 or 100% then the project is ahead of schedule. (SPI = BCWP/BCWS = EV/PV)

Using the above measurements and the base measurements, we can also calculate completion figures as follows:

Budget at Completion (BAC): This is the final value of the BCWS, that is, the figure we expect the project to cost if it runs exactly as the Work Breakdown Structure (or other budgeting tool used) would predict.

Time at Completion (TAC): This is the duration of the project, as determined by the Gantt chart.

Estimated Cost at Completion (EAC): This figure shows the cost of the project where the remainder of the project is to be completed according to plan. Precisely, EAC = BAC/CPI = BAC*ACWP/BCWP = BAC*AC/EV.

Estimated Time at Completion (ETAC): This is the estimated completion time based on the current schedule performance index and the TAC. Precisely, ETAC = TAC/SPI = TAC*BCWS/BCWP = TAC*PV/EV.

Calculated Cost at Completion (CAC): This is the cost of the project if the remainder of the project is completed in the same manner as the previous, completed portion of the project. (CAC = BAC/CV%)

Senior Managers who manage multiple projects may find it helpful to see this information in a graphical format. For instance the use of earned value data placed in tables will clearly show how far along each project is and how quickly they arrived at any given point at a glance. In addition, performance charts such as Gantt Charts, histograms, and S-curves, based on the above data provide the various stakeholders with the kind of information and detail that is required by each respective party as illustrated in Figure 12.6.

WBS Element		Budget ($) (BCWS)	Earned Value ($) (BCWP)	Actual Cost ($) (ACWP)	Cost Variance ($) (BCWP– ACWP)	Cost Variance (%) (BCWP ÷ (ACWP)	Schedule Variance ($) (BCWP– BCWS)	Schedule Variance (%) (BCWP ÷ BCWS)
1.0	Pre-pilot planning	63,000	58,000	62,500	–4,500	–7.8	–5,000	–7.9
2.0	Draft checklists	64,000	48,000	46,800	1,200	2.5	–16,000	–25.0
3.0	Curriculum design	23,000	20,000	23,500	–3,500	–17.5	–3,000	–13.0
4.0	Mid-term evaluation	68,000	68,000	72,500	–4,500	–6.6	0	0.0
5.0	Implementation support	12,000	10,000	10,000	0	0.0	–2,000	–16.7
6.0	Manual of practice	7,000	6,200	6,000	200	3.2	–800	–11.4
7.0	Roll-out plan	20,000	13,500	18,100	–4,600	–34.1	–6,500	–32.5
	Totals	**257,000**	**223,700**	**239,400**	**–15,700**	**–7.0**	**–33,300**	**–13.0**

Note: All figures are project-to-date.

Figure 12.6: Illustrative Tabular Performance Report

Risk Control and Earned Value

Barry Boehm defines the practice of Risk Management in terms of two primary activities, each with three subsidiary steps. The first activity, risk assessment, consists of risk identification, risk analysis, and risk prioritization. The second activity, risk control, includes risk-management planning, risk resolution, and risk monitoring (Boehm, 1991). It is in primarily two of these activities, risk identification and risk monitoring, that Earned Value analysis can play an important role.

The use of Earned Value Analysis for risk identification, involves comparing actual task cost and schedule performance against estimated values using the methods described above. Specifically, the use of cost and schedule variance to assess work package performance against the plan will alert the manager of a project to a potential risk area whenever that task or task area cost or schedule variance exceeds a predetermined value. However, this method may not provide absolute confirmation that the work package is in trouble. The cost or schedule variance could be due to a delay in reporting or some other cause. An assessment of earned value does provide an indicator of cost and/or schedule problems that can indicate an area of program risk.

According to Boehm, "Risk monitoring involves tracking the project's progress toward resolving its risk items and taking corrective action where appropriate" (Boehm, 1991). Earned Value Management is useful in monitoring the impact risk-management planning and risk-resolution activities have on task performance, utilizing the same methods Boehm utilized to alert him to the risk items initially. In addition, if the risk resolution involves rework or additional program tasks, these tasks should be subjected to Earned Value Analysis as well in order to determine their performance against the modified plan.

Examples

As “warm-ups” to the issues to be addressed, we shall investigate some contrived examples to gain intuition. In this first example, consider the following four-task problem.

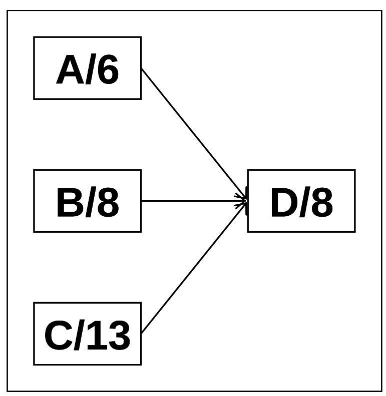


Figure 12.7: A Four-Step, Activity-on-Node Network (activity durations are numbers following forward slashes)

In the above, assume tasks A, B and C all started on the same day, seven business days ago. Planned durations are in days and are the numbers in the boxes shown above. A is 60% complete, B is 50% complete and C is 70% complete. Task D has not yet started and won’t until the tasks A, B and C are complete. So far, $30,000 has been spent on A, $30,000 on B, $40,000 on C, and nothing on D. The budgeted daily costs for A, B, C and D are $4,000, $5,000, $6,000 and $7,000, respectively. The budget for A is 6*$4,000 or $24,000, for example. Assume five-day work weeks, with no work being done on Saturday or Sunday. For A, B, C and D, the BCWP, BCWS, ACWP, CV and SV are determined below, where the inputs are shown in bold.

Task	Days	Cost/Day	Budget	% COMP	ACWP (AC)	BCWS (PV)	BCWP (EV)	CV	SV
A	**6**	**$4,000**	$24,000	**60%**	**$30,000**	$24,000	$14,400	-$15,600	-$9,600
B	**8**	**$5,000**	$40,000	**50%**	**$30,000**	$35,000	$20,000	-$10,000	-$15,000
C	**13**	**$6,000**	$78,000	**70%**	**$40,000**	$42,000	$54,600	$14,600	$12,600
D	**8**	**$7,000**	$56,000	**0%**	**$0**	$0	$0	$0	$0
Totals			$198,000		$100,000	$101,000	$89,000	-$11,000	-$12,000

Table 12.1: Basic EVA Calculations for the Network Exhibited in Figure 12.7 (inputs are shown in bold)

Task	CPI	SPI	Days Ahead	Days Slack
A	0.48	0.60	(2.4)	7
B	0.67	0.57	(3.0)	5
C	1.36	1.30	2.1	0
D	N/A	N/A	0	0
Totals	0.89	0.88		

Table 12.2: Further EVA Calculations for the Network Exhibited in Figure 12.7

From Table 12.2 above, we can calculate the EAC (Estimate at Completion) using the constant cost efficiency rate formula: EAC = BAC/CPI. It should be evident that EAC = $198,000/0.89 = $222,472.

Likewise from Table 12.2 above, we can calculate the ETAC (Estimated Time at Completion) based on the TAC (Time at Completion). Since ETAC = TAC/SPI, it should be evident that ETAC = 21/0.88 = 23.86. Days Slack (in Table 12.2 above) is determined by standard conventions applied to the network diagram. Days Ahead (Behind) is calculated by dividing the schedule variance SV by the cost per day. So the project appears, based on conventional EVA considerations, to be a little over budget and a little behind schedule.

Let us look next at the concepts of planned value rate (PV Rate) and time variance (TV) in the context of this problem. By definition, planned value rate is BAC/TAC = $198,000/21 = $9,428.57 per day. Using the standard definition for time variance, TV = SV/PV Rate = -$12,000/$9,429 = -1.27 days. We conclude that the project is 1.27 days behind schedule. Worthy of note is the fact that PV Rate is actually not a constant, but varies over the life of the project. If the project runs on schedule, the planned value rate starts out (assuming an early start for all tasks) at the sum of the daily burn rates for activities A, B and C or $4,000 + $5,000 + $6,000 = $15,000. After day 13, however, if the project runs on schedule, only activity D is underway with a daily burn rate of $7,000. Thus, the planned value rate varies over time.

Next, we shall look at the critical path for this project. The critical path involves tasks C and D. Task C is well ahead of schedule. Task D has yet to be started since only seven days have transpired and task C is 13 days in duration. In fact the Days Ahead column of Table 12.2 suggests that C is 2.1 days ahead. If this is maintained, the project will finish two days early, roughly. Notice, in Table 12.2, that the lateness of the non-critical tasks A and B does not interfere with task C finishing 2 days ahead. For the case of A, 2.4 of the seven days of slack are used up, leaving 4.6 net days of slack. Similarly for task B, 3.0 of the five days of slack are used up leaving two days net.

Based on conventional EVA considerations, this project would be reported to be both over budget and behind schedule, costing $25,000 additional (roughly) and taking almost 3 days longer. But, in fact, this project has a very good chance of finishing ahead of schedule.

In this next example, a six-task problem is considered that is 12 days old.

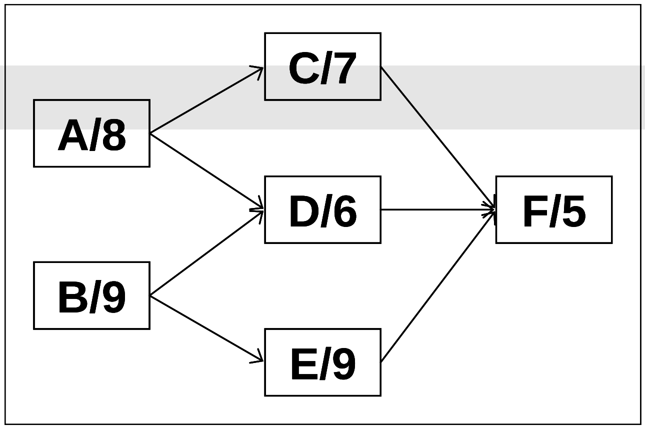


Figure 12.8: A Six-Step, Activity-on-Node Network (activity durations are numbers following forward slashes)

For each of the six tasks that make up the project above, assume the following:

TASK	Percent Complete	Expenditures/Day	Actual Expenditures to Date
A	100%	$1,000	$10,000
B	100%	$1,200	$9,000
C	80%	$1,000	$4,000
D	90%	$1,500	$5,000
E	20%	$1,500	$3,000
F	0%	$1,000	$0

Table 12.3: Data Required for EVA Calculations of the Network Exhibited in Figure 12.8 above.

From Table 12.3 above, it should be clear the budget for A is 8*1,000 or $8,000. The project is 12 days old (12 business days have transpired), where the units on time are days. Clearly, the BCWS for A is $8,000; the BCWP is also $8,000 because it is 100% complete. The BCWS for C, however, is $4,000, while the BCWS for F is 0.

TASK	TOTAL BUDGET	%COMP	ACWP (AC)	BCWS (PV)	BCWP (EV)	CV	SV	SPI	CPI
A	$8,000	**100%**	**$10,000**	$8,000	$8,000	-$2,000	$0	1.00	0.80
B	$10,800	**100%**	**$9,000**	$10,800	$10,800	$1,800	$0	1.00	1.20
C	$7,000	**80%**	**$4,000**	$4,000	$5,600	$1,600	$1,600	1.40	1.40
D	$9,000	**90%**	**$5,000**	$4,500	$8,100	$3,100	$3,600	1.80	1.62
E	$13,500	**20%**	**$3,000**	$4,500	$2,700	-$300	-$1,800	0.60	0.90
F	$5,000	**0%**	**$0**	$0	$0	$0	$0	0.00	0.00
Totals	$53,300		$31,000	$31,800	$35,200	$4,200	$3,400	1.11	1.14

Table 12.4: Basic EVA Calculations for Network Exhibited in Figure 12.8 (inputs are shown in bold)

In this problem, the BAC = $53,300, while the TAC = 23 (the length of the critical path). From these numbers, EAC = BAC/CPI= $53,300/1.14 = $46,754, while the ETAC = TAC/SPI = 23/1.11 = 20.72. This project appears to be both under budget and ahead of schedule.

Let us look next at the concepts of planned value rate (PV Rate) and time variance (TV) in the context of this problem. By definition, planned value rate is BAC/TAC = $53,300/23 = $2,317.39 per day. Using the standard definition for time variance, TV = SV/PV Rate = $3,400/$2,317.39 = 1.47

days. We conclude that on day 13, the project is 1.47 days ahead of schedule. The PV Rate could be viewed not as a constant, but as a time function that varies over the life of the project. If the project runs on schedule, the daily burn rate after 12 days (day 13 is the day of interest in this problem) is the sum of the daily rates for activities C, D and E (assuming an early start for all tasks) or $1,000 + $1,500 + $1,500 = $4,000. Thus the planned value rate appears to be $4,000 on day 13, if it is allowed to vary. After day 18, however, if the project runs on schedule, only activity F is underway with a daily burn rate of $1,000. Thus after day 18, the planned value rate appears to be $1,000, assuming it is allowed to vary over the life of the project.

However, when we examine the critical path (B-E-F), we see that task E is well behind schedule. In fact task E is a full 1.2 days behind. It will, consequently, cause the entire project to be delayed. Rather than finishing in 20.72 days (more than 2 days early) as EVA would predict, the project appears likely not to finish until 24.2 days have elapsed.

What do these models show us? These measures (the total project CV, SV, SPI, and CPI) should be examined from a path perspective. Particular interest should be devoted to the critical path.

In his 1997 novel Critical Chain, (Goldratt, 1997) Goldratt suggests that conventional tracking techniques are not very useful because they do not take into consideration the critical path. The result is that, taken in aggregate, the schedule variance might suggest the project is ahead of schedule when in fact work on the critical path is behind schedule, or vice versa. As Goldratt would be quick to point out, the main thing that matters is what's happening on the critical path. If the critical path is behind schedule while all other (non-critical) paths are ahead of schedule then EVA tells you incorrectly that the entire project is ahead of schedule. This is the point of the simple illustrative models discussed above: to provide definitive examples of how conventional tracking techniques do not provide the "total picture" with respect to project duration.

From the examples we looked at above, certain observations are in order. First, with respect to schedule, three states are possible: the project is on schedule, the project is ahead of schedule, or the project is behind schedule. When the critical path and the EVA are consistent and in agreement with respect to these states, there are no "problems;" i.e., when both indicate the project is on schedule, we can accept the verdict of both. In all other, circumstances where there is disagreement, the state suggested by the critical path should dominate over that suggested by the EVA. The reason behind this assertion is thus: the critical path determines total project duration. A partial solution to this problem is to require a late start for all paths that are non-critical, making all paths critical. Doing so removes the slack on non-critical paths; it also makes the probability of a delayed project that finishes behind schedule much higher. But a "late start solution" mitigates only the first of the two dilemmas discussed above, not the second. Probabilistic project models will be taken up in the next section.

Project Quality Control

"Quality" is a word that is found in most advertising clichés. Whether you are buying hamburgers or solid oak furniture, the operative word is "quality." Quality is also one of the most written about subjects in books, magazines, and Internet articles. And, quality is one of the most talked about subjects in business seminars and conferences (Collins, 1987, p. 1). It has been argued that quality is the world's oldest documented profession. This is found in Genesis 1:31: " . . . and God looked at all that He had made, and it was very good . . . ." The creator of the earth did a first-article inspection of His work and declared that it had turned out just as He had planned (Collins, 1987, p. 2). From the Creator's point of view, the quality was perfect. However, in today's time, producing quality is usually thought of more in the business world of manufacturing. When one produces quality, he or she must also utilize quality control. The object of quality control is to create quality which: satisfies the customer, is as cheap as possible, and can be achieved in time to meet delivery requirements. Therefore, the objective is not to simply produce the highest quality but to satisfy the customer (Duncan, 1965, pp. 8-9). The definition of quality control usually adopted is that: "Quality control is the function or collection of duties which must be performed throughout an organization in order to achieve its quality objectives" (Caplen, 1969, p. 12). There are various stages to quality control. Some of the key stages include the following: conformance to requirements, prevention, zero defects, price of nonconformance, testing, correcting, and education of employees. These key stages answer important management questions. What is quality? What system is needed to cause quality? What performance standard should be used? What measurement system is required?

What is Quality Control?

This question is a good one. It provokes thought regarding whether or not a company is doing enough (and "enough" is a very subjective term) to control the quality of its products, processes and projects, and how the company may be able to improve its existing processes to either cut costs or reduce defects. Before quality control can be defined, however, it is good to begin with a definition of quality:

Quality is "a predictable degree of uniformity and dependability, at low cost and suited to the market" (Gitlow, 2001, p. 2).

Now, what does this mean exactly? It means several things. The quality of your product determines whether or not your customers will look elsewhere for something better. If your product has poor quality, then one or more components in your value-chain are not performing to their full capacity. This could be due to a design flaw, a mechanical problem, or incompetent staff. Such problems are usually easy to determine, upon a thorough analysis of the value-creation process. Fixing them correctly, however, can take a tremendous amount of time and capital to achieve. The lesson learned here is simple: make sure that a very thorough analysis is performed of the entire process before production is started, as the sooner a defect is caught, the more quickly, easily and inexpensively it can be rectified. Some of the world's best known corporations have lost millions, even billions, on defective products that could have been avoided if more testing and analysis had been done prior to launch. The further down the product lifecycle that a defect is discovered, the more expensive it will be to fix. If the defect is found internal to the firm it is far less expensive to fix than once the product is set into operation outside the firm, where there can be liabilities as a result of loss of assets, property or human life that can result.

The first key stage of quality control is *conformance to requirements*. In order to accomplish this stage, management must perform three basic tasks: first, establish the requirements that employees are to meet; second, supply the resources that the employees need in order to meet those requirements; and third, spend time encouraging and helping the employees to meet those requirements (Crosby, 1984, p. 61). This helps employees operate to standards other than experience and opinion. Simply stated, the best brains and most useful knowledge will not be used in fixing a problem or smoothing over coarse edges; instead, they will be used in establishing the requirements in the first place.

Prevention receives high priority within quality control. Prevention is something we know how to do if we understand the process. This type of thinking is basically commonsense. For example, if a courier is driving to an unknown destination, it is best to ask for directions before driving out to the new location. This is a simple example, but this thinking can be applied to any business situation. A method to help this thinking is called statistical quality control, or SQC. SQC is the application of statistical techniques for measuring and improving the quality of processes. SQC includes statistical techniques for measuring and analyzing the variation in processes, diagnostic tools, sampling plans, and other statistical methods (Juran, 1988, p. 24.2). Under the SQC method, each variable in the process is identified and is measured as the process continues. If all the variables are inside their "control limits," then the end result should be what was planned to begin with (Crosby, 1984, p. 70). If not, the process is stopped, diagnosed, and corrected as necessary before being restarted. There are many other theories to use when practicing prevention. Analysis of variance, regression and correlation, and random sampling are examples of other methods used (Duncan, 1965, pp. 20-45).

The practice of *zero defects* (ZD) is a well-known key stage to quality control. A company is made up of millions of actions that come together to make up the whole process or plan. Every little action has to be done right in order for the process to come out correct. Phillip Crosby (1984) vividly describes the zero defect method as follows:

> People are carefully conditioned throughout their private life to accept the fact that people are not perfect and will therefore make mistakes. By the time they seek an industrial life, this belief is firmly rooted. It becomes fashionable to say, "People are humans and make mistakes. Nothing can ever be perfect as long as people take part in it," and so it goes . . . Mistakes are caused by two factors: lack of knowledge and lack of attention. Knowledge can be measured and deficiencies corrected through tried-and-true means . . . Lack of attention is an attitude problem. The person who commits himself or herself to watch each detail and carefully avoid error takes the gain step toward setting a goal of Zero Defects in all things (pp. 82-83).

Careful communication and planning are ways to establish this ZD thinking. Management should train employees to be cautious and aware of problems that might arise and to not accept any such problems or errors. Diagnostic tools to help find these errors are discussed under "Tools for Quality Control."

One measurement of quality is the *price of nonconformance*. Cost of quality can be divided into two areas. These areas include the price of nonconformance (PONC) and the price of conformance (POC). Prices of nonconformance are the expenses involved in doing things wrong. For example, this would include the cost to correct a sales clerk's order when they come in, to do any type of work over, or to pay for warranty and other types of nonconformance claims (Collins, 12). If one were to sit down and add all these amounts up, he or she would come up with a huge amount of money. This represents twenty percent or more of sales in manufacturing companies and thirty-five percent of operating costs in service companies. Price of conformance is what is necessary to spend to make things come out right. An example would be prevention efforts and quality education. This only comes out to three to four percent of all sales in a well-run company. Management can come up with a number or price of nonconformance and then come up with a procedure that can be used forever. The price can then be used as a total to track whether the company is improving, and as a basis for finding where the most beneficial corrective-action opportunities dwell. Another method that is popular among companies is to use indexes and charts to measure results in quality control systems.

Testing is an imperative stage of quality control. One way to assure the product or process is in "control" is to predict consumer acceptance. There are several ways to do this. Finding consumer likes and dislikes, performing consumer preference testing, and performing consumer sensitivity testing are all ways to test consumer acceptance. One approach to prediction of consumer acceptance of a new product is to secure data on consumer likes or dislikes. A test is submitted to potential, numerous users. Their responses are secured on a "hedonic" scale. The scale contains (1) like very much, (2) like, (3) neither like nor dislike, (4) dislike, (5) dislike very much. Looking at the patterns on the scale summarizes the data on the hedonic scale. Another approach is consumer preference testing is used to discover preference. In competitive markets, such preference tests can give useful guides to decisions on product marketability, pricing, etc. In order to do this there needs to be two or more samples. The responses are "forced" by choosing A or B. Consumer sensitivity testing is another testing method. Its purpose is to discover the "threshold" level at which consumers can detect the existence of sensory qualities. The qualities under this test may be either desirable or undesirable. A graduated set of samples is prepared. These samples include new products that are under examination. The consumers are shown a certain product and asked to inspect it. Their response is then plotted on the sample graph. This testing goes along with the saying "the consumer is always right." These three testing methods help to show the company if their product is in "control" enough to put out on the market.

Another key stage to quality control is *correcting*. Unfortunately, life being what it is, people do not always achieve perfection. One must use corrective measures with the object of learning from mistakes, so to avoid that fault in the future. The first step in correcting is to identify what went wrong and correct it. One can do this by analyzing the statistical control charts (SQC) that were used in the prevention stage. From the control charts, one should be able to infer which operations or tasks must be responsible. The next step to correcting is to analyze the "scrap" or rework itself. As mentioned earlier in the zero defects discussion, the diagnostic tools to help find errors are the matrix, Pareto analysis, and time-to-time analysis (Juran, 1988, 22.54). The Pareto curve (discussed later in the Chapter) is a very popular method to use in this stage. The last part of the correcting stage is to set rules to follow so every employee knows when to make changes. For example, "any process making more than 5 percent scrap should be examined" is a rule every employee can follow. By following these three steps, anyone can correct any shortcoming of a process (Caplen, 1969, pp.194-208).

In order to launch quality control, education at every management level must be implemented. *Education* is a vital key component in quality control. When a service organization embarks on a comprehensive quality effort, each step in the process of designing and developing a quality program needs to be communicated clearly. All levels of the company are informed about the purposes of and need for quality control, and their individual roles in the efforts are defined (Juran, 1988, pp. 33-40). To make a hassle-free, prevention-oriented company requires that everyone really know what is involved. Each and every person in the company must understand every individual's role in causing quality. Those involved with a specific function have to have special education in order to carry out their roles. The overall education aspect requires executive education, management education, and employees' education. The purpose of executive education is to help senior people understand their role in causing problems and then causing improvement in the quality process. Executives need to understand what everyone else is going to be taught; they need to understand what they can do to encourage the control and improvement process as well. Because they are the "big-wigs" of the overall management, everything they do is important and watched. Management education should include material on communication skills and presentation skills. Without these skills, managers can never find out where the underlying quality problems are or how to tell the rest of the company how to correct these problems. Employee education comes from managers usually. They should be taught what quality is and how they can individually control quality. They must also take this education and apply to their job. Education is very important because every person on the project can then work together on what they have learned and produce the finished process or product they want (Crosby, 1984, pp. 91-99).

Certainly, no one expects a process's quality to stay in "control" at all times. After all, mistakes are a part of life. Because of this, there are key rules for businesses to follow that deal with maintaining and establishing quality control. Conformance to requirements, prevention, zero defects, price of nonconformance, testing, correcting, and education of employees are all the important stages. Quality control deals with management issues and statistical issues. Conformance to requirements and education of employees both deal with management issues. Prevention, zero defects, price of nonconformance, testing, and correcting all have some statistical issues that help to maintain quality control. By using all these rules, any project should be able to keep their quality in control.

TOTAL QUALITY CONTROL THEORY AND STANDARDS

This section will discuss the work of quality control pioneer W. Edwards Deming and his Total Quality Control (TQC) theory, discuss quality standards, perform case studies on several large players in the semiconductor chip manufacturing industry, summarize these findings, and conclude with several opinions on the importance of quality control and how it will change in the future.

Deming's Pioneering of Total Quality Control Theory

W. Edwards Deming is one of the true pioneers in the field of quality control. Receiving a doctorate in mathematical physics from Yale University in 1928, Deming went on to achieve great success by using statistical processes to develop new ways to produce and develop products. He instructed engineers on how to use statistics to improve production of war supplies, during World War II. After the war had finished, Deming traveled to Japan to show Japanese engineers his methods of quality control, and how they could use his methods to improve production and achieve greater profits. Some of the Japanese wisely used his teachings to achieve great profitability in the post-war depression that Japan faced.

With these achievements alone, Deming could be thought of as a true American, one who worked hard to become successful and used his gifts to help others. Deming's greatest achievement in the field of statistical modeling, however, was yet to come. In 1951, Deming unveiled a new way of thinking about quality control: a term known as "Total Quality Control" (also known by many as Total Quality Management, or TQM). Total Quality Control, or TQC for short, was a revolutionary new way of thinking about how quality was measured in an organization. It emphasized the "joy in work," and detailed how quality should be checked for at every step in the process, not merely at the completion (Gitlow, 2001).

How did Deming propose to check for quality at each step? Deming described three types of quality to be measured in the workplace. They are the quality of design, quality of conformance, and quality of performance.

The *Quality of Design* focuses on developing products with a customer orientation. They center on determining the quality characteristics of products or services that are suited to the needs of the market. Much customer research should be performed in design to accurately know what consumers are seeking in the product(s) they buy. The process of Quality of Design is an ongoing one; it is constantly evolving through time, just as consumers' preferences and needs change over time.

The *Quality of Conformance* answers the question, "How consistent is the company in producing a quality product?" Once the Quality of Design has been established, the Quality of Conformance is needed to exceed the specifications of the design stage. A company's Conformance shows how good it is at producing uniform, dependable products at a set cost (specified in the design stage).

Finally, the *Quality of Performance* is used by a firm to determine how well its products are actually performing in the marketplace. Much of the research in this step comes from sales/service call analysis and consumer research. A company that has a loyal consumer base but is experiencing difficulty selling a new product may want to review the performance of the product to check for noticeable defects or design flaws that may have been missed previously.

Quality Control Measurement

As explained above, firms must want to meet or exceed their own quality control requirements if they are to remain successful in their industry. However, in addition to the internal quality requirements that they must meet, they also must comply with established guidelines for the industry. In 1994, a new certification standard was unveiled that companies in many industries strived to achieve: ISO-9000.

ISO-9000[6]

ISO-9000 consists of five specific standards, which are each classified as either a conformance model (a standard that your organization must conform to become certified) or a guide (a set of recommendations to help the organization meet a conformance model). Each of the five standards are listed below, along with a brief description of what each standard entails.

1. ISO-9001 – This standard includes measuring quality assurance in design/development, production, installation, and servicing.

[6] ISO stands for International Orgainzation for Standardization and consisted originally of the twelve countries that made up the European Union—Belgium, Denmark, France, Germany, Ireland, Italy, Luxemburg, the Netherlands, Portugal, Spain, and the United Kingdom.

2. ISO-9002 – ISO-9002 details how an organization should perform in quality assurance of production, installation, and servicing. ISO-9002 does cover the installation and servicing just like ISO-9001, but ISO-9002 is designed for organizations that do not participate in any design or development activities.
3. ISO-9003 – ISO-9003 is responsible for measuring quality assurance in final inspection and testing of a product.
4. ISO-9004 – ISO-9004 is the first of two sets of guidelines of the standard. It covers selection and use of the standards of quality management, quality system elements, and quality assurance.
5. ISO-9005 – The final standard of ISO-9000. ISO-9005 is another set of guidelines that focuses on quality management and quality system elements.

An organization chooses to have its quality system certified against either ISO-9001, ISO-9002, or ISO-9003, depending on the business processes it performs and which standard relates to them. There is no difference in ranking between the three standards.

In ISO-9000, there are twenty sections that measure different activities in the organization. A few of the more significant ones are described below.

Contract Review – How well is your response to a customer's request for a proposal for a project? Are the product's specifications completely and accurately detailed in the response? These are a few questions that pertain to Contract Review. It ensures that organizations know how to respond and negotiate a contract sufficiently with vendors.

Document and Data Control – How well does your organization control and manage important documents and data related to a project? Is the information able to be accessed rather easily and is it complete and accurate? An organization should have good document/data accessibility, and methods for dealing with the different types of information that the organization will come across in its operations.

Inspection and Testing – Does incoming product meet specified requirements? Is the product being produced inspected and tested as necessary? Inspection and testing ensures that the organization is inspecting/testing products upon receipt, during processing, and after production has finished.

Internal Quality Audits – Does your organization have an internal quality audit plan? What corrective actions are taken on deficiencies found in the audit? The Internal Quality Audits section verifies that the organization is performing internal quality audits that meet standards followed by industry leaders and the ISO-9000 spec.

In conclusion, ISO-9000 is highly regarded as one of the top certifications available to any company in the business world today. While it may take years to perform the entire certification process, a company that gains the ISO-9000 certification is not only given a strong competitive advantage over rivals who may not have it, but also assured that its own internal processes are of the highest possible quality found in their industry.

Tools for Quality Control

Many technical tools are used to create quality control; some of these that will be described later in detail are the Pareto charts, cause and effect diagrams, check sheets, flow charts, control charts, histograms, and scatter diagrams. These tools can be used in reducing the process variability or to identify specific problems in the process of the project. Although these tools may be helpful in order to ensure quality control, they do not constitute a quality program. The program you establish for quality needs to promote quality in all aspects of its operations.

Pareto Charts

Pareto charts are extremely useful because they can be used to identify those factors that have the greatest cumulative effect on the system, and thus screen out the less significant factors in an analysis. Ideally, this allows the user to focus attention on a few important factors in a process. They are created by plotting the cumulative frequencies of the relative frequency data (event count data), in descending order. When this is done, the most essential factors for the analysis are graphically apparent. From the Pareto chart it is possible to see that the initial focus in quality improvement should be on reducing the largest characteristic.

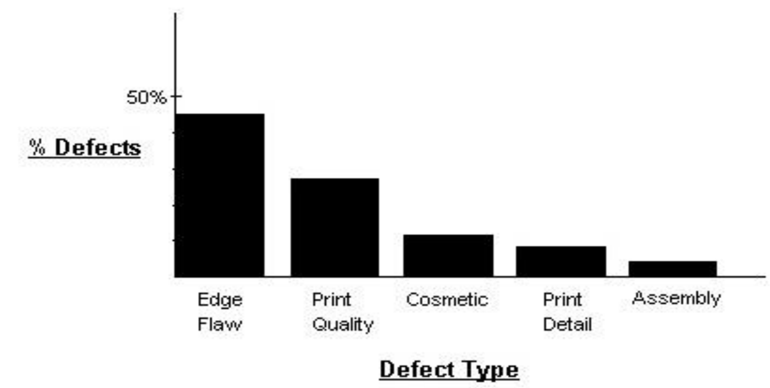


Figure 12.9: Pareto Chart

From Figure 12.9, we learn that 70% of the defects come from edge flaw and print quality. The Pareto chart is named after an Italian economist who used it for studying the wealth of Italy. The Pareto curve is also sometimes called the 80/20 curve, because it is often found that some 80 percent of the defective work comes from only 20 percent of the causes. To establish a Pareto curve, a percentage scale is drawn vertically where 100 percent means all the defective work made during this period. Horizontally, a list of the reasons why the work was defective is drawn, starting with the most numerous types and then going down in descending order.

Cause and Effect Diagrams

Cause and Effect Diagrams also called Fishbone Diagrams are used to associate multiple possible causes with a single effect. Thus, given a particular effect, the diagram is constructed to identify and organize possible causes for it. The primary branch represents the effect (the quality characteristic that is intended to be improved and controlled) and is typically labeled on the right side of the diagram. Each major branch of the diagram corresponds to a major cause (or class of causes) that directly relates to the effect. Minor branches correspond to more detailed causal factors. This type of diagram is useful in any analysis, as it illustrates the relationship between cause and effect in a rational manner thus enabling quality to be represented in the delineation of causal factors. An example of fishbone diagram for edge flaws is presented in Figure 12.10.

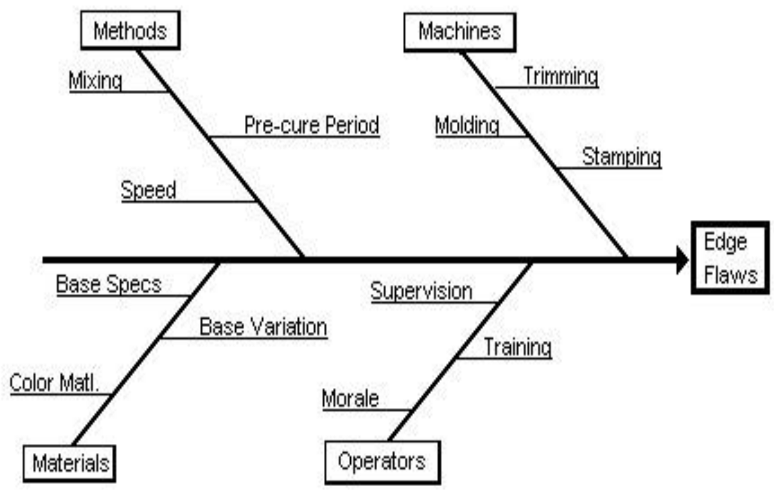


Figure 12.10: Fishbone or Cause and Effect Diagram for Edge Flows

Check Sheets

Check sheets represent the information in a graphical representation that is easily understood. Basically, it is a list of different problem sources (causes). Users can record the problems they come across. Therefore, when looking back at specific processes you are able to determine where your problem areas may be occurring. Then, once you have identified the problems, you will have a better chance at being able to create a way to decrease the amount of defects you come across in the specific process. Figure 12.11 shows an example of check sheets.

Defect Type		Totals
1.Assembly	II	2
2.Print Quality	IIIIIIIIIIIII	13
3.Print Detail	IIII	4
4.Edge Flaw	IIIIIIIIIIIIIIIIIIIIII	22
5.Cosmetic	IIIII	5

Customer Complaints		Totals
1.Missing Ring	II	2
2.Print Quality	IIIIIIIIIIIIIIIIIIIIIII	23
3.Misplace Print	IIII	4
4.Rough Edge	III	3
5.Type Error	IIIIII	6
6.Excess Flash	IIIIIIIIIIIII	13
7.Late Shipment	IIIIII	6
8.Bad Count	IIII	4

Figure 12.11: Sample Check Sheets

Flowcharts

Flowcharts are an illustration of the sequential steps that comprise a process. By breaking down the process into its elemental steps, you are able to follow the steps in the process in order to identify where errors are likely to be made. These can be helpful in maintaining quality control because if you can predict the steps in the processes where you are most likely to have errors, then you will be able to find the actual source of the error and remove the problem. Flowcharts can be used as diagnostic tools in quality control, but they have many other uses as well. Figure 12.12 is an example of plastic tag production flowchart.

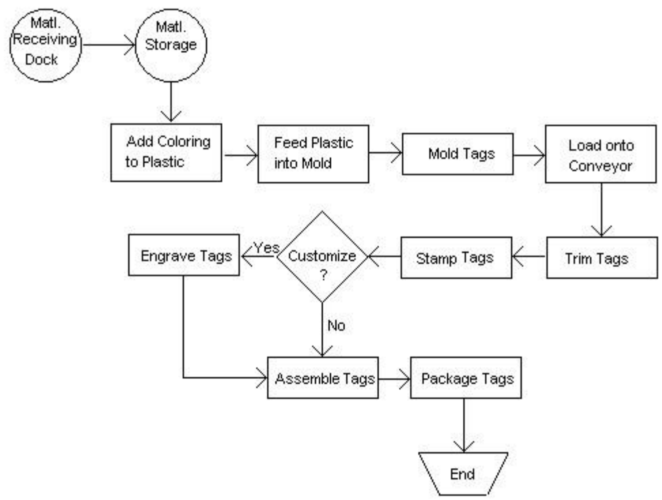


Figure 12.12: Plastic Tag Production Flowchart

Control Charts

The control chart, as shown in Figure 12.13, is the fundamental tool of statistical process control, as it indicates the range of variability that is built into a system (known as common cause variation). Thus, it helps determine whether or not a process is operating consistently or if a special cause has occurred to change the process mean or variance. The bounds of the control chart are marked by upper and lower control limits that are calculated by applying statistical formulas to data from the process. Data points that fall outside these bounds represent variations due to special causes, which can typically be found and eliminated. On the other hand, improvements in common cause variation require fundamental changes in the process. Thus quality is encompassed within the conception of a control chart.

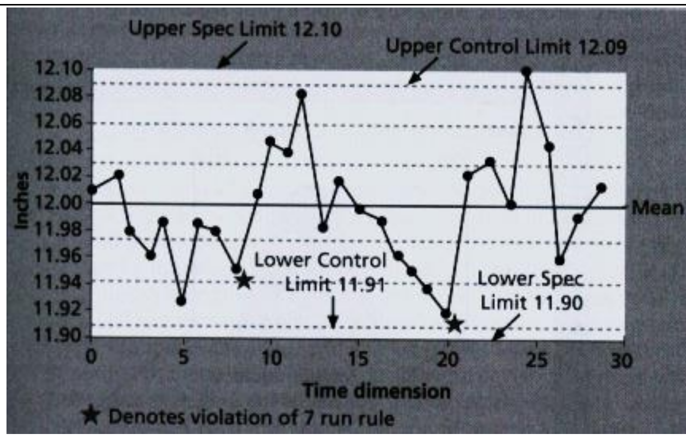


Figure 12.13: Control Chart

Histograms

Histograms provide a simple, graphical view of accumulated data, including its dispersion and central tendency. In addition to the ease with which they can be constructed, histograms provide the easiest way to evaluate the distribution of data. Deviations from a normal distribution in a histogram suggest the involvement of additional influences in the process. An example of frequency histograms is displayed in Figure 12.14.

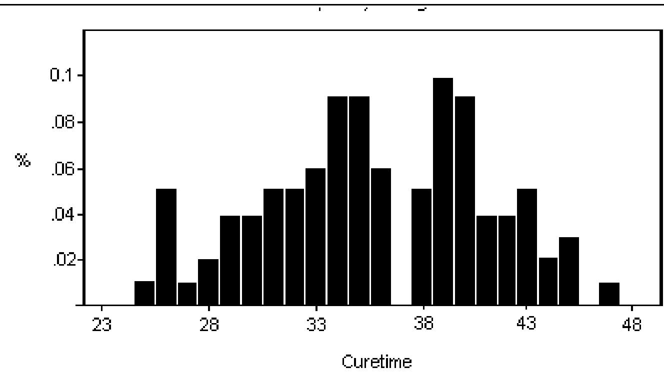


Figure 12.14: Frequency Histogram

Scatter Diagrams

Scatter diagrams, the last of the quality control tools, are graphical tools that attempt to depict the influence that one variable has on another. A common diagram of this type usually displays points representing the observed value of one variable corresponding to the value of another variable. Figure 12.15 is presented a scatterplot of defects and curetime.

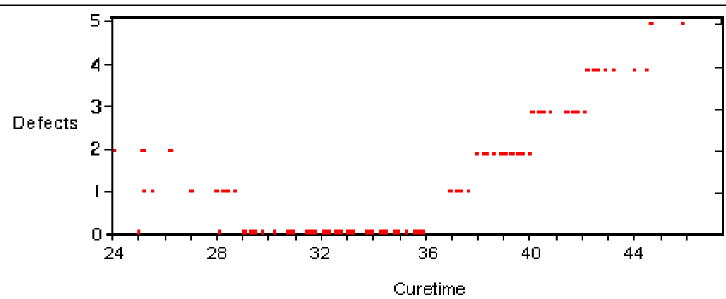


Figure 12.15: Scatterplot of Defects vs Curetime

One reason we use quality control is to ensure that a project's activities take place as they were intended to, which is especially needed in the IT field since it has such a high failure rate. The use of quality control within a project will help to deliver a product that has all of the capabilities and supporting features needed in an effective and timely manner and without defects. These diagrams become very helpful in identifying problems in order to keep the project in control. Many companies use prescribed templates or reports to regularly report quality issues. In addition to diagrams and reports, companies schedule weekly meetings to communicate with the rest of the project team and the PM their progress and any risk or quality problems they have come across. Meetings and reports were discussed in Chapter 11 along with other communication concerns.

Case Studies in Quality Control

The case studies, we will concentrate on include HEB and several large firms in the semiconductor manufacturing industry: Motorola, Intel, and AMD.

HEB's Use of Quality Control

H.E. Butt Grocery Company, one of the largest regional food retailers in the United States, has its headquarters in San Antonio, Texas. The main areas HEB focuses on when it comes to quality control is:

When do you report progress?

HEB uses two kinds of reporting methods. They have Standard Reporting which consists of a weekly Project Status Report, a bi-weekly Project Activity Report and a monthly Project Assessment. The second method is a Relaxed Reporting Method that skips all weekly or bi-weekly reporting and reports the Project Status Report and the Monthly Project Assessment monthly.

A Project Status Report (PSR) is a deliverables-based schedule of the project. This report shows when deliverables from the project will be completed. It also breaks the project into phases. In this report specific dates are not assigned for deliverables occurring after the current phase; dates for deliverables produced in the next phase are determined only after the current phase is completed. HEB has chosen this type of reporting because they believe it is easier to understand than MS Project. They also believe that this report gets to the "essence of the Project" since it mainly focuses on deliverable due dates. In order to maintain control with the project, once they have begun work on the current phase they cannot change any dates within that phase without consulting with the PM by using a Change Request Form. A Project Activity Report (PAR) is used to communicate progress with the key stakeholders. HEB calls this report "The Heartbeat of the Project." This report states the monthly progress of the project. It lists all of the deliverables that have reached completion and warns project team members of what critical dates and milestones are coming up next. This report will also list any new issues or risks that have come up since the start of the project.

A Monthly Project Assessment (MPA) is used to give a more detailed look at the triple constraint (Time + Cost + Scope = Quality). The MPA alerts the project team and the PM of the project's status and concerns. It is also used to study trends within the company to define areas that may need more action for correction.

Who needs to know about the Project?

HEB believes that anyone who will participate in the development of the project or is accountable in any way for the project should know about the project. This means, in order to ensure quality, everyone needs to be informed. This may extend out to such people as the Financial Advisors, the Technical Experts, and of course the Executive Sponsor. The key to a successful project is having everyone on the same path. Everyone should be aware of what and when things are expected and the budget assigned for each of these tasks.

How do we raise concerns/issues?

Since every successful project runs across concerns and issues it is important to know how to deal with them when you come across one. HEB deals with this by including in their reports a place to address new concerns or risks that have been discovered while working on the project. They also address this in their weekly meeting so they are able to quickly resolve any new concerns a team member or a stakeholder might hold. Having the ability to quickly communicate and resolve concerns and issues allows for the project to stay in better control, because you address such problems before they become out of control and out of your ability to quickly fix them within your allotted time and budget.

How are we measured?

Now the question is how do you measure if the project is successful or if it is on a successful path. Well, HEB measures this by using their Key Success Factors (KSF). They use a scale-like system to determine how successful their project will be. For example, each project deliverable that is completed and delivered by the scheduled deadline will receive the highest rating for success. Then after that it will decrease. For instance, if a deliverable will be completed in less than 15% behind schedule, they will receive a medium rating. Then it will decrease once again if it is more than 15% behind schedule. They will also receive the same kind of rating to determine how successfully they stay within their budget. Therefore when the project is completed and all of the deliverables have been turned in, they can examine their success chart and determine how successful they were at achieving the project in an effective and efficient manner.

Motorola, Inc.

As a world leader in the semiconductor industry, Motorola has proven that they possess the skills and ability to fabricate some of the world's most advanced chips. Many of their chips power Apple computers, Motorola cell phones and pagers, and automotive/industrial products.

Motorola itself is no stranger to producing high-quality products. In 1988, Motorola was awarded the first ever Malcolm Baldridge award by the National Institute of Standards and Technology. This award was given to the company because of an unprecedented improvement in the size of wafer yields produced. At the time, many companies were practicing what was known as "Three Sigma." Three Sigma was a mathematical expression designating that in a company's manufacturing line, the company expected to run into several defects per thousand units produced. At this time, Motorola was just beginning to practice "Six Sigma," which means that defects are limited to a few per million or even per billion! This was such a huge step in the right direction of quality processes that Motorola actually gained a competitive advantage through its Six Sigma practice. Other companies in the industry realized that as time passed and semiconductors became more and more advanced, with more and more transistors, that a higher quality process would be needed to keep up with the technology. In this aspect, Motorola led the way for other companies to follow.

At www.motorola.com, there is a rather interesting page that details the company's "Six Steps of Quality." First, a Customer Needs Analysis and Network Design is performed. Motorola's technologists will completely analyze the information flow in the organization and develop a preliminary plan to improve the dissemination of information. The second part of the process is to develop an Implementation Plan, perform Equipment Integration and Factory Testing. This phase involves procuring all of the equipment for the company and sending it to Motorola's Customer Center for Systems Integration to be rigorously tested and integrated.

The third step is Site Preparation/Equipment Testing. Motorola works with local subcontractors in this step to ensure that their site meets government/environmental regulations and is well equipped to handle the new equipment. Next comes Optimization and Commissioning. Motorola engineers perform quality audits and verify network connectivity at the site to ensure that the network is capable of handling the new technology. The fifth step of the process is Team Training. Motorola provides certification programs to help develop the project team to perform at their best. They also provide instruction to in-house trainers, giving them control of their employee's education. The final phase of Motorola's Six Steps of Quality is Continuous Support. If your project should experience a hardware failure, Motorola will quickly work with them to help get the project back on its feet with minimal downtime. Some of the methods include Technical Phone Support, Remote Diagnostics, and Field and Dispatch Services.

Motorola has committed itself to providing high-quality semiconductors to meet the needs of changing technology in this information age. With over 60 years of experience in the manufacturing industry, Motorola will surely be leading technological growth through the 21st century.

Intel Corporation

The leading producer of PC-compatible microprocessors and chipsets, Intel is no stranger to technology. In 1965, an Intel scientist named Gordon Moore noticed something unique about how often the company was adding transistors to its chips. He observed that each 18-24 months, a new processor was released that doubled the existing capacity (in transistors) of the current chip. Termed Moore's Law, the observation is still valid today. The Pentium II processor contains over 7.5 million transistors, quite an increase from the 2,300 transistors found in Intel's original 4004 processor (which pre-dated the 8086).

Aside from that interesting fact, Intel itself is also no stranger to quality products. In the company's "Intel Quality Culture" document, Intel describes a "total quality culture" that they strive to facilitate. They seek to:

1. Continuously improve the customer-perceived value of our products, processes and people **(work better)**.
2. Continuously reduce the time it takes to perform every activity **(work faster)**.
3. Continuously reduce the total cost of doing business **(work cheaper)**.

To help to implement these behaviors, the company regularly awards exceptional progress made by employees. The Intel Achievement Award is given to individuals or small teams that make a large contribution to the company's operations.

Similar to Motorola's Six Steps to Quality, Intel has its own "Seven Steps of Problem Solving." They consist of:

1. Define the Problem
2. Clarify the Current Situation
3. Analyze Causes
4. Develop Solutions
5. Validate Solutions
6. Embed Solutions
7. Determine the Future Direction

This is a small part of Intel's approach to continuous improvement. Other important steps include Process Management, Human Resource Management, Monitoring Business Results, Leadership/Strategic Planning, and Market Focus. All of these are significant contributors to the overall success of the company, and must be followed closely to ensure that the company yields the results they desire. Intel has enjoyed tremendous success through the years. Its microprocessors have dominated the PC industry for many years, and Intel's constant focus on quality planning and control is vindicated by their success in the marketplace.

Advanced Micro Devices, Inc.

Advanced Micro Devices, or AMD, has been competing with Intel for years. Recently, they have begun to become a serious threat to Intel's PC market dominance. AMD has shown that they possess the technical knowledge and creativity to succeed in this competitive market. They were the first to reach clock speeds of 1Ghz, and this accomplishment gave them ample media exposure, propelling AMD into the spotlight. Their Athlon processor provides superior performance at a competitive price.

AMD has not succeeded through the years without measuring their output quality. The company's quality manual states: "AMD is committed to excellence in all its operations." (4-0, section 1). The company has six core values that it retains, despite the changing external environment. They are:

1. Respect for People. The company and its employees must respect equally other employees, the company's customers, and treat everyone fairly.
2. Integrity and Responsibility
3. Competition. AMD believes that competition drives the marketplace and is beneficial to technological growth.
4. Knowledge
5. Initiative and Accountability
6. Our Customers' Success. AMD wants its customers to be successful in their endeavors, and AMD provides the technology that companies need to excel in business.

Summary

Scope Change Control

Ideally, project managers would prefer frozen requirements when projects start executing. However, scope changes might be necessary due to several reasons, i.e., market conditions changes, forces from new competitors, customers' requests. A scope change control process involving a combination of procedures, responsibilities, and systems should be defined and implements when changes are requested.

Schedule Control

Schedule control ensures that projects are finished on-time. Timeliness often becomes paramount in any environment in which time is the most important priority. Often you will hear managers say, I'd rather have the product partially complete rather than have it late. In such environments, time is of the essence and getting the product out on schedule is of utmost importance.

Cost Control

It is self-evident that cost control goes far beyond any simple three-line definition. In order for cost control to be effective, there are many processes and steps that need to be followed. One might start learning more about cost control by learning the basics, who is involved in controlling costs, establishing targets, warning signs, and the major job tasks of a control cost engineer and a project manager.

Quality Control

In the semiconductor industry, or in any industry for that matter, quality should be the number one priority. Without well-performing products and services, a company has no chance of long-term survival. The case studies in this chapter have summarized what Motorola, Intel, and AMD are doing to ensure that their products are of the highest quality, and that they continue to be a competitive force in their environment. Only time will tell if new firms will appear that threaten to steal their market share.

Chapter 12 – Exercises

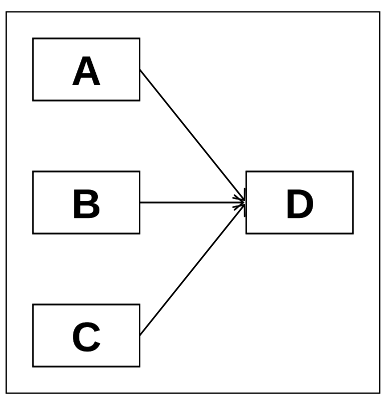
1. Define what is meant by:

Actual Cost, AC
Actual Cost of Work Performed, ACWP
Budget at Completion, BAC
Budgeted Cost of Work Performed, BCWP
Budgeted Cost of Work Scheduled, BCWS
Earned Value, EV
Estimated Cost at Completion, EAC
Estimated Time at Completion, ETAC
Multitasking
Planned Value, PV
Quality Control
Safety
Schedule Control
Scope Change Control
Single-tasking
Student Syndrome
Time at Completion, TAC

2. Name and briefly describe the seven stages to quality control. Which of these have statistical aspects or issues? Which have management aspects or issues?

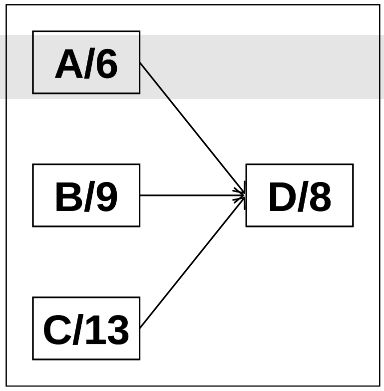
3. Deming described three types of quality to be measured in the workplace. What are they?

4.



Consider the network involving four activities as shown above. Activity A requires 60 days to complete at $800/day. Activity B requires 90 days to complete at $1,000/day. Activity C requires 120 days to complete at $500/day. Currently, the project is in its 70th day of operation. Activity A is 70% complete, B is 60% complete and C is 70% complete. So far, $50,000 has been spent on A, $40,000 on B and $30,000 on C, and nothing on D. Determine: BCWP, BCWS, ACWP, CV, SV, CPI, SPI. What about cumulative earned value, taken in relation to cumulative cost? Is this project behind or ahead of schedule, over or under budget? Is the project likely to be completed by its due date? Why or why not?

5.

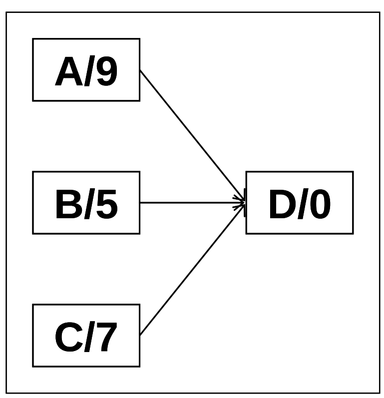


In the above, assume tasks A, B and C all started six business days ago. Planned durations are in days and are the numbers in the boxes shown above. A is 80% complete, B is 50% complete and C is 70% complete. So far, $,2000 has been spent on A, $3,000 on B, $4,000 on C, and nothing on D. The budgeted daily costs for A, B, C and D are $400, $500, $700 and $500, respectively. The total budget for A is 6*$400 or $2,400. To determine BCWS, assume six working days have transpired. Assume five-day work weeks, with no work being done on Saturday or Sunday. For example, the BCWS for A is $2,400. Determine for A, B, C and D, BCWP, BCWS, ACWP, CV (= BCWP – ACWP), SV (= BCWP – BCWS), CPI and SPI. Complete the following table.

TASK	TOTAL BUDGET	%COMP	ACWP (AC)	BCWS (PV)	BCWP (EV)	CV	SV	CPI	SPI
A									
B									
C									
D									
Totals									

Is the project ahead of or behind schedule? Is the project over or under budget? Will the entire project be early or delayed? What is the BAC, Budgeted Cost at Completion? What is the EAC, Estimated Budget at Completion? What is the Estimated Time to Complete the project, ETAC, assuming an existing completion TIME of 22 days?

6. A project has three activities that have been budgeted and scheduled. A fourth activity succeeds the first three. The network diagram is shown below.

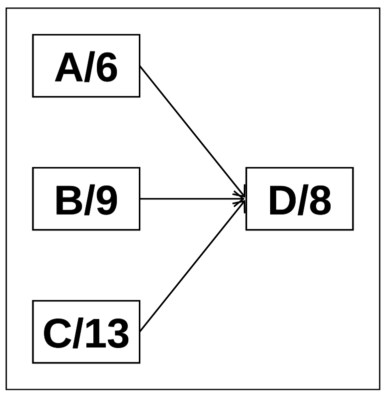


In the above, assume tasks A, B and C all started seven business days ago. Planned durations are in days and are the numbers in the boxes shown above. A is 80% complete, B is 50% complete and C is 70%. So far, $2,000 has been spent on A, $3,000 on B, $4,000 on C, and nothing on D. The budgeted daily costs for A, B, C and D are $400, $500, $700 and $500, respectively. The total budget for A is 6*$400 or $2,400. To determine BCWS, assume seven working days have transpired. Assume five-day work weeks, with no work being done on Saturday or Sunday. For example, the BCWS for A is $2,800. Determine for A, B, C and D, BCWP, BCWS, ACWP, CV (= BCWP – ACWP), SV (= BCWP – BCWS), CPI and SPI. Complete the following table.

TASK	TOTAL BUDGET	%COMP	ACWP (AC)	BCWS (PV)	BCWP (EV)	CV	SV	CPI	SPI
A									
B									
C									
D									
Totals									

Is the project ahead of or behind schedule? Is the project over or under budget? Will the entire project be early or delayed? What is the BAC, Budgeted Cost at Completion? What is the EAC, Estimated Budget at Completion? What is the Estimated Time to Complete the project, ETAC, assuming an existing completion TIME of 22 days?

7.

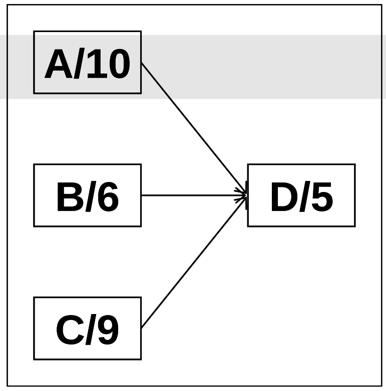


In the above, assume tasks A, B and C all started seven business days ago. Planned durations are in days and are the numbers in the boxes shown above. A is 80% complete, B is 50% complete and C is 70% complete. So far, $20,000 has been spent on A, $30,000 on B. $40,000 on C, and nothing on D. The budgeted daily costs for A, B, C and D are $4,000, $5,000, $6,000 and $7,000, respectively. The total budget for A is 6*$4,000 or $24,000. To determine BCWS, assume seven working days have transpired. For example, the BCWS for A is 6*$4,000 or $24,000, since it should be finished. The BCWS for B is 7*$5,000 = $35,000. Assume five-day work weeks, with no work being done on Saturday or Sunday. Determine for A, B, C and D, BCWP, BCWS, ACWP, CV (= BCWP – ACWP), SV (= BCWP – BCWS), CPI and SPI. Complete the following table.

TASK	TOTAL BUDGET	%COMP	ACWP (AC)	BCWS (PV)	BCWP (EV)	CV	SV	CPI	SPI
A									
B									
C									
D									
Totals									

For the above table and network, determine BAC, EAC, TAC, ETAC. Comment on whether this project is behind schedule, ahead of schedule, over or under budget.

8.

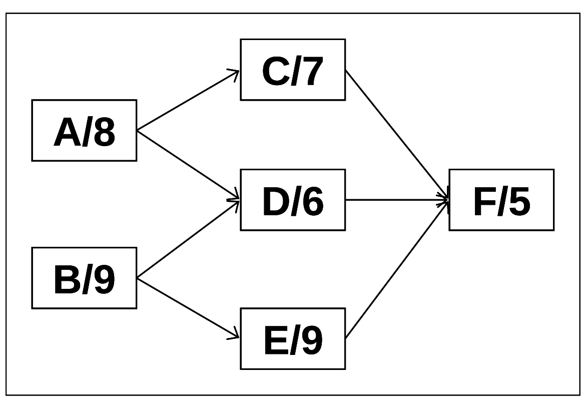


In the above, assume tasks A, B and C all started five business days ago. Planned durations are in days and are the numbers in the boxes shown above. A is 60% complete, B is 50% complete and C is 70% complete. So far, $8,000 has been spent on A, $3,000 on B, $6,000 on C, and nothing on D. The budgeted daily costs for A, B, C and D are $500, $300, $400 and $700, respectively. The total budget for A is 10*$500 or $5,000. To determine BCWS, assume five working days have transpired. Assume five-day work weeks, with no work being done on Saturday or Sunday. For example, the BCWS for B is 5*$300 = $1,500. Determine for A, B, C and D, BCWP, BCWS, ACWP, CV (= BCWP – ACWP), SV (= BCWP – BCWS), SPI and CPI. Complete the following table.

TASK	TOTAL BUDGET	%COMP	ACWP (AC)	BCWS (PV)	BCWP (EV)	CV	SV	CPI	SPI
A									
B									
C									
D									
Totals									

What is the BAC, Budgeted Cost at Completion? What is the EAC, Estimated Budget at Completion? What is the Estimated Time to Complete the project, ETAC, assuming an existing completion TIME of 15 days? Is the project ahead of or behind schedule? Is the project over or under its budget? Will the entire project be early or delayed?

9. For the network below, calculate for each task, BCWP, BCWS, ACWP, CV, SV, CPI, SPI. Calculate these numbers for the entire project as well.



For each of the six tasks that make up the project above, assume the following:

TASK	Percent Complete	Expenditures/Day	Actual Expenditures to Date
A	100%	$1,000	$10,000
B	100%	$1,200	$9,000
C	30%	$1,000	$4,000
D	20%	$1,500	$5,000
E	40%	$1,500	$3,000
F	0%	$1,000	$0

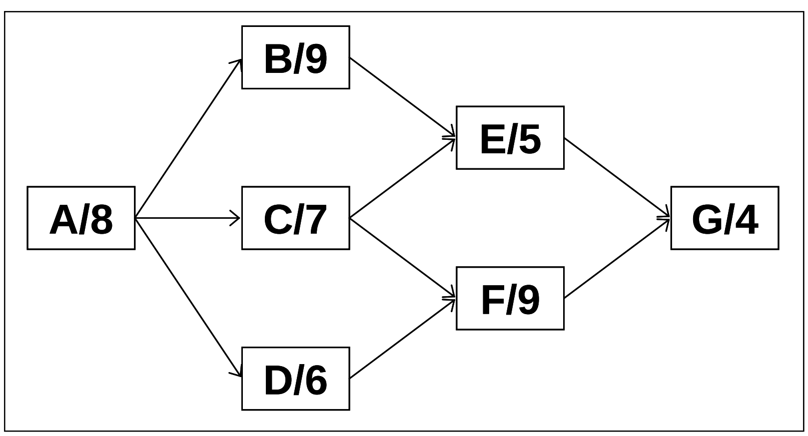
From the above, it should be clear the total budget for A is 8*1,000 or $8,000. Assume that the project is 12 days old (12 business days have transpired), where the units on time are days. Clearly, the BCWS for A is 8*$1,000 = $8,000; the BCWP is also $8,000 because it is 100% complete. Use the following table to complete your analysis.

TASK	TOTAL BUDGET	%COMP	ACWP (AC)	BCWS (PV)	BCWP (EV)	CV	SV	CPI	SPI
A	$8,000	100%	$10,000						
B		100%	$9,000						
C		30%	$4,000						
D		20%	$5,000						
E		40%	$3,000						
F		0%	$0						
Totals									

For the entire project calculate BAC, EAC, TAC, ETAC. Comment on whether the entire project is behind schedule or not. Solve this problem using a spreadsheet.

10. Solve the problem immediately above with the use of MS Project. Contrast the numbers it creates with those you produced in problem 9 above.

11. For the network below, calculate for each task, BCWP, BCWS, ACWP, CV, SV, CPI, SPI. Calculate these numbers for the entire project as well.



For each of the seven tasks that make up the project above, assume the following:

TASK	Percent Complete	Expenditures/Day	Actual Expenditures to Date
A	100%	$1,000	$10,000
B	100%	$1,200	$9,000
C	30%	$1,000	$4,000
D	20%	$1,500	$5,000
E	40%	$1,500	$3,000
F	0%	$1,000	$0
G	0%	$1,200	$0

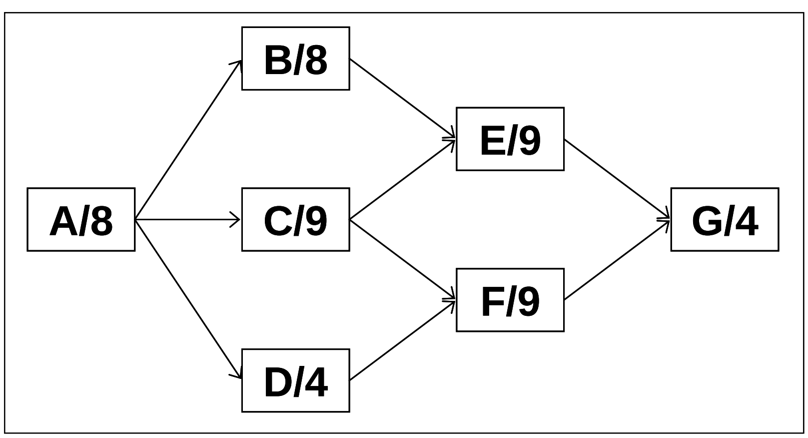
From the above, it should be clear the budget for A is 8*1,000 or $8,000. Assume that the project is 12 working days old (12 business days have transpired). Clearly, the BCWS for A is 8*$1,000 or $8,000; the BCWP is also $8,000 because it is 100% complete. Use the following table to complete your analysis.

TASK	TOTAL BUDGET	%COMP	ACWP (AC)	BCWS (PV)	BCWP (EV)	CV	SV	CPI	SPI
A	$8,000	100%	$10,000						
B		100%	$9,000						
C		30%	$4,000						
D		20%	$5,000						
E		40%	$3,000						
F		0%	$0						
G		0%	$0						
Totals									

For the entire project calculate BAC, EAC, TAC, ETAC. Comment on whether the entire project is behind schedule or not. Solve this problem using a spreadsheet.

12. Use MS Project to perform all calculations in problem 11 above. Contrast the numbers it creates with those you produced in 11 above.

13. For the network below, calculate for each task, BCWP, BCWS, ACWP, CV, SV, CPI, SPI. Calculate these numbers for the entire project as well.



For each of the six tasks that make up the project above, assume the following:

TASK	Percent Complete	Expenditures/Day	Actual Expenditures to Date
A	100%	$1,000	$10,000
B	20%	$1,200	$9,000
C	50%	$1,000	$4,000
D	80%	$1,500	$5,000
E	0%	$1,500	$3,000
F	0%	$1,000	$0
G	0%	$1,200	$0

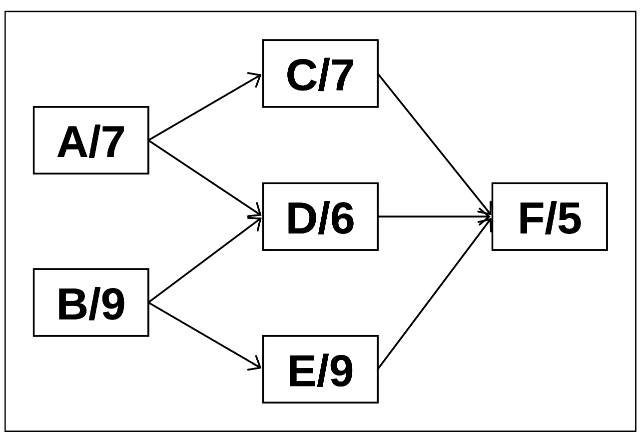
From the above, it should be clear the budget for A is 8*1,000 or $8,000. Assume that the project is 10 working days old (10 business days have transpired). Clearly, the BCWS for A is 8*$1,000 or $8,000; the BCWP is also $8,000 because it is 100% complete. Use the following table to complete your analysis.

TASK	TOTAL BUDGET	%COMP	ACWP (AC)	BCWS (PV)	BCWP (EV)	CV	SV	CPI	SPI
A	$8,000	100%	$10,000						
B		20%	$9,000						
C		50%	$4,000						
D		80%	$5,000						
E		0%	$3,000						
F		0%	$0						
G		0%	$0						
Totals									

For the entire project calculate BAC, EAC, TAC, ETAC. Comment on whether the entire project is behind schedule or not. Solve this problem using a spreadsheet.

14. Use MS Project to perform all calculations in problem 9 above. Contrast the numbers it creates with those you produced in problem 13 above.

15. A six-task problem is depicted below that is 12 days old.



For each of the six tasks that make up the project above, assume the following:

TASK	Percent Complete	Expenditures/Day	Actual Expenditures to Date
A	100%	$1,000	$9,000
B	100%	$1,200	$9,000
C	80%	$1,000	$4,000
D	90%	$1,500	$5,000
E	20%	$1,500	$3,000
F	0%	$1,000	$0

From the above, it should be clear the budget for A is 7*1,000 or $7,000. Assume that the project is 12 days old (12 business days have transpired), where the units on time are days. Clearly, the BCWS for A is 7*$1,000 or $7,000; the BCWP is also $7,000 because it is 100% complete. Use the following table to complete your analysis.

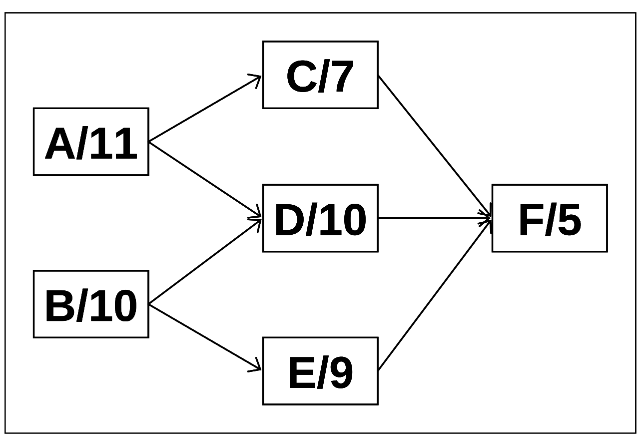
TASK	TOTAL BUDGET	%COMP	ACWP (AC)	BCWS (PV)	BCWP (EV)	CV	SV	CPI	SPI
A	$7,000	100%	$9,000						
B		100%	$9,000						
C		80%	$4,000						
D		90%	$5,000						
E		20%	$3,000						
F		0%	$0						
Totals									

For the entire project calculate BAC, EAC, TAC, ETAC. Comment on whether the entire project is behind schedule or not. Solve this problem using a spreadsheet.

16. Set problem 15 up in MS Project. Contrast the numbers it creates with those you produced in problem 15 above.

17. For the problem 15 above, assume that each of the above six task contain 33% safety. Remove the safety from each task by reducing its duration by 33%. Place the safety appropriately in feeding or project buffers as explained in the chapter.

18. For the network below, calculate for each task, BCWP, BCWS, ACWP, CV, SV, CPI, SPI. Calculate these numbers for the entire project as well. Assume the project is 14 days old. Assume all tasks will be started at their earliest start times.



For each of the six tasks that make up the project above, assume the following:

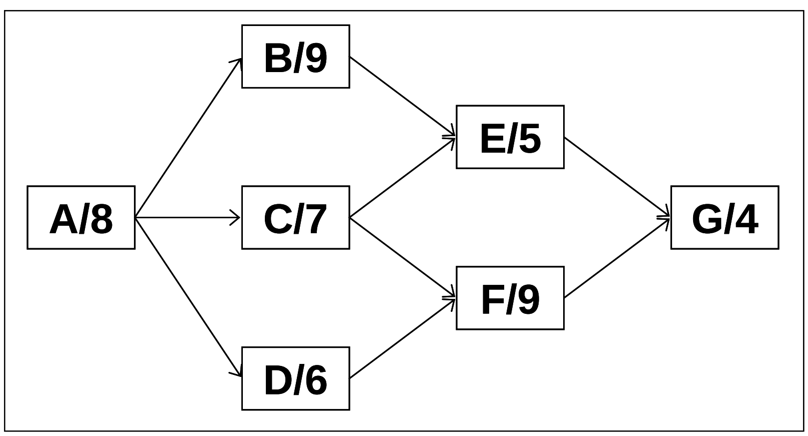
TASK	Percent Complete	Expenditures/Day	Actual Expenditures to Date
A	100%	$1,000	$10,000
B	100%	$1,200	$9,000
C	80%	$1,000	$4,000
D	90%	$1,500	$5,000
E	20%	$1,500	$3,000
F	0%	$1,000	$0

From the table above, it should be clear the budget for A is 11*1000 or $11,000. The project is 14 days old (14 business days have transpired), where the units on time are days. Clearly, the BCWS for A is 11*$1,000 or $11,000; the BCWP is also $11,000 because it is 100% complete. The BCWS (= PV) for C, however, is 3*$1,000 = $7,000, while the BCWS for F is 0.

TASK	TOTAL BUDGET	%COMP	ACWP (AC)	BCWS (PV)	BCWP (EV)	CV	SV	CPI	SPI
A	$11,000	100%	$10,000						
B		100%	$9,000						
C		80%	$4,000						
D		90%	$5,000						
E		20%	$3,000						
F		0%	$0						
Totals									

For the entire project calculate BAC, EAC, TAC, ETAC. Comment on whether the entire project is behind schedule or not.

19. For the network below, calculate for each task, BCWP, BCWS, ACWP, CV, SV, CPI, SPI. Calculate these numbers for the entire project as well.



For each of the seven tasks that make up the project above, assume the following:

TASK	Percent Complete	Expenditures/Day	Actual Expenditures to Date
A	100%	$1,000	$10,000
B	100%	$1,200	$9,000
C	30%	$1,000	$4,000
D	20%	$1,500	$5,000
E	40%	$1,500	$3,000
F	0%	$1,000	$0
G	0%	$1,200	$0

From the above, it should be clear the budget for A is 8*1,000 or $8,000. Assume that the project is 14 working days old (14 business days have transpired). Clearly, the BCWS for A is 8*$1,000 or $8,000; the BCWP is also $8,000 because it is 100% complete. Use the following table to complete your analysis.

TASK	TOTAL BUDGET	%COMP	ACWP (AC)	BCWS (PV)	BCWP (EV)	CV	SV	CPI	SPI
A	$8,000	100%	$10,000						
B		100%	$9,000						
C		30%	$4,000						
D		20%	$5,000						
E		40%	$3,000						
F		0%	$0						
G		0%	$0						
Totals									

For the entire project calculate BAC, EAC, TAC, ETAC. Comment on whether the entire project is behind schedule or not. Solve this problem using a spreadsheet.

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CORPORATE CASE—Stonebridge Technology

This $70-$100 million dollar company is growing very rapidly and competes regularly with big-six consulting firms. They are the #1 Sun reseller in the Dallas-Forth Worth (DFW) Area. They are "best-in-class" in HP in the DFW metroplex. They are considered a Premier ORACLE systems integrator. They do projects involving the use of Netscape products, OLAP—business objects, and micro-strategy. They provide project consulting in which they help companies organize their project teams, plans, methodology, etc. They do lots of data warehousing. They take a RAD focus and are looking for long-term relationships with firms. In terms of back-end products they are experienced with and have expertise in the use of Oracle/Sybase/Informix. In terms of front-end, they use Power-Builder, Visual Basic on a WIN98 or NT client. Servers can be Unix or NT. They are very bullish on relational OLAP, very datamart driven. They are building WEB-enabled applications, C/S financial applications, Intranet systems utilizing JAVA scripts.

One of Texas Tech alumni, Keith Robertson (Class of 1996), interacts regularly with CEO's and Presidents at his level. He gets involved with projects from start to finish. He is currently handling a project with a large insurance company. He wants FedEx reliability—able to produce the product by its due date every time. He wants his clients to be raving fans. The company wants each project to be rewarding to the individual, yet challenged to the ultimate. It is like drinking from a fire hose. The firm is profitable, debt free. Clients include AMD, Compaq, CompUSA, and Texas Instruments. Goal is to take the company public. They are finding there is lots of room for growth as a regional systems integrator. Their competitors are Accenture, PricewaterhouseCoopers, EDS, and Systems House. They provide a minimum of two-week training each year. They use the waterfall and spiral development methodologies. There is a requirements definition phase. The time entailed to execute the requirements definition, detailed design, development, test and implementation phases is compressed. They get the customer into the feedback loop at each phase. They will insist on breaking the total project down into usable, deliverable chunks. There is a customer sign-off on the deliverable at the end of each phase and the customer pays at the end of each phase. Stonebridge's mission is to provide open systems solutions—to add value. (You have to add a dollar of revenue or you have to subtract a dollar of cost.) Fairness and fun is important to the company's culture; they want everyone to grow.

They have created Stonebridge University. It is designed to be modular. Some courses take as little time as a week; others take as long as seven weeks. Initial modules are designed to support later modules. After the "boot-camp" in information technology is completed, the student selects one or more "tracks" for specialization. Follow-up tracks include decision support, intranet development, and system integration. It is hard work, but made to be fun; there is stress involved just as there would be in any real-world project. They spend a lot of time on establishing a corporate vision with their own student-employees. They video-tape and role-play. They believe strongly in soft-skills—communication, coordination, collaboration. They teach their students how to understand clients who put a spin on a collection of requirements and get aggravated. When they are told you are going to get requirements for a system from them, you must understand their personality and how to manage that. A lot of role playing takes place in front of a video camera. Leadership and team-building are important. They use outside consultants to teach personal productivity skills, time management skills and professional excellence skills.

Supplement 12.1: TRACKING AND CONTROLLING YOUR PROJECT WITH MS PROJECT 200X

Tools within MS Project 200x let you know how the project is progressing, whether its going as it was planned. To track the progress, you need to save key progress-indicating information after fine-tuning your project and before the project starts. This information is called the baseline. It is against this information that you compare the actual data. Tracking helps you to:

- Identify sources of problems, such as project finish date being pushed out & cost overruns.
- Determine solutions to the problems.
- Develop project history which can be used to improve future project planning.

<u>Baseline</u>

A baseline is the approved project plan and budget information such as task start and finish date, resource assignments & costs that represent the best estimate of how your project will progress and how much it will cost. To set a baseline:

1. On the **Tools** menu, point to **Tracking** and then click S**ave Baseline**.
2. Select S**ave Baseline** and **Entire project.**

<u>Putting in the actual information</u>

Generally, the information that is tracked and updated are:

- Task start dates.
- Task finish dates.
- Task remaining duration
- Task cost
- Work
- Percentage of task that is complete.

<u>Entering actual start and finish dates or actual duration for a task</u>

1. On the **View** menu, click **Gantt Chart**.
2. In the **Task Name** field, select the task to update.
3. On the **Tools** menu, point to **Tracking** and click **Update Tasks**.
4. To enter actual start and finish dates: Under **Actual**, type the dates in the **start** and **finish** boxes.

Note: The dates you type will appear in the Actual Start and Actual finish fields of the selected task.

5. To enter the actual duration of a task: In the A**ctual Duration** box, enter the actual duration of the task.

<u>Indicating progress on a task as a percentage</u>

MS Project displays percent complete as a thin black line within Gantt bars to indicate progress on a task as a percentage:

1. On the **View** menu, click **Gantt Chart**.
2. In the **Task Name** field, select the task you want to update; double-click on it.
3. On the **Task Information** box, click the **General** tab.
4. In the **Percent complete** box, type a whole number between 0 and 100.

Updating work completed on a task

If the availability of the resource is crucial to your project and you want to track the work that each resource is performing, you can track task progress by updating the work completed on each task by each. To update the work completed on a task:

1. On the **View** menu, click **Task Usage**.
2. On the **View** menu, point to **Table**, and then click **Tracking**.
3. Drag the divider bar to the right to view the **Activity work** field.
4. In the **Activity Work** field, type the updated work value and the duration abbreviation for the assigned resource under the task for which you want to update the actual work value.

Updating actual costs for a resource assignment manually

By default MS Project calculates the actual cost of a resource assignment as the task progresses, according to the accrual method you choose. To enter the actual cost of a resource assignment the automatic calculation has to be turned off and the cost has to be entered as follows:

1. On the **Tools** menu, click **Options**, and then click the **Calculation** tab.
2. Clear the **Actual costs are always calculated by Microsoft Office Project** check box.
3. Click **OK**.
4. On the **View** menu, click **Task Usage**.
5. On the **View** menu, point to the **Table** , and click **Tracking**.
6. Drag the divider bar to the right to view the **Activity Cost** field.
7. In the **Activity Cost** field, type the actual cost for the assignment for which you want to update costs.

ANALYZING THE VARIANCE BETWEEN ACTUAL DATA AND THE BASELINE DATA.

A variance is any difference between baseline data and actual data. Among the most important variances that have to be looked into when comparing the updated schedule to the baseline data are the following:

- Tasks that are starting or finishing late.
- Tasks that require more or less work than scheduled.
- Tasks that are progressing more slowly than planned.
- Tasks that are costing more than you planned for the actual work that's been completed.
- Resources that aren't working hours as scheduled.

Displaying progress lines to determine project status

A progress line is a vertical line that represents either the current date or status date that you specify. It gives you an idea as to whether the project is ahead of or behind schedule. Jutting from a progress line are horizontal peaks connected to taskbars representing tasks that are either in progress or should have started prior to the current date or status date. A peak pointing leftwards indicates a task that is either behind schedule or hasn't been completed. A progress line pointing rightwards indicates a task that is ahead of schedule. A progress line does not connect to completed tasks or tasks that start after the progress-line date.

To display progress lines:

1. On the **View** menu click **Gantt Chart**.
2. On the **Tools** menu, point to **Tracking**, and click **Progress Lines**.
3. Click the **Dates and Intervals** tab, select the **Always display current progress line** check box. To show the progress for the project status date, select **At project status date**. To show progress for the current date, select **At current date**.

4. To show your progress relative to baseline data, on the **Dates and Interval** tab, under **Display progress lines in relation to**, select **Baseline plan**.

Viewing baseline costs and actual costs on a daily basis

When costs matter and need to be tracked closely, you can do this by comparing baseline costs with the actual costs in the task usage view, which breaks down cost on a day-by-day timescale. To view baseline costs and actual costs on a daily basis, do the following:

1. On the **View** menu, click **Task Usage**.
2. On the **View** menu, point to **Table**, select **Cost**.
3. On the **Format** menu, click **Detail Styles**, and then select the **Usage Details** tab.
4. In the **Available fields** list, hold down CTRL, click **Actual Cost, Baseline Cost** and **Cost**.
5. Click **Show**.

Determining if tasks are starting and finishing on time

1. On the **View** menu, click **Tracking Gantt**.
2. On the **View** menu, point to **Table** and then click **Variance**. MS Project displays the scheduled and baseline dates for each task.
3. Drag the divider bar to the right to view the **Variance** fields.

Determining if tasks are using more or less work than planned.

1. On the **View** menu, click **Gantt Chart**.
2. On the **View** menu, point to the **Table**, and then click **Work**.
3. Drag the divider bar to the right to view the **Work** and **Baseline** fields.
4. Compare the values in the **Work** and **Baseline** fields.

Determining if tasks cost more or less than budgeted

1. On the **View** menu, click **Gantt Chart**.
2. On the **View** menu, point to the **Table**, and then click **Cost**.
3. Drag the divider bar to the right to view the **Total Cost** and **Baseline** fields.
4. Compare the values in the **Total Cost** and **Baseline** fields.

WHAT IS THIS ABOUT? PERHAPS IT CAN BE PUT IN COMMUNICATION MANAGEMENT? OR CLOSE OUT?

The next step to successfully completing a project on schedule is to make visible progress towards the goal. The project manager communicates the progress toward the goal of completion to the rest of the stakeholders.

One step towards successfully completing a project on time is to create a project stage deliverable completion checklist. This is concerned with completing deliverables, project stages, or the entire project and turning it over to the client. It provides guidelines for ensuring that product acceptance and project or stage completion steps are visible and acknowledged by all individuals involved. The project manager may delegate some responsibilities to the stage coordinator or other members of the team.

Another step in successfully completing a project on schedule is project or stage completion. The process to be followed to ensure that all parties accept that the end has occurred is for a project stage completion form to be completed. The purpose of this form is to answer the question, "Is the project or stage completed?" It provides a formal mechanism to communicate to all participants the completion of each project, sub-project or stage, and the acceptance of responsibility for the results by the acceptor. It is the responsibility of the project manager to acquire the acceptor's signature on this document as well as the signatures of those who will recommend acceptance. The approach for the project manager to acquire the acceptor's signature on this document is to work closely together. This should be from the time that the unsigned document is first displayed in the project plan through to the project completion, which is signified by acceptance of responsibility for the project's results, by the acceptor.

The next step to successfully completing a project on schedule is deliverable completion. This step also requires that a form called the deliverable acceptance form be completed and signed. This form ensures that deliverables are completed and the question, "Is the deliverable complete?" is answered. This provides a formal mechanism to communicate the completion of a project product and the transfer of the responsibility for the product from the project manager to the deliverable acceptor. Like the project or stage completion step, this step also requires that the project manager and the acceptor work closely from deliverable initiation to deliverable completion.

The second to last step to be followed in successfully completing a project on schedule is to complete a stage completion report. This report will build acceptor and management confidence in getting project or stage acceptance. The stage completion report answers the question, "How can the results of the project or stage be made known to all interested parties?" In approaching the writing of this report it is important to remember that the contents should be a surprise to absolutely no one since the contents should be continually be made visible throughout the stage.

The final step to be taken to ensure that projects are completed on schedule is to conduct a performance review. This review serves as a notice of the culmination of a review process started when a team member was first assigned to a project. The purpose of this review is to answer the question, "How can I let the resource managers know of the level of performance of my team members?" Some suggested points to be covered by this review are as follows: one, a description of the employees responsibilities, and/or goals; two, a description of the degree of attainment of each responsibilities; three, an assessment of overall performance; four, an assessment of skills, abilities, and personal suitability; five, assessment of individuals career potential and required training; and six, although review is to be conducted according to the resource manager, the team member should participate by reviewing it and commenting on it before it goes to the resource manager.

When creating a project schedule, one of the most difficult decisions a project manager faces is which method of calculating time estimates to use. The key to accurately creating a schedule is to understand the basic scheduling computations.

There are five of these basic computations that will be briefly discussed. The fist computation is forward pass computations[1]. Here a forward pass is made through the network to calculate the earliest achievement times for each event in the network. There are two terms to keep in mind when making forward pass computations: one, earliest finish or the earliest an event or activity can be completed; and two, earliest start or when the beginning of an event or activity is to be scheduled. Furthermore, an event or activity cannot begin until all work prior to that event is completed.

The second computation is the backward pass computation[1]. This computation makes a backwards pass through the network to determine the latest time for each event in the network. The latest time will represent the latest finish for a preceding activity and a latest start for a succeeding one. Subtracting activity durations from a previous event late times makes this computation.

The third basic scheduling computation is event slack[1]. This "slack" is created when there is a difference between earliest finish of one event and the earliest start of the next event. This slack can be used by project managers to help manage their resources more efficiently.

Another basic scheduling computation is activity maximum float[1]. Float occurs when an activity can begin and end over a longer period of time than is needed to actually complete the activity. For example, activity A can begin as early as day eight and end as late as day twenty-two. The distance between these two times is fourteen days. However, the activity only takes seven days to complete. Therefore, the difference between the fourteen-day distance between the two events and the seven-day working time leaves seven days for activity A to "float" around.

The fifth basic scheduling computation is the critical path[1]. A critical path is created when there is no float between activities. Since the path has no float, if any work on the path falls behind schedule, then the end date will slip accordingly.

Though the methods described earlier are not the only means managers may use to control schedules, they are likely the most effective means to do so. Creating a schedule is one of the most difficult tasks a project manager faces. However, identifying the types of activities the schedule is composed of will aid in the creation of a schedule. Second, successfully completing a project on schedule is made possible by following the seven steps listed. Finally, understanding the basic scheduling computations will prove to be a very important skill for the project manager to develop.

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Best Practices

Change Board

Daily Build and Smoke Test

This best practice is performed during the construction phase of any development project. Developers will make enhancements to the product throughout the day and then at then end of each day, run the product through a collection of basic tests. It will be ascertained that the product still performs certain basis tests correctly. The practice reduces the likelihood of several common, time-consuming risks—unsuccessful integration, low quality, and poor progress visibility. The practice provides critical control for development projects in recovery mode. Its success depends on developers taking the process seriously and on well-designed smoke tests. This practice trades small increases in project overhead for large reduction in integration risk and improvement in progress visibility.

The build involves 1) a recompilation of all source modules that have undergone change since the last build, and 2) a linking of all of the modules to create the integrated executable module, or simply the build. A successful build means that all the modules are still compatible and that they still all compile correctly.

The smoke test involves an exercise of the entire system from end to end. It is not necessarily an exhaustive test that exercises every logic path in the system. It should, however, be capable of detecting major problems. If the build passes the smoke test, it is stable enough to be tested and is a good build. Individual developers should not add their code to the build until they have a significant chunk of well-developed and tested code to add.

The daily build and smoke test can be used on just about any type of development project in which construction is involved. One of the largest projects it has been used on was Microsoft's NT development in the mid 90's. This product contained 5.6 million lines of code spread across 40,000 modules. The daily build took 19 hours in spite of the fact that it was spread across several machines. Nevertheless, the development team still managed to build and test every day and the NT team attributed much of their success on that huge project to their daily builds. It has been said (McCarthy, 1995c) that if Microsoft could evangelize only one idea from its development process, the daily build-and-smoke test practice would be the one. Some developers claim that daily build-and-smoke test practices improve overall product quality; more widely accepted is the notion that daily builds will reduce integration risk, quality risk while increasing progress visibility.

Designing for Change

As its name would suggest, this best practice entails designing the product so that it is easy to change. This would usually mean that the product is modular so that changes made to a single module do not affect other modules, or at least minimally affect them. Since the testing required subsequent to the change can be substantial, the basic idea is to minimize testing. If the product is primarily a software product, one would want to create a "plug-and-play" landscape in which a module can be replaced and there are no consequences for the other modules. To create such a landscape, the use of inheritance within objects must be minimized. Inheritance creates a plethora of interconnections, all of which must be tested, when a parent or super-parent object gets replaced.

Evolutionary Delivery

This is delivery in which a crude form of the product is delivered and brought online. Then as the users learn more about what they want, the product is changed to reflect their maturing requirements. The benefits of this best practice is that it generates at least some value for its users even as the product is being conceived. This approach works well when the requirements are unstable.

Evolutionary Prototyping

This best practice entails prototyping the product, learning from that prototype and then evolving the prototype into more mature and improved forms.