The Latest Rage in Quality Management — Six Sigma

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1. Introduction

The purpose of this paper is to provide an explanation of one of the most significant movements in the quality management field since the advent of total quality management (TQM)[1] some twenty years ago in America and even earlier in Japan. This movement, called Six Sigma, might be characterized as "Super-TQM" since, in essence, it really doesn't call upon anything that hasn't already been a part of TQM. The difference is the way "TQM" is applied; in a highly disciplined way that seeks to directly link quality improvement actions to what the customer wants and the company's bottom line. TQM, on the other hand has been a more generalized approach to quality improvement, seeking continuous improvement often for its own sake. It might be analogous to comparing the aphorism of "Do good and avoid evil" (TQM) with the Ten Commandments (Six Sigma). That Six Sigma is more than a passing fad seems to be borne out by its remarkable success when properly applied. For example General Electric's Jack Welch has enthusiastically embraced Six Sigma and is now claiming billions of dollars in savings as a result.

This paper is organized as follows:

- What is Six Sigma?
- How Six Sigma Got Started
- The Steps to Six Sigma
- The Six Sigma Players

1) See Austenfeld (1994) for a discussion of TQM.

- The “Cost of Quality” and “Hidden Factories”
- A Couple of Examples
- Conclusion

2. What is Six Sigma?

Six Sigma is both a way of thinking about quality and a set of specific steps and tools for attaining extremely high levels of quality. As far as a way of thinking about quality, the ultimate goal of Six Sigma is to produce products and services that are defect free. If we think of a product or service as the result of a set of processes then the question is: how good are those processes? For the sake of simplicity, let’s assume we are talking about a single process that produces a steel cylinder and that the critical dimension for meeting its specification is its diameter[2)]. This means we don’t want the diameter to be either too much bigger than our specified value or too much smaller. One common way to characterize a process is to represent it as a normal distribution with a certain variability. Many processes act this way. Assuming the output of our “steel cylinder” process is normally distributed, we can now ask how far from our target value can the diameter vary and still meet the specification? (Note, we are assuming the average (or center) value of our normal distribution is also our target value—as we shall soon see, such is not always the case.) Traditional quality standards call for this average to be at least 3 standard deviations (or sigma’s[3)]) away from the specification limits (Pyzdek, 1999). This means that “only” 99.73% of the area

2) Of course the length and, perhaps, other characteristics such as hardness or finish, might also be specified but for simplicity we will assume only the diameter is critical for meeting the specification.

3) Sigma is the Greek letter used for standard deviation. Standard deviation is a measure of the extent to which a set of values (say sample diameter measurements), on the average, deviate from their mean. In other words, a measure of the variability of the values and, hence, the variability inherent in the process itself.

under our normal distribution curve would be within the specification limits, leaving 0.27% outside. (In manufacturing terms we would say our process yield is 99.73%.) This area outside the limits (the 0.27%) represents the number of parts that did not meet specification; i.e., "defects." Although this may seem like a small amount, by Six Sigma standards it isn't — Six Sigma measures defects in terms of parts per million (ppm). At a three sigma level (just described) the 0.27% outside specification equates to 2,700 ppm; hardly zero defects! It is important to remember that this is only one process. If we are talking about a series of processes, which is usually the case, the final yield will be the product of the individual yields of each process. For example, if our product is the result of ten processes and each has a "three sigma" yield of 99.73% our final yield would be $(.9973)^{10}$ or 97.33% or 26,674 ppm! In fact, most products and services are the result of many more processes.

So, what would be the improvement given we move to a "six sigma" level of quality? Now we are saying we want the target (average) value to be at least six sigma from the specification limits. Figure 1 shows such a case with the upper and lower specification limits (USL and LSL) set at plus and minus six sigma. The improvement is several orders of magnitude. At six sigma, the amount of area under the normal distribution curve is 99.99999998%, equating to only 0.002 ppm (or only 2 parts per billion!). Let's again consider that set of ten processes. For this six sigma level of quality, the final yield would be 99.999998% or 0.02 ppm, still a negligible amount.

Thus far we have assumed that the average (the population mean) remains right on the target value of the specification. In reality, there is always some amount of drift. Motorola, the company that pioneered Six Sigma, has determined that this drift is seldom more than 1.5 sigma. And, if it is as much as this, it would be detected by those running the process (Naumann, 2000). To ensure that the number of parts per million represents a truly realistic number, Six

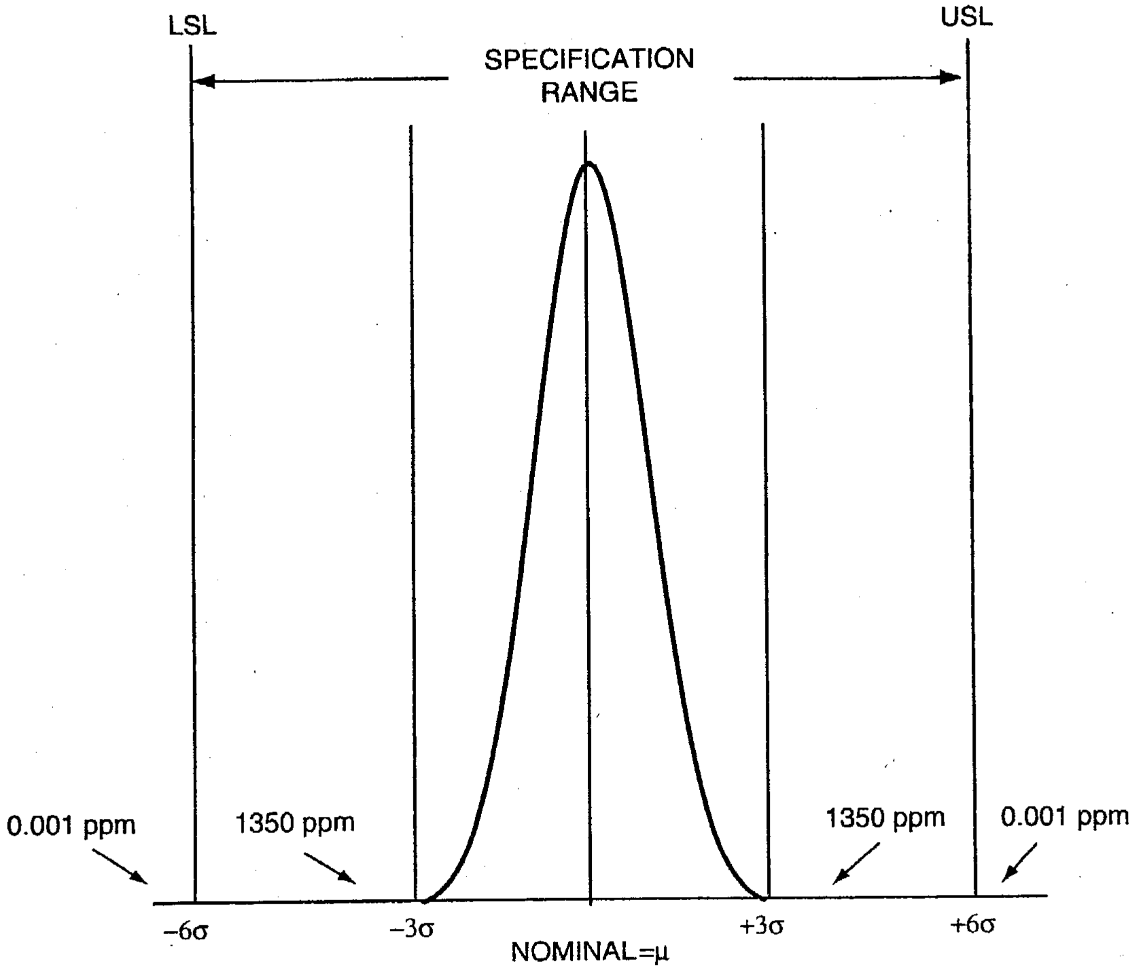

Figure 1. A normal distribution showing "defective" parts per million (ppm) at the three and six sigma levels (Pyzdek, 1999, p. 141).

Sigma takes this possible 1.5 sigma shift in the population mean into account. If the normal distribution curve were to shift 1.5 sigma in either direction, it would mean we are now looking at the amount of area under the curve beyond 4.5 sigma on one side (versus both sides when we were considering a non-shifted population mean). Even with this 1.5 sigma shift the amount of area under the curve and within specification limits is 99.99966% for a defect rate of only 3.4 ppm. And, for our example of a series of ten process, the cumulative yield would be 99.9966 or 34 ppm; still a very high level of quality; especially when compared with the 499,158 ppm we get at a three sigma level when taking the 1.5 sigma shift into account.

Now the next logical question is how do we get our non-shifted population mean of our processes to be at least ± six sigma from the specification limits. The answer is that we "tighten up" our processes by eliminating variability. According to Deming[4] there are two types of variation in processes: that due to *special* causes and that due to *common* causes (Gabor, 1990). The special cause variation is because of some specific event such as a machine getting out of adjustment. The common cause variation is because of things inherent in the process itself such as the quality of material and parts that go into the process or the ability of the equipment to meet certain tolerances. One of the main goals of TQM and, to an even greater extent, Six Sigma is to first ensure there are no special causes present. Once this is accomplished, the true capability of the process can be determined; that is its "sigma level." Then, using common sense and various statistical tools the common causes of variation can be attacked. It is important to remember that a major premise of Six Sigma is that everything done is to be related to some specific purpose such as meeting a "critical to quality" customer requirement or reducing costs or cycle time. This means that as the common causes are identified and eliminated, they are done so with the intention to either better serve the customer or increase the company's profit by improving the product's (or service's) quality, cost, or cycle time.

Another question that might be asked is: why is it necessary to have *so few* defects? We've already mentioned the problem of accumulating a lower overall yield when the product/service results from multiple processes. Also consider these examples from Pyzdek (1999) on how a *three sigma* level would affect our daily life:

4) Although he died in 1993, Dr. W. Edwards Deming continues as perhaps the most influential person in the quality movement. Largely responsible for turning around Japanese quality after World War II, he was subsequently "discovered" in his own back yard of America in the 1980s. His famous Fourteen Points have formed the basis for many quality programs throughout the world.

- Virtually no modern computer would function.
- 10,800,000 healthcare claims would be mishandled each year.
- 18,900 US Saving bonds would be lost every month.
- 54,000 checks would be lost each night by a single large bank.
- 4,050 invoices would be sent out incorrectly each month by a modest-sized telecommunications company.
- 540,000 erroneous call details would be recorded each day from a regional telecommunications company.
- 270,000,000 (270 million) erroneous credit card transactions would be recorded each year in the United States. (p. 142)

To graphically illustrate the difference between a six sigma level and a three sigma level look at Appendix A. Page 1 of Appendix A is an extract from *A Christmas Carol* by Dickens with a "quality level" of three sigma (i.e., 26,674 ppm defects) and page 2 shows the same extract at a Six Sigma quality level (3.4 ppm defects). As might be noted, page 2 is virtually defect free.

Another reason for Six Sigma is the improvements a company can expect as it moves from three sigma to six sigma:

- a 20 percent margin improvement
- a 12 to 18 percent capacity improvement
- a 12 percent reduction in the number of employees
- a 10 to 30 percent capital reduction (Harry & Schroeder, 2000, p. 2)

The other side of the coin is that, according to Harry & Schroeder, a company operating at two sigma or below simply can't survive; most companies operate at the three to four level. The real bottom line here is that *Six Sigma is about making money.*

Why has Six Sigma proven so effective compared with the more generalized TQM programs? The answer probably lies in two facts: (1) with Six Sigma individual projects are identified versus just "improving all your processes" and (2) full-time highly trained experts (called Black Belts) are in charge of these projects. We will have more to say about these two facts later. Now let's see how Six Sigma got started.

3. How Six Sigma Got Started

Motorola Motorola is a large electronics company headquartered in Schaumburg, Illinois. Motorola has always been famous for its wireless communications products from some of the earliest car radios to the walkie-talkies used in World War II to today's cellular phones. It also makes other products such as semiconductors. The story of Six Sigma begins in the late 1970s when Motorola came to the realization that, compared with some foreign companies, its quality stank (Harry & Schroeder). For example, at that time Motorola had just turned over to a Japanese company one of its U.S. factories that manufactured TVs. The Japanese company immediately made changes in how the factory operated and was soon producing TVs with 1/20th the number of defects. This got the managers at Motorola thinking about the connection between how a product was designed and manufactured and its quality. In fact one of those managers, Bill Smith, produced a paper in 1985 based on some studies he'd done about the connection between products that had to be reworked during manufacturing and the number of problems experienced by customers once the product was delivered. This led to some heated discussion within Motorola as to whether "quality" meant detecting and fixing defects or trying to prevent them in the first place with the latter "school" winning out. Ultimately Motorola came to the conclusion that by giving more attention to design and manufacturing, quality not only didn't cost, it saved money. In 1988 Motorola won America's national quality award, the Malcolm Baldridge and, after that, the secret of its success was out: Six Sigma (Pyzdek, 2000b).

By concentrating on making its processes "defect-free," Motorola began to reap the many benefits of the Six Sigma approach to management. As Harry & Schroeder (2000) put it:

> In other words, the company had higher-quality products and happier customers at a cheaper cost. Within four years, Six Sigma had saved the company $2.2 billion. Motorola's Six Sigma architects had done what most companies thought was impossible. By 1993, Motorola was operating at nearly six sigma in many of its manufacturing operations. (p. 11)

Harry & Schroeder cite the development of Motorola's Bandit pager as a good example of what Six Sigma thinking can accomplish. This pager was designed and produced so well, its average life was 156 year! It became more cost effective to simply replace the occasional bad one than test the product. This, by the way, is exactly in line with Dr. Deming's philosophy of improving your processes to the point where final inspection is not necessary (Point 3, Cease reliance on mass inspection to achieve quality). Now that Six Sigma was "out of the bag" with Motorola's winning of the Baldridge, it began to attract the attention of other companies not the least of which were AlliedSignal and General Electric.

AlliedSignal AlliedSignal, a large producer of various products especially automotive and aerospace, began its Six Sigma program in November of 1994. Although it experienced many problems along the way, it gradually overcome these to the point where its overall savings due to Six Sigma had reached $1.5 billion by 1998 (Harry & Schroeder). The person responsible for driving the Six Sigma program at AlliedSignal is its CEO, Larry Bossidy. Although not against the traditional quality programs, Bossidy believes they are often too long on process improvement and "customer satisfaction" and too short on what he calls "making the numbers." Harry & Schroeder (2000) sum up Bossidy's view as follows:

> Six Sigma is a program designed to generate money for the company, either

through savings resulting from reduced costs, or from boosting sales by increasing customer satisfaction. (p. 228)

Interestingly enough, it was Bossidy who turned another famous company on to Six Sigma, General Electric.

General Electric When someone asks for a model company today the first one that usually comes to mind is General Electric (GE). And this is no small feat, especially considering the size of GE. Credit for this company's amazing continuing superior performance goes to its CEO, Jack Welch. Welch has not sponsored many major initiatives but those he has have had a major impact on the company; for example his dictate that each business of the conglomerate would be either number one or two in its field (otherwise it would be dumped).

Recovering from surgery in mid-1995, Welch, by a quirk of fate, had turned over GE's annual meeting of top managers to Larry Bossidy of AlliedSignal, a long time friend. Bossidy was given free rein to talk about anything that would get the managers excited. Since he had recently kicked off Six Sigma at AlliedSignal, Bossidy spoke on that. The result was mangers so fired up that when Welch came back to work a couple of months later he decided to make Six Sigma a major initiative. Once someone like Welch decides to do something there's no half way. Recognizing that training was the key, Welch invested $200 million in it during the first year (1996) and $250 million in 1997. By this time, however, the initiative was already returning money to the bottom line to the tune of $300 million. According to Harry and Schroeder (2000), GE's further investment of $500 million in 1998 has produced savings of $750 million and the company expected to save some $1.5 billion in 1999. In fact, according to its 1999 Annual Report, Six Sigma "produced more than $2 billion in benefits in 1999" (General Electric home page, 2000).

If the one of the world's most successful and savvy companies (GE) has embraced Six Sigma, it must be a solid program. Because of the attention GE's adoption of Six Sigma has given the program, it is now being widely adopted by other companies and is becoming the latest business rage among quality consultants. In fact, Harry and Schroeder run what they call the Six Sigma Academy — “a teaching facility we designed to educate and train executives in the principles of Six Sigma so that they can transform their companies into world-class organizations” (p. viii). Let’s now turn to the steps involved in carrying out a Six Sigma project.

4. The Steps to Six Sigma

There are four core steps to complete a Six Sigma project: measure, analyze, improve, and control (MAIC). An admittedly incomplete review of the literature indicates both some differences in terms of what each of these steps mean and, in some cases, vagueness. However, I generally will follow the guidance from Harry & Schroeder (2000) since they seem to have both the most to say about it and the most experience with implementation of Six Sigma projects. Although Six Sigma can (and should) be applied at the higher levels of the organization, it is at the process level where the actual differences to the company’s products/services are made. This might be analogous to the difference between strategic versus tactical operations. For success you need both; that is, a good overall strategy and then expert tacticians whose battlefield successes contribute to that strategy. To understand Six Sigma at its most fundamental level we will focus on the “tactical” level of process improvement.

Measure The purpose of this step is to describe our process and develop measures of its capability. To describe the process a good starting point is the use of a process flow chart such as shown in Appendix B. Typical process capability measures are: yield, number of defects, etc. We are also interested in the output of our process and which parts of that output are important to the customer — something Harry & Schroeder call critical to quality (CTQ) characteristics. An example of the CTQ characteristic might be a dimension on a part. A major output of this step is a set of good metrics for determining how well our process is performing now and how well it improves in the future.

Analyze Now we are going to look more closely at the process and, in particular at the CTQ characteristics. Using various analytical tools, such as cause and effect diagrams and Pareto analysis, we attempt to determine which elements of the process (including all its inputs) most affect the CTQ characteristics. To better understand this relationship consider the following from Harry & Schroeder:

> The capability of any given CTQ [characteristic] is the result of such things as machine capability, material capability, human capability, and management capability. For example, capability of any given machine is simply the sum of its mechanical and electrical capabilities,. An individual's capability is a reflection of his or her intellectual, physical, emotional, and spiritual capabilities. (p. 133)

Improve Now we are ready to confirm what we found out in the Analyze step in terms of which parts of the process are impacting our CTQ characteristics. In particular, we want to know which variables most affect these characteristics. One way to do this is called design of experiments (DOE). In DOE, variables thought to affect a given CTQ characteristic are systematically varied while carefully measuring the characteristic. As a result, we are able to (1) confirm that a particular variable is indeed having an influence on the characteristic, (2) the extent to which it has such an influence, and (3) how we should control that variable to yield the greatest improvement in our process and CTQ characteristic. Another powerful but quite involved method is called quality function deployment (QFD)[5]. With QFD the improvement phase may result in an entirely new way to manufacture the product.

5) See Bossert (1991) for a good explanation of QFD.

Control As might seem logical, at this stage it is time to ensure the changes we've made to our process continue and, in fact, there is a continuing effort to improve it. This is done by setting up appropriate monitoring measures of the CTQ characteristics (and the variables that affect those characteristics); e.g., statistical process control (SPC) charts and process capability indices such as C_p and C_{pk}.[6)]

We have just looked at the core Six Sigma steps (MAIC) at the process level. Harry & Schroeder identify four more; two before the core steps (*Recognize* problems that link to operational issues and *Define* the processes that contribute to the problem) and two after (*Standardize* the methods that produce best-in-class process performance and *Integrate* standard methods and processes into the design cycle). The first two are a natural extension backward of the "measure" step in that we must first identify the problems that are causing us operational difficulties and then relate those problems to our processes. For example, if one of our operational difficulties is customer complaints about not receiving their bills on time we might "recognize" the problem as too many billing errors resulting in excessive time required for detection and correction. From this we would conclude that we need to focus on our bill preparation process.

Regarding the "standardize" step, it only makes sense to standardize across the company any process that we've "Six Sigma'd" rather than reinvent the wheel or let similar processes continue at a subpar level. And, as for their last step about integrating standard methods into the design process, the point is: sometimes it is better to modify the design than the manufacturing process. In fact, according to Harry and Schroeder (2000) Motorola has now changed the way they reward their design engineers to encourage them to make their designs more "manufac-

6) See Breyfogle (1999) for a thorough discussion of process capability measures and other Six Sigma statistical tools.

turable."[7)]

The other point that needs making here is that these steps (now RDMAICSI) apply at all levels throughout the organization. For the sake of simplicity, Harry & Schröeder break the organization into three levels: the business level at the top, the operation level below that, and, as we've just discussed, the process level. At the business level we are concerned with the big picture and how we are relating to the "outside" world such as our customers, suppliers, and partners. Here we want to relate the feedback we get from those interfaces with the applicable parts of the company. For example, is the feedback from our customers mostly due to the design features of our product or its quality? If it is the former we would want to home in on improving our design processes. At the operation level, we are working more at a "project" level versus a "process" level. Here we might take whatever we've learned from the business level analysis and translate that into a project to remedy, say, a generally poor design capability. That project would, in turn, break down into discrete process improvement activities at the process level.

Before leaving the subject of Six Sigma steps it would be worth showing the steps Six Sigma pioneer Motorola uses in to improve their processes (Figure 2). A fuller description of these steps can be found Appendix B of Breyfogle (1999). Notice how the "Responsible Agent" is sometimes management at the business or operation level.

Finally, one of the most comprehensive and understandable sets of steps I've found was by Naumann (2000). Because of this I feel it is worth repeating here (Figure 3). Although a full understanding of these steps is not possible without

7) When I worked at McDonnell Douglas Corporation (now merged with Boeing) several years ago I recall seeing this picture on someone's cubical wall that was meant to be a joke. But, as is often the case, it had a lot of truth to it. A monkey (identified as being from "design") was holding up this picture of a part that was, in fact, an optical illusion. The caption read: "Hey, we just design this stuff, manufacturing it is your problem."

	Step Activity	Responsible Agent
1	Prioritize opportunities for improvement	Management
2	Select the appropriate team	Management
3	Describe the total process	Team
4	Perform measurement system analysis	Engineering
5	Identify/describe the potential critical product(s)/process(es)	Team
6	Isolate and verify critical process(es)	Team
7	Perform process capability study; if "capable" continue, if not go to "action required on process."	Engineering
8	Implement optimum operating conditions and control methods	Team
9	Monitor process over time	Manufacturing
10	Reduce common cause variation (is $C_p \geq 2.0$ and $C_{pk} \geq 1.5$?); if yes, continuous improvement, if no, go to the "action required."	Management

Figure 2. Motorola's Six Sigma steps (Breyfogle, 1999, Appendix B).

	Step Activity		Step Activity		Step Activity
1	Secure management commitment	8	Develop an "As Is" map	15	Calculate benefits
2	Clarify the Six Sigma objectives	9	Develop time estimates	16	Develop a "Should Be" map
3	Select a process	10	Develop cost estimates	17	Identify cost expected savings
4	Align customer needs and internal processes	11	Identify disconnects	18	Develop an implementation plan
5	Select the team	12	Problem solving	19	Identify responsibilities
6	Provide training	13	Make recommendations	20	Identify re-enforcement strategy
7	Develop a relationship map	14	Identify underlying assumptions	21	Measure outcomes

Figure 3. Naumann's Six Sigma steps (2000, pp. 635–640).

more information, just seeing the names of the activities will give us an idea of some of the more important elements of a Six Sigma project. For example, step activity number one indicates the first and most important thing for a successful project is management commitment. In fact, one of the lessons AlliedSignal learned was Six Sigma can't be diffused from the bottom up; they tried that and it got nowhere. Once they began training the top managers and flowing the philosophy down, things turned around. This is also the way GE did it where Jack Welch became a committed believer and expected every one else to do likewise. Another important point to be drawn from Naumann's steps is number 20, "identify re-enforcement strategy." Without that follow-up you can be sure there is a good chance things will return to "normal"; especially until the company becomes completely "Six Sigma'd" with everyone fully committed to its ideals.

In summary, the core steps of Six Sigma are:

- Develop the necessary metrics and *measure* current process capability.
- *Analyze* the process to determine the relationships between its different elements/inputs to the desired CTQ outputs.
- *Improve* the process with reference to these outputs using techniques such as DOE or QFD.
- *Control* and refine the improvements with appropriate statistical monitoring techniques.

However, these four steps are not undertaken until a process improvement project has been identified for action by higher levels within the company and this, in turn, is related to strategic intent (the *recognize* and *define* steps). Also there should be appropriate follow-up to the four steps to fully exploit the gains made (the *standardize* and *integrate* steps).

Also, there are other ways to describe essentially the same important activities as indicated by Figures 2 and 3 above. Finally, remember that the steps apply at other levels within the company — at the strategic level and the operating level; each dealing with the concerns appropriate to that level and in harmony with the activities at the other two levels. In fact, the Six Sigma activities at the higher levels should be triggering those at the lower levels. Now it is time to talk about who does these steps: the Six Sigma Players.

5. The Six Sigma Players

In a Six Sigma company almost every one is (or should be) a player. However, certain people will have a more important role since they will be leading Six Sigma projects. Figure 4 highlights a fundamental truth about Six Sigma; that is, it is a way to unleash the creativity and initiative of everyone throughout the organization in the interest of the customer. The most noticeable thing about Figure 4 is that the triangle is inverted showing that, rather than the typical "command and control" type of organization, with Six Sigma control is given at the lower levels so as to better serve the customer's interests. In other words, the workers are empowered to do their jobs in the best way possible. The role of those further down the inverted triangle is to support those closer to the customer. Returning to our military analogy, it is those at the strategic level that not only provide the broad direction for those at the tactical level but also the

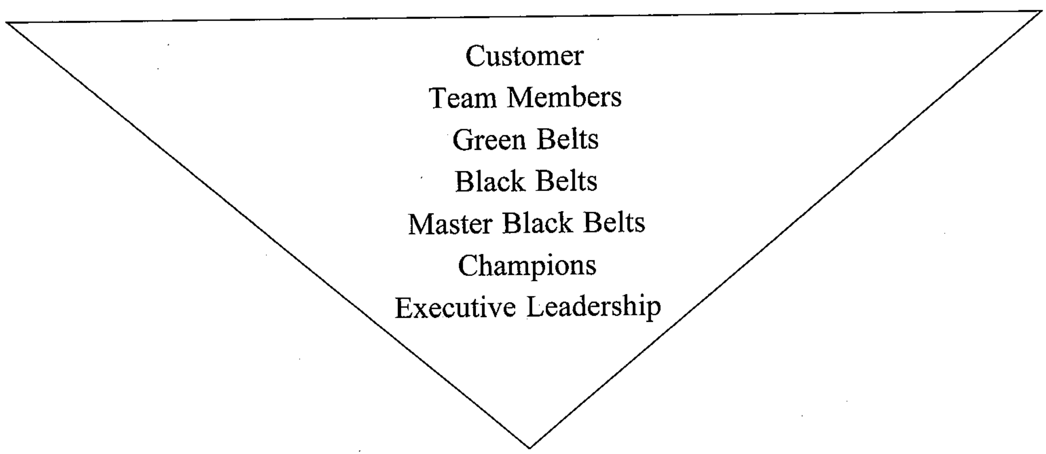

Figure 4. The Six Sigma organizational paradigm (adapted from a similar figure in Harry & Schroeder, 2000, p. 189).

"beans and bullets" support needed to wage a successful battle. Let's now take a closer look at each of these players.

Executive leadership As with any important change program, it is top management's commitment that will make or break it. Specifically, it is the CEO who must lead the effort by providing the vision and a rationale for Six Sigma that everyone in the organization can understand. Furthermore, it is the CEO who will be sure everyone knows this is the way the company will go regardless of any long-time attachments people may have to traditional ways of doing things. Perhaps the following quote about GE from Harry & Schroeder (2000) best illustrates this point (note: GE began Six Sigma in late 1995):

> On March 12, 1997, Welch sent an e-mail message to every GE manager throughout the world, stating that anyone interested in being promoted to a senior management position within GE must start Black Belt or Green Belt training by January 1, 1998, and complete the training by July 1, 1998. Until that message, many employees regarded Six Sigma as another "flavor of the month" initiative, despite the fact that Welch had never let up chanting the mantra of achieving Six Sigma by 2000. (p. 45)

Champions Champions are executives who are sufficiently knowledgeable about the Six Sigma methodology to effectively interface between management and the technical implementers such as the Black Belts. Harry & Schroeder (2000) list three types of Champions[8]:

- The *Senior Champion* operates at the corporate strategic level and has overall responsible for driving the Six Sigma effort within the company. He or she will work with both business unit leaders and senior management to

8) Although Harry & Schroeder list these three types of Champions, it is a little difficult to distinguish between their duties from the information given in the book. For example, I find it hard to understand why a company would need both a "Deployment" and "Project" Champion.

ensure the business units are undertaking improvement projects and senior management is committing the necessary resources for carrying out those projects.

- *Deployment Champions* act also at the strategic level as aides to the business unit leaders in developing plans for deploying Six Sigma within that leader's area of responsibility. These people also work to ensure the necessary support systems are in place and working. Usually these Champions report to the Senior Champion. It is conceivable that in a smaller organization the Deployment Champion might work with more than one business unit. I see this type as sort of an extension of the Senior Champion.
- *Project Champions* work at the tactical level and oversee the Black Belts within their respective areas of business responsibility. They represent the immediate interface between the Black Belt leading a Six Sigma project and upper management, ensuring the necessary support is available and, when necessary, breaking down any barriers to cross-functional cooperation.

Sponsors Sponsors are those line managers who own the processes being improved. It is their responsibility, along with whatever Champions and Black Belts are involved, to be sure the project gets the support it needs and to ensure the gains captured are sustained after the Black Belt has moved on to another project.

Master Black Belts These are perhaps the most important people in terms of disseminating the Six Sigma philosophy and methodology. Master Black Belts are highly trained and proficient experts in both statistical and other quality improvement techniques and in communications and training. Their job is to work closely with the Champions in identifying and initiating Six Sigma projects, training those who will lead those projects (Black Belts) and acting as a readily available source of expertise for both the Champions and Black Belts. The Master Black Belt not only knows how to use statistical tools but understands the theory behind them so he or she can adapt them to any unusual situation. It is important for the Master Black Belt to be the single training source for all statistical training to avoid "propagation of error" that would occur should Black Belts train Green Belts and Green Belts train team members. From this description it can be seen that the Master Black Belt will be spending most of his or her time organizing projects and training Black Belts, Green Belts, and team members. As a rule of thumb, a company should have about one Master Black Belt for every 1,000 employees.

Black Belt This player is more formally known as a Six Sigma Black Belt and undergoes 160 hours of classroom training while concurrently working on a real-world project and receiving real-time feedback and advice on his/her execution of the project. Harry & Schroeder call this the "Plan-Train-Apply-Review" cycle. See Appendix C for a typical schedule for taking Black Belts through this training. Once trained, Black Belts are then ready to take on more projects. Black Belts are devoted full-time to Six Sigma improvement projects. The knowledge of the Black Belt is, indeed, extensive. See Appendix D for a list of things a Black Belt is expected to know. Normally there would be about ten Black Belts for every Master Black Belt.

Green Belt Green Belts work on Six Sigma projects as part of their job. They are given five days of classroom training in connection with a Six Sigma project. They assist Black Belts and can even take on small projects on their own.

Team members These employees generally would be involved part-time on Six Sigma projects under the leadership of a Green Belt or Black Belt. For large projects they could be involved on a full-time basis.

Financial expert For every project there needs to be someone from finance to set up the expected cost savings (together with the Champions and Black Belt involved) and then ensure those saving are tracked through project realization. This is very important if the payoff from Six Sigma is to be meaningfully measured.

Summarizing this section, we see that one of the distinguishing features of Six Sigma is not leaving to chance who will champion Six Sigma initiatives and who will actually execute Six Sigma projects. At the higher levels we have the CEO and senior management, Champions, Sponsors, and financial experts. At the lower levels we have Master Black Belts, Black Belts, Green Belts and team members. It should be apparent that there is a tremendous amount of training required to be sure everyone involved has the knowledge needed. This means training Champions, Master Black Belts, Black Belts, Green Belts, and, to a lesser extent, everyone else in the company. For example, GE has invested millions of dollars in training—but is now realizing billions in cost savings. In fact, the average well-trained Black Belt would be expected to complete five to seven projects per year with estimated savings of about $150,000 to $243,000 per project (Pyzdek, 2000b). The corollary to all this is companies must be sure their compensation system appropriately rewards those involved with Six Sigma, especially the Black Belts. Let's now turn to one of the big things Six Sigma does: attacks the "cost of quality" and "hidden factories."

6. The "Cost of Quality" and "Hidden Factories"

One might ask at this point how it is possible for Six Sigma to return so much money to a company's bottom line? A lot of this money comes by reducing the so-called cost of quality and eliminating hidden factories. Let's look at each of these.

The cost of quality Actually this is a misnomer and gives the impression that "quality" costs when, in fact, we now know that improving our quality actually decreases overall costs — this is what Six Sigma is all about! A better term, as Pyzdek has said (1999), would be the cost of *poor* quality. These costs can be broken down into the following four categories: prevention costs, appraisal costs, internal failure costs, and external failure costs.

Prevention costs Prevention costs are all costs associated with prevention of defects or of producing something that does not conform to the customer's requirements; for example, market research, design reviews, quality education, and quality improvement programs. Six Sigma training costs and the use of full-time people to work on Six Sigma projects (such as Black Belts) would be included in these costs. So, in a sense, some quality costs are "good" costs if the return on that investment is favorable.

Appraisal costs Appraisal costs are all costs associated with measuring and controlling the production process so it will produce as much defect-free/conforming product as possible. For example inspection of incoming materials, process control measures, end-of-the-line inspections, etc. In a sense, these could also be considered "good" costs but, in line with what Deming preached, it is better to concentrate on improving your process to the point where you don't have to rely on mass inspection. In fact, in the case of the Bandit pager cited earlier in this paper, if you can perfect your design and your manufacturing processes so that the product is essentially defect free, it is not even necessary to inspect it.

Internal failure costs Internal failure costs are those incurred before the product leaves the factory. They are the result of your appraisal system detecting nonconforming material or product. Examples include such things as design rework; nonconforming incoming material that must be returned or disposed of; defective product that must be either reworked, downgraded, or completely scrapped; additional inventory that must be held to accommodate the waste; and the additional labor involved in all these activities. Internal failure costs can indeed be high and are often go unnoticed as will be discussed shortly when we talk about hidden factories.

External failure costs External failure costs are those due to a nonconforming product being shipped to the customer. They are the result of your appraisal system *not* working as well as it should. Examples include costs associated with complaint handling, returned products, retrofits, warranty claims, and, in serious cases, liability claims. Beyond these measurable costs are more insidious ones such as lost customer good will and loss of reputation. It is well known that customers will usually not go to the trouble of telling a company that they were unhappy with its product but *will* tell their friends and neighbors. As with internal failure costs, many of these costs are not accounted for.

As Pyzdek (1999) points out "The classical model [see Figure 5] created a mindset that resisted the idea that perfection was possible" (p. 167). Juran's new model (see Figure 6) suggests (as does the whole Six Sigma program) that we can economically drive our failure costs (defects/nonconformances) down to zero.

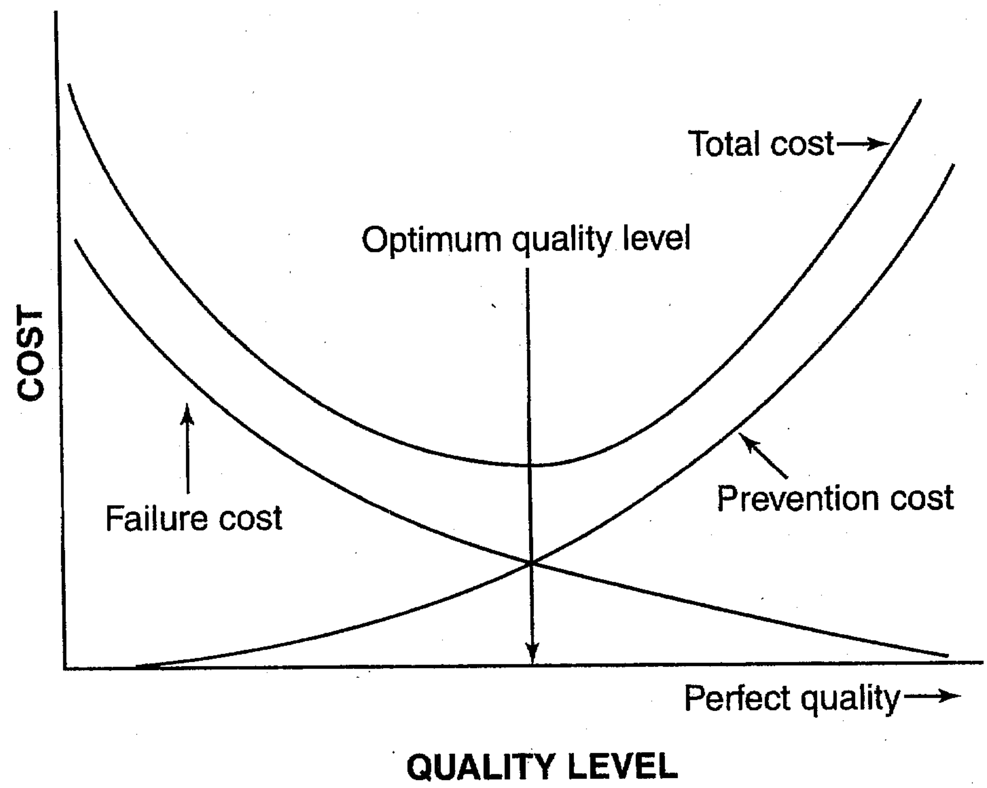

Figure 5. Classical model of "optimum quality level" (from *Juran's Quality Control Handbook, 4th ed.* J. M. Juran, editor; taken from Pyzdek, 1999, p.166).

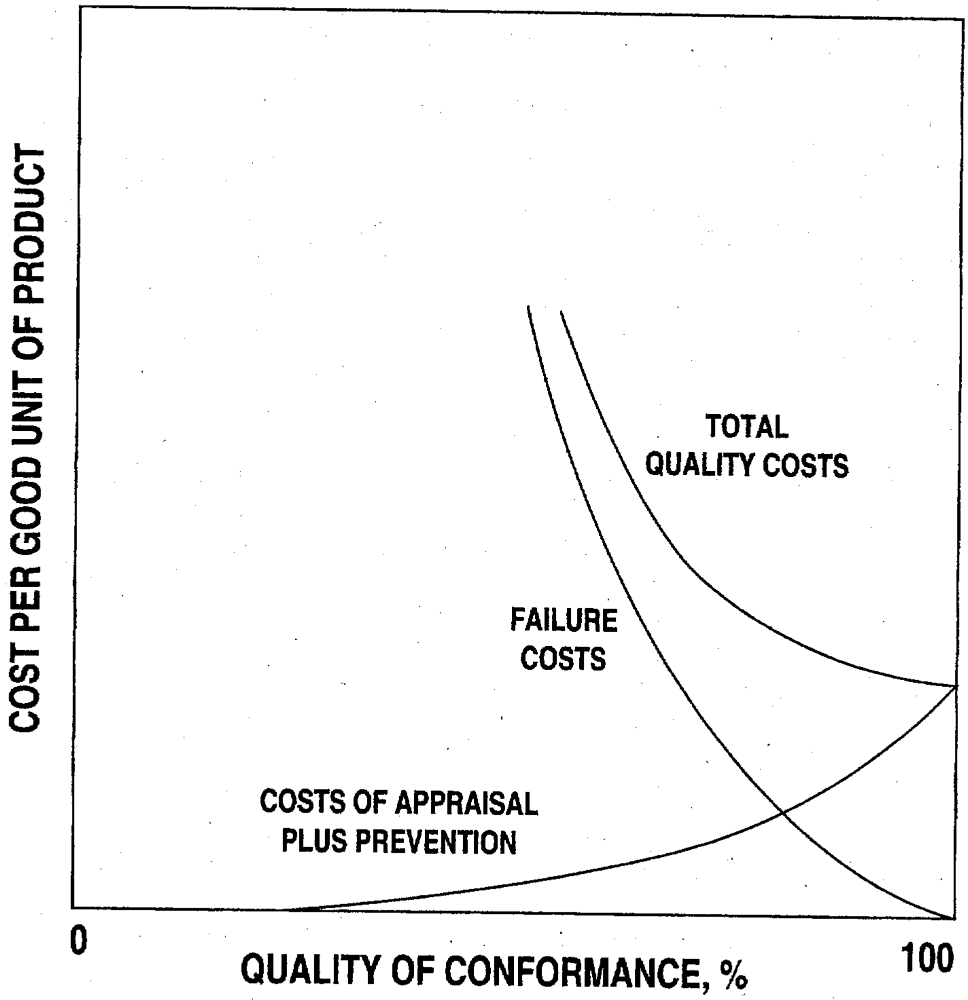

Figure 6. New model of "optimum quality level" (from *Juran's Quality Control Handbook, 4th ed.* J. M. Juran, editor; taken from Pyzdek, 1999, p.167).

Another point Pyzdek makes is the importance of catching nonconformances early in the whole production process. As the product moves closer and closer to completion and then, ultimately, into the hands of the customer, detecting defects and, more important, their cause, becomes harder. For example, if the cause of a defect is poor incoming materials, then this is where you want to detect it rather than, at the other extreme, when it is returned by a dissatisfied customer.

It is important to track all costs of quality even those difficult to quantify such as lost customer loyalty due to external failures. However, it is not necessary to have precise figures for all costs; intelligent estimates of costs due to lost customer loyalty, for example, will suffice for seeing trends. Appendix E shows an example of a form for tracking costs of quality.

Hidden factories One of the reasons many internal failure costs are not recognized is the "hidden factory" that exists in many companies. These are costs usually unwittingly accrued by well meaning employees. For example Suzy, who works in Department B has just received a part from Jane who works in Department A. As Suzy attempts to use the part in an assembly she notices it is "not quite right" and returns it to Jane for rework. Jane then reworks the part and eventually returns it to Suzy for further processing. All this sounds innocent enough and, in fact, like a good thing: employees taking the initiative to make sure the product is right. The only problem is whatever caused the part to be "not quite right" will probably never be investigated and there will continue to be replays of this scenario with its waste of manpower and time.

Or, to take a more extreme example as given by Harry & Schroeder (2000), Mike manages an operation that makes starter field coils. The company rewards Mike for getting x number of field coils "out the door" to the starter assembly area. Accordingly Mike will do almost anything to meet his quota including extensive inspections and rework requiring excessive amounts of material and labor. There is little time available or, even, motivation for tracking down root causes of the nonconformances. That is, the company sees only the results in terms of output without realizing there is a great deal of hidden and wasteful activity behind those results.

Eliminating quality costs and hidden factories The answer is, of course, to make every part of the process as transparent as possible. This begins with a detailed description of the process and a meaningful measurement of its output — see the MAIC steps outlined in section 4 above. An important part of measuring a process's output is using the right metric. Most companies use a measure called yield based on the output of good product at a certain step in the production process. To use a simple example from Harry & Schroeder, suppose the two units have just been produced at some point; one is defect-free, the other has two defects. The yield would be 50 percent. Now two more units are produced. Once more one is defect free but the defective one contains eight defects. Again the yield is 50 percent meaning that step in the process is seemingly consistent in producing a constant yield. However, if we were to compute defects per unit (DPU), we would get a completely different picture: in the first case 2/2 = 1 DPU and, in the second case, 8/2 = 4 DPU. Now we are getting a much truer picture of the efficacy of the process since we are focusing on defects, not simply the number of good units.

To take another example, suppose out of 100 units there are five defects. Here the average DPU would be 5/100 = 0.05. According Harry & Schroeder (2000), a new metric, *throughput yield*, is a better way to assess the process. In this case the throughput yield would be (1-DPU) or 95 percent. The traditional yield could be anywhere from 99 percent (if all five defects were in a single unit) to 95 percent if they were spread out over five units. The point being, throughput yield gives a more realistic assessment of the process based on an average DPU.

Two other important metrics are *rolled throughput yield* and *normalized yield.* Rolled throughput yield is simply taking the product of all the throughput yields in the complete process. This metric is equivalent to the traditional metric of final yield based on all the individual yields in the complete process. Again, you are getting a more realistic measurement, however, since it is based on throughput yields which take the number of defects into account.

Normalized yield is the simply the average of the individual throughput yields of a process and is found by taking the x root of the rolled throughput yield where x equals the number of individual yields (steps in the process). For example, a rolled throughput yield of 36.8 for a ten step process would give a normalized yield of $(0.368)^{1/10}$ = 90.5 percent. From this it can be seen that anything that can be done to simplify the process by reducing the number of steps involved will substantially improve the rolled throughput yield and sigma value for the process.

A further refinement of seeing just how well your processes operate is to take into account "opportunities for defects" (OP). These might be the critical to quality (CTQ) characteristics discussed in section 4 above. Now we are able to think about our processes not only in terms of the number of defects at the unit level but in terms of the number of defects at the "opportunity" level. To illustrate this consider the example given in Breyfogle (1999, pp. 140–142). Here defects are categorized by character (A, B, C, etc.) and, for each type of defect, data was collected over time. Such data can be set up in spreadsheet form as follows:

type of defect by characteristic	defects D	units U	oppor-tunities OP	total opportunities TOP = U × OP	defects per unit DPU = D/U	defects per total oppor. DPO = D/TOP	defects per mil. oppor. DPMO = DPO × 1 m.
Type A	21	327	92	30,084	0.064	0.0007	698
Type B	10	350	85	29,750	0.029	0.0003	336
Type C	8	37	43	1,591	0.216	0.0050	5,028
Type D	68	743	50	37,150	0.092	0.0018	1,830
Type E	74	80	60	4,900	0.925	0.0154	15,417
Type F	20	928	28	25,984	0.022	0.0008	770
Totals:	201			129,359		0.0016	1,554

For example, Type A defect could have occurred 92 times as each unit was produced and Type B defect 85 times for each unit, etc. For Type A defect, since our sample consists of 327 units, there were 30,084 total opportunities for a defect and so forth for the other types of defects. The fifth number column tells us how many defects we have per unit. Finally we can calculate what is even more meaningful, defects per total opportunity and defects per million opportunities (DPMO). Using the DPMO we can further characterize each defect in terms of a sigma level and the entire process that way. For example the 698 DPMOs for Type A defect would translate to a sigma level of around 4.6 (fairly good) and for the process as a whole the 1,554 DPMOs translates to a sigma level of about 4.35.

Another nice thing about analyzing our defects this way is their DPMOs can be displayed on a Pareto chart to tell us which defects we should give the most attention to. A Pareto chart for our example would look like Figure 7. It is obvious that Type E defect should be the initial focus of our attention.

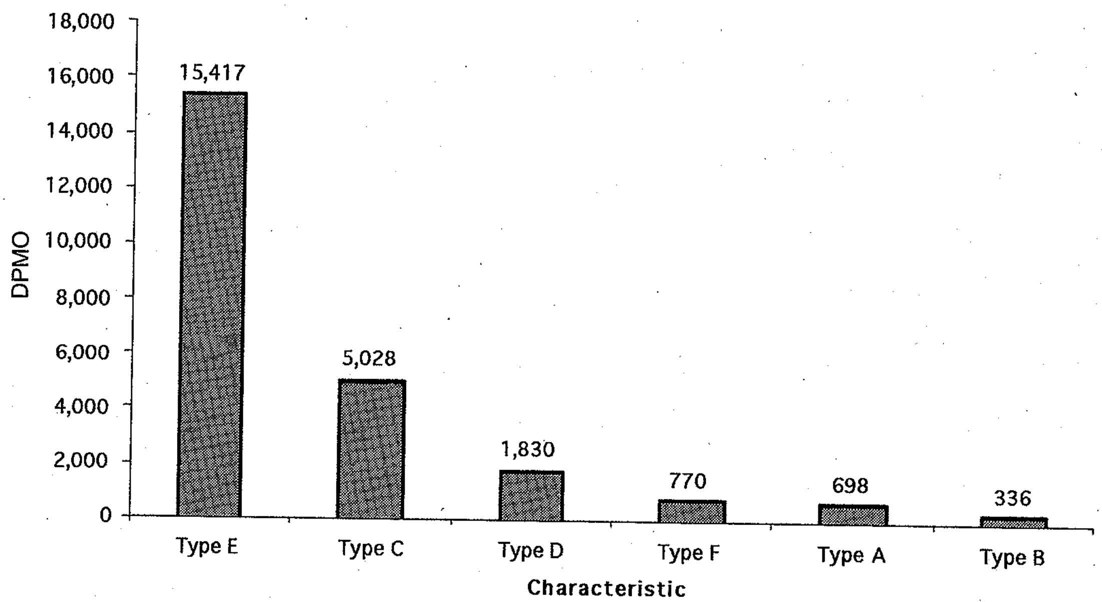

Figure 7. A Pareto chart showing defects per million opportunities (DPMO) by type (adopted from Breyfogle, 1999, p. 142).

In summary, with Six Sigma our goal is to fully reveal our processes in terms of the defects being produced and, ideally, to do this against the opportunities for defects; such opportunities being characteristics critical to customer satisfaction. By using metrics such as throughput yield versus the simple traditional yield, we are able to get that better picture of just how good our processes are. And, when we have factored in the opportunities for defects, we can also begin to see just how well our processes are truly doing from a DPMO and "Six Sigma" point of view. Of course striving to accurately measure the efficiency of our processes is important but so is developing a culture consistent with such measurements. Obviously this means we first must be sure everyone knows that our primary goal is not to just meet some arbitrary quota no matter the cost — remember Mike and the starter field coils? — but rather to seek to constantly improve our processes by measuring them with the right metrics and using the data obtained to ferret out the root causes of our defects. We will now take a look at a couple of examples of successful Six Sigma projects.

7. A Couple of Examples

Drawing once more on Harry & Schroeder (2000) let's see how Six Sigma techniques[9] proved very successful for a couple of companies: Polaroid, makers of the famous instant camera, and General Electric, specifically the General Electric Medical Systems division.

Polaroid The Polaroid example pertains to improving the exposure system on is biggest seller, the 600 Series camera. Previous quality improvement efforts had brought the sigma level of the exposure system to a 3.5 sigma. Having undertaken an extensive customer survey, Polaroid found having the film properly exposed was one of the most important CTQ characteristics. For the Polaroid camera this is especially true since there is no way to adjust over or under exposure once the picture is taken as with non-instant film that is developed later.

One of the things the Six Sigma team found was that by making it possible to adjust the internal exposure system in smaller increments, they could get better adjustments of the system and significantly increase the chances of the customer

9) These techniques, as trained by Harry & Schroeder, are known collectively as the "Breakthrough Strategy." Much of what has been discussed in this paper is based on this Breakthrough Strategy set of techniques.

getting a perfectly exposed picture. Another important result of this project was discovering that a lot of the problem of variability on the exposures was the test equipment used to make final adjustments to the exposure system. There were two ways this was causing problems: (1) the test equipment was not accurate enough and (2) there was no definite standard for test equipment across all the sites where the 600 Series camera was made. Armed with this knowledge, the team first improved the test equipment's accuracy and then made sure every assembly plant used exactly the same equipment in the same way. This improvement help Polaroid in two ways: it reduced the variability in the exposure systems (and, therefore, in the exposures themselves) and saved over $200,000 in annual operating expenses since employees no longer had to spend a lot of time making daily test equipment adjustments that were formerly required with the old equipment.

These efforts brought the sigma level up to a 5.0 sigma. In terms of DPMOs, they went from approximately 22,750 at the 3.5 level to only 233 at the 5.0 level; an improvement factor of almost 100! The ultimate effect of applying Six Sigma techniques to improving the 600 Series camera's exposure system was to increase customer satisfaction. In fact, Polaroid estimated that due to that improvement, they could expect an increase at least a $1,000,000 in annual sales for their division! Furthermore, employee morale increased since it was no longer necessary to make the time-consuming, manual adjustments to the test equipment. It was a win-win situation all the way around.

General Electric Medial Systems (GEMS) This case is interesting because GEMS already led the market in sales of computed axial tomography (CAT) scanners. However, worried about competitors known to be working on better scanners, GEMS undertook a major Six Sigma project in 1995 to radically improve the existing one. Two hundred engineers were organized into three Six Sigma teams and given the goal of completing the project by 1998. At the outset it was determined that two of the most important components that the Six Sigma project should focus on were "the tubes that focus the X rays and the detectors, which convert them into pictures." One of the problems with the tubes was their poor reliability. Having determined the CTQ characteristics for the tube through customer research, GEMS knew the customer wanted the tubes to provide twice the life presently possible; this would be a capability to function at least twelve hours a day for six months. Since the replacement cost for the current tubes was $59,000, it was understandable why longer life was desired. From the company's perspective, improving the tube quality was also a laudable goal since each year some $20 million in tubes were failing preshipment inspection.

In true Six Sigma fashion, the tube was completely taken apart and every step in its fabrication process analyzed. One of the problems was that the insulating oil used inside the tube was breaking down, significantly reducing the tube's life span. Using Six Sigma methods, it was ultimately determined that this breakdown was due to the type of paint that coated the inside of the tube; it caused a chemical reaction which, in turn, was responsible for the oil's breakdown. By using a different kind of paint, the "oil breakdown" problem was solved.

A second major problem associated with these tubes was their inability to hold a perfect vacuum. Even a very, very small amount of air could adversely affect the imaging process. Again, methodically applying Six Sigma techniques, three things were found to contribute to this problem: oxidization of the metal connector through which current flowed into the tube, the gas used in the fabricating process, and the process used to anneal the tube's glass. By preoxidizing the connector, changing the type of gas used in fabrication, and changing the annealing process, the Six Sigma team was able to significantly improve the life of the scanner tubes and cut the preshipment scrap rate by 40 percent. While the new tubes would cost more ($85,000), their warranted life was increased to one-year, a full six month more than asked for by the customer.

Another problem with the current scanner was readings that weren't precise enough for conclusive diagnoses. One solution to this would have been to redesign the tube so it would target smaller areas of the body. However, this solution would entail a major effort and prevent completion of the project by the 1998 deadline. Faced with this dilemma, the team working on this problem found they could get the same result — more accurate readings — by simply increasing the width of some tungsten wires used in the detector. In effect, this widening of the wires compensated for "tiny inaccuracies in the beam's trajectory." This is a good example of how the "systems" thinking inherent in the Six Sigma methodology can bring about surprising novel solutions — in this case, variation in the tube's performance was accepted since there were other ways to accommodate that variation and still get the results desired.

Another example of developing alternative solutions and then picking the best one was solving the problem of dissipating the excessive amount of heat the scanner generated. It was initially thought to use a $100,000 resistor but further experimentation revealed the same results could be obtained with "changing a few inexpensive capacitors" and "redesigning how the wires were insulated."

As another example of this "consider all the alternatives" thinking, it was also found that reprogramming the scanner's software would accomplish the same thing as a physical redesign as far as compensating for energy emitted within the scanner that was causing shadows on the images.

The new scanner, dubbed LightSpeed, was ready for market by September, 1998 with these improvements:

- Able to do full-body scans in only 20 seconds whereas it had taken three minutes before.
- Able to dissipate the heat generated during scans better than competitors, thus requiring less time between scans for cooling down.
- Able to provide a significantly greater life span.

- And, in general, able to meet the CTQ characteristics demanded by the customer.

Although the new scanner cost more, customers were happy to pay this for the increases in performance, especially speed and reliability. And GEMS also "won" with its ability to increase margins not to mention the pride that must come from making a world-class product.

Conclusion

It should be apparent now that Six Sigma is more than just another passing "flavor of the month." After all if it is embraced so wholeheartedly by people like Jack Welch, there must be something to it. As already mentioned, there are two things that distinguish Six Sigma from other quality improvement programs: the careful selection of specific, "bottom-line" relevant projects (versus simply "improving everything") and the use of full-time, highly qualified personnel (Master Black Belts and Black Belts) to work these projects using a rigorous methodology. I suppose we could add a third distinguishing feature: the careful tracking of cost savings that accrue to the company due to these projects to validate the effort.

Six Sigma is not easy. It requires a true commitment of top management because a lot of resources must be dedicated to the program if it is to succeed. Furthermore, it should not be considered something we accomplish and then go on to another program. You never stop improving; both in terms of moving closer to a true six sigma level on projects already started and on undertaking new projects as Six Sigma resources become more available.

As a final comment, I think it is safe to say, Six Sigma is here to stay. In fact, it may be the answer to removing the somewhat nebulous feeling many people get when "TQM" is mentioned. Now we can say real TQM is Six Sigma!

Postscript

As the reader of this paper will note, I have relied on three books to help me better understand Six Sigma. These seem to be the main references available at this time (May 2000). I was somewhat disappointed in all three as a source of exactly what constitutes the Six Sigma methodology. The Harry & Schroeder book, although the best in terms of discussing this methodology directly, was not clear on a number of key points. For example, it was difficult to pin down just exactly what the duties of all the "Champions" were as they seemed to get confounded as I read about them in two different places in the book. Also, I didn't feel there was a very good description of the measure, analyze, improve, and control (MAIC) steps (and other steps) despite the many words devoted to them.

The Pyzdek book is more a compilation of general knowledge about how to manage a project, give instruction, and carry out various statistical and other quality measurements and experiments.

The Breyfogle book was even less directly related to the general Six Sigma methodology in that it is really just another compilation (like Pyzdek but more so) of statistical knowledge useful for quality projects. Breyfogle did breakup his book in terms of the four core steps (MAIC) so this, at least, is a help for those wondering what techniques would apply at what steps.

I guess I was looking for something more specific in terms of what should happen at each of the MAIC steps. In particular, I would have like to have seen a good case example that illustrated each step. Even the cases cited in Harry & Schroeder, such as described in section 7, seemed to shy away from getting into that kind of detail — detail that would have been most helpful for better understanding Six Sigma. Maybe this would be a good project for another book or article on Six Sigma.

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APPENDIX A—page 1 of 2

A Comparison of the Three Sigma and Six Sigma Quality Levels

(Source: Pyzdek, 2000a, tutorial handout)

3 Sigma

M_rley was dead: to begin with. T_ere is no doubt wh_tever ab_ut that. The register of his burial was signe_ by t_e clergyma_, the clerk, the undertaker, and the _hief mourner_ Scro_ge_signed it. And Scrooge_s name __s good upon `C_ange, for any_hing he _hose _o put his hand to.

Old Marley _as as dead _s_a door-_ail.

Mind! I don_t mea_ to say that I kn_w, of my own knowledge, w_at th_re is particul_rly dead ab_ut a do__-nail. I might h_ve been inclined, m_self, _o regard a coffin-nail as the deadest piece of ironmongery_ in the trade. But the wisdom of our a_c_stors is in the simile; an_ my unhal_owed hands shall not d_st_rb it, or the C_untry's _one f_r. Y_u will therefore perm_t me to repeat, empha__cally, th_t Marley was _s dead_a_ a door-nail.

Scrooge knew he was de_d_ Of course he did. How could it be otherwis_? __rooge and he were partners for I don't kn_w how many years. Scrooge w_s his sole executor, h_s s_le administr_to_, h_s sole assign, his sole resi_uary legatee, his sole fr_e_d, and s_le mourner._And even Scrooge was not so _readfully cu_ up by the sad event, bu_ that h_ was an excellent man _f business on the very day of __e funeral, and solemnised it with an undoubted bargain.

The men_ion of_Marley's funeral brings me back to the point_I started from. There is no doubt that Marley_ was dead. T_is must be distinctly understood, _r nothing _onderful can co_e of_th_ story I am going to _el_te. If _e were not perf_ctly convinced that Hamle_'s Father died _efore the p_ay began_ t_ere wo_ld be nothing mor_ remarkable in h__ tak_ng _ _t_oll at night, _n a_ easterly wind, upon his own ramparts, than ther_ wo_ld be in an_ other middle-aged gen_leman rashly turning out after dark in a breezy sp_t -- say_Saint P_ul's Church_ard for instance -- _iterally to astonish hi_ son's weak mind.

APPENDIX A (continued) — page 2 of 2

A Comparison of the Three Sigma and Six Sigma Quality Levels

(Source: Pyzdek, 2000a, tutorial handout)

6 Sigma

Marley was dead: to begin with. There is no doubt whatever about that. The register of his burial was signed by the clergyman, the clerk, the undertaker, and the chief mourner. Scrooge signed it. And Scrooge's name was good upon `Change, for anything he chose to put his hand to.

Old Marley was as dead as a door-nail.

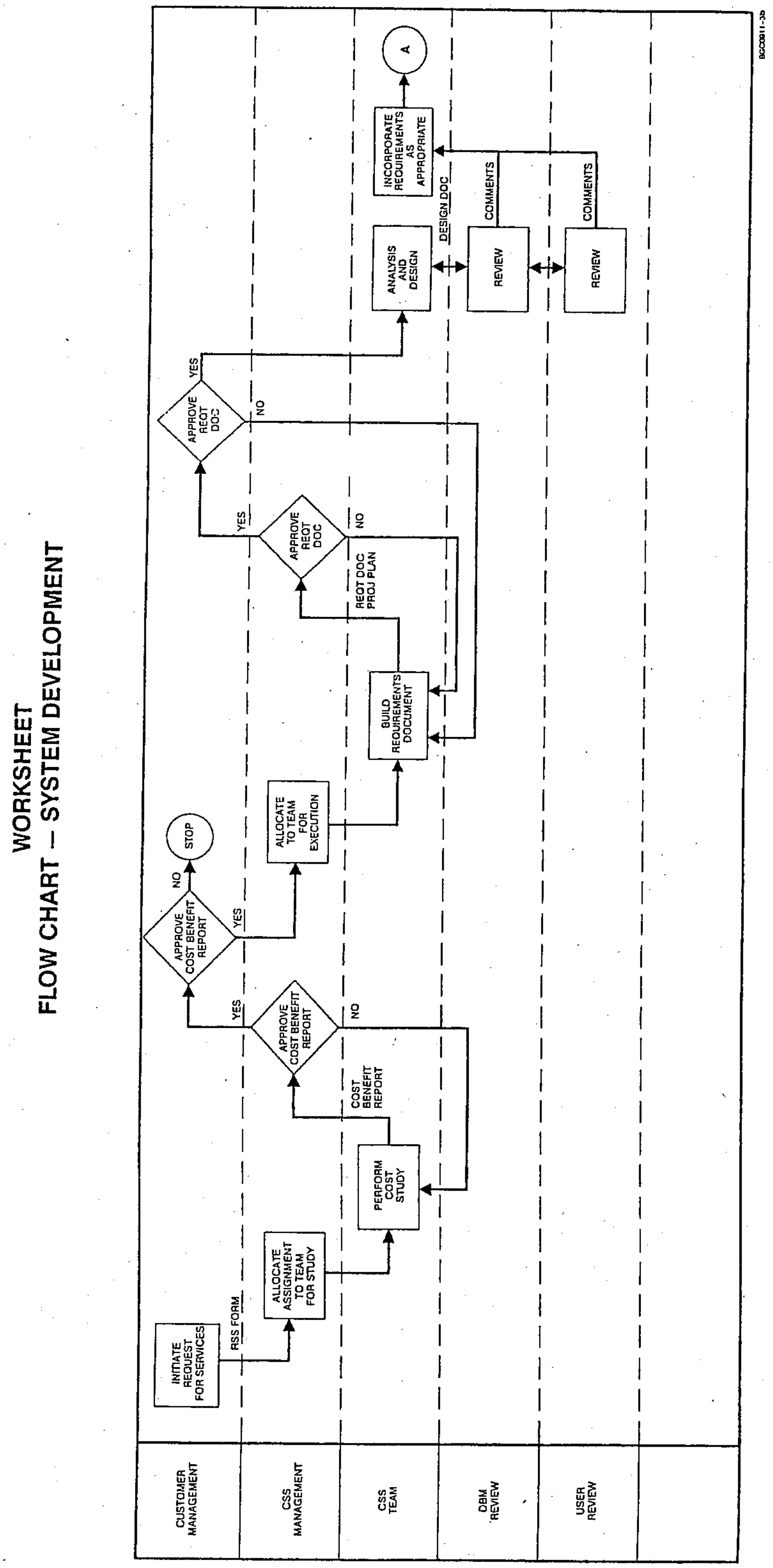
Mind! I don't mean to say that I know, of my own knowledge, what there is particularly dead about a door-nail. I might have been inclined, myself, to regard a coffin-nail as the deadest piece of ironmongery in the trade. But the wisdom of our ancestors is in the simile; and my unhallowed hands shall not disturb it, or the Country's done for. You will therefore permit me to repeat, emphatically, that Marley was as dead as a door-nail.

Scrooge knew he was dead? Of course he did. How could it be otherwise? Scrooge and he were partners for I don't know how many years. Scrooge was his sole executor, his sole administrator, his sole assign, his sole residuary legatee, his sole friend, and sole mourner. And even Scrooge was not so dreadfully cut up by the sad event, but that he was an excellent man of business on the very day of the funeral, and solemnised it with an undoubted bargain.

The mention of Marley's funeral brings me back to the point I started from. There is no doubt that Marley was dead. This must be distinctly understood, or nothing wonderful can come of the story I am going to relate. If we were not perfectly convinced that Hamlet's Father died before the play began, there would be nothing more remarkable in his taking a stroll at night, in an easterly wind, upon his own ramparts, than there would be in any other middle-aged gentleman rashly turning out after dark in a breezy spot -- say Saint Paul's Churchyard for instance -- literally to astonish his son's weak mind.

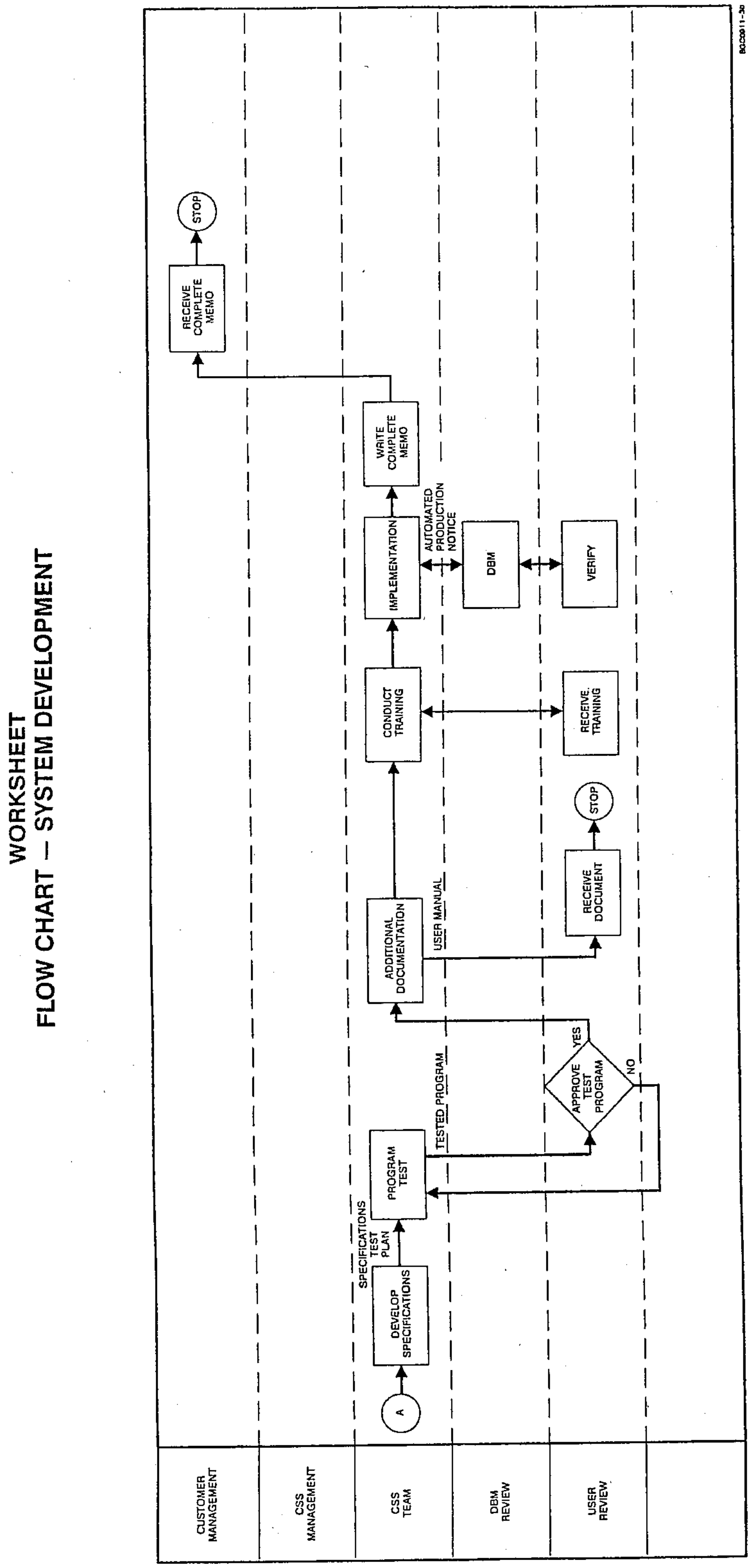
APPENDIX B — page 1 of 2

Process Flow Chart Example



APPENDIX B (continued)—page 2 of 2

Process Flow Chart Example



APPENDIX C

Black Belt Training Schedule*

(Source: Harry & Schroeder, 2000, p. 187)

***Harry & Schroeder refer to this as "A Six Sigma Deployment Schedule"**

A SIX SIGMA DEPLOYMENT SCHEDULE	
Week 1	Orientation and planning
Weeks 2 to 5	Champion training
Week 6	Champion review
Week 7	The first wave of Black Belts begins the first five-day training session and covers the Measure phase of the Breakthrough Strategy.
Weeks 8 to 10	Black Belts apply knowledge learned in the Measure phase training to their designated training projects.
Week 11	The first wave of Black Belts returns for the second five-day training session to review the Measure phase and learn the Analyze phase of the Breakthrough Strategy.
Weeks 12 to 14	Black Belts apply knowledge learned in the Analyze phase to their designated learning projects.
Week 15	The first wave of Black Belts returns for the third five-day training session to review the Analyze phase and learn the Improve phase of the Breakthrough Strategy.
Weeks 16 to 18	Black Belts apply knowledge learned in the Improve phase to their designated training projects.
Week 19	The first wave of Black Belts returns for the fourth, and final, five-day training session to review the Improve phase and learn the Control phase of the Breakthrough Strategy.
Weeks 20 to 22	Black Belts apply knowledge learned in the Control phase to their designated training projects.
Weeks 23 and 24	The first wave of Black Belts returns for a review of the Control phase and reviews the overall Breakthrough Strategy.
Weeks 22 to 24	A contingency plan is developed to identify and replace Black Belt trainees who can't successfully manage a Six Sigma project. Experience shows that fewer than 8 percent of those who participate in training do not succeed as Black Belts.

APPENDIX D

Black Belt Body of Knowledge

(Source: International Quality Federation [IQF] Home Page [www.iqfnet.org])

- Discrete Distributions
  - Poisson
  - Binomial
  - Hypergeometric
  - Geometric
- Continuous Distributions
  - Normal
  - Lognormal
  - Weibull
  - Exponential
- Multiple Regression
  - Significant Factors
  - Coefficient values
  - Identify co-linear factors
- Simple Regression
  - Coefficient Value
  - Confidence limits for coefficients
  - Correlation coefficient
  - Coefficient of determination
  - Confidence limits for y estimate
  - Identify a Non-linear model
- Measurement Assurance
  - Estimate bias
  - Determine significance for bias
  - Estimate linearity
  - Estimate repeatability
  - Estimate reproducibility
  - Estimate interaction between parts & appraiser
  - Estimate R&R
  - Determine significance for reproducibility
  - Determine significance for interaction
- Hypothesis Testing
  - Mean against constant - determine significance
  - Two means - determine significance
  - Two paired means - determine significance
  - Variance against constant - determine significance
  - Two variances - determine significance
  - Determine sample sizes
  - Determine beta risk
- Confidence Intervals
  - For mean
  - For variance or standard deviation
  - For proportions
- Process Capability
  - Compute C_p or C_{pk} - 1 & 2 side tolerances
  - Determine acceptable tolerance width given data & required C_{pk}
  - Cpk for skewed data
- Control Charts
  - Compute Limits for standard charts
  - Give autocorrelated data & ask when process went out of control
  - Give data by operator, shift, and batch & ask for major source of variation
- ANOVA
  - One way - given data ask for any item in ANOVA table
  - Multi-factor
    - significant variables
    - any ANOVA table entries
- Experimental Design
  - Given a set number of trials, determine the significant factors.
  - Given an experimental design, determine which factors are confounded
- Fundamental statistics
  - Given an equation - determine constant to make a valid density function
  - Given a distribution & parameters determine mean & std
  - Compute probabilities from independent variables, mutually exclusive variables, etc.
  - Compute mean, std, skewness, chi-square test
- Continuous Improvement Tools
- Finance
  - Compute IRR, PV or FV
- Project Management
- Reliability
  - stress-strength system
  - series parallel system
  - mtbf with confidence limits
- Simulation
  - Determine system specification from components using simulation

APPENDIX E

Example of a Form for Tracking Costs of Quality

(Source: Pyzdek, 1999, p. 176)

QUALITY COST SUMMARY REPORT
FOR THE MONTH ENDING ________
(In Thousands of U.S. Dollars)

DESCRIPTION	CURRENT MONTH			YEAR TO DATE		
	QUALITY COSTS	AS A PERCENT OF		QUALITY COSTS	AS A PERCENT OF	
		SALES	OTHER		SALES	OTHER
1.0 PREVENTION COSTS						
1.1 Marketing/Customer/User						
1.2 Product/Service/Design Development						
1.3 Purchasing Prevention Costs						
1.4 Operations Prevention Costs						
1.5 Quality Administration						
1.6 Other Prevention Costs						
TOTAL PREVENTION COSTS						
PREVENTION TARGETS						
2.0 APPRAISAL COSTS						
2.1 Purchasing Appraisal Costs						
2.2 Operations Appraisal Costs						
2.3 External Appraisal Costs						
2.4 Review Of Test And Inspection Data						
2.5 Misc. Quality Evaluations						
TOTAL APPRAISAL COSTS						
APPRAISAL TARGETS						
3.0 INTERNAL FAILURE COSTS						
3.1 Product/Service Design Failure Costs						
3.2 Purchasing Failure Costs						
3.3 Operations Failure Costs						
3.4 Other Internal Failure Costs						
4.0 EXTERNAL FAILURE COSTS						
TOTAL FAILURE COSTS						
FAILURE TARGETS						
TOTAL QUALITY COSTS						
TOTAL QUALITY TARGETS						

BASE DATA	CURRENT MONTH		YEAR TO DATE		FULL YEAR	
	BUDGET	ACTUAL	BUDGET	ACTUAL	BUDGET	ACTUAL
Net Sales						
Other Base (Specify)						