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Six sigma : changing a culture.

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SIX SIGMA: CHANGING A CULTURE

By

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BS Industrial Technology, 1989
Eastern Illinois University

A Thesis
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A Thesis Approved on

July 17, 2002

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ABSTRACT

Six Sigma: Changing a Culture

Lee E. Leathers

December 17, 2002

The objective of this thesis was to apply what was learned from Six Sigma while working for General Electric, towards real applications to improve processes. Two manufacturing problems were targeted. One of the issues dealt with variation, in an assembly process, which caused a large amount of missed opportunities. The other issue was based on defects caused by a reflector coating process that was creating haze and affecting lumens generated by the lamp.

While analyzing the missed opportunity issue, a DMAIC approach was followed, measuring the collected data and analyzing the variation and mean of the processes by the use of box plots, Cause and Effect analysis, Pareto Diagrams, and Statistical analysis. After analyzing the data, three improvements on the machine were implemented. After analyzing the haze issue, a DOE was conducted to prove what factor was causing the haze.

The missed opportunities were improved upon by implementing a preventative maintenance schedule and driving some "Quick Hit" projects for a total annualized savings of $140,000. The haze issue was proven, by a very simple 2X2 Design of Experiment, to be caused by the environment. By controlling the environmental conditions, the business was able to save $121,000 annualized.

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CHAPTER I

INTRODUCTION

<u>Background of the problem</u>

The concept of continuous improvement is common practice in most industry today.
It is even a required metric for the new ISO 9001:2000 quality standard. But what does
Continuous Improvement really mean? Simply put, as time goes by processes are
expected to improve. Time on the job, by itself, will make most people more efficient
because they become better trained. But can one be sure that the same person will be
doing the same job tomorrow? Maybe new equipment is the. Or maybe it is simply a
matter of streamlining the process that is in place. Perhaps even a different type of raw
material or new supplier would improve the process. These are all questions that quality
and process engineers, who deal with continuous improvement issues, face every day.
Some of these analysts have found the field of statistics to be quite helpful in analyzing
these types of issues. However, the statistics are a means, not the end. And what about
teamwork - aren't two heads better than one? What about the manager who has all of the
power and control to drive change, but is afraid to because he doesn't understand what his
engineer is talking about. How much better could an organization improve if everyone in
the company knew basic statistics and methods of process improvement? Many
businesses and industries want to improve their operations. They understand they need to
improve their processes. However, many find it difficult to package these ideas in a

logical way to communicate the discipline and rigor down through the organization and across an entire business. Six Sigma is a program that claims to provide a foundation for this type of goal.

Statement of the Problem

The basics of Six Sigma are nothing new to the field of Quality Engineering. It uses standard statistical tools to analyze data taken from existing processes. It uses a very methodical approach, not unlike many problem-solving models being taught in technical universities today. What is different about the Six Sigma initiative that other quality programs fail to include? Furthermore, how can some companies claim to make such a profit on this program while others write it off as a hype or fad?

Research Objectives

The objective of this thesis is to analyze what Six Sigma means, to investigate the impact Six Sigma has had on certain organizations, and to show some real-world case studies of Six Sigma methodology. Part of this thesis will be dedicated to some of the statistical and analysis tools that are use in Six Sigma Projects. The intent of this thesis is not to make an expert out of the reader. It briefly touches on some of the common tools used in Six Sigma projects and gives an overview of the philosophy of Six Sigma - what it means to different people. Six Sigma means many things. These differences will be identified and defined. This thesis will discuss some of the organizations and resources that are dedicated to educating others in the use of Six Sigma methodology. The Six Sigma drive toward quality improvement has affected many businesses. This thesis will review the bottom line - how much money has been saved by some companies through the use of Six Sigma methodology. Finally, this thesis will summarize with some

thoughts on why some companies may have failed. This thesis assumes a basic working knowledge of statistics on the reader's part. It is by no means conclusive of Six Sigma methods, practices, or theory.

CHAPTER II

SIX SIGMA EVOLVES

Six Sigma is all about proactive, logical thinking - backing decisions up with what we know rather than what we think. "Show me the data" is commonly heard in any facility that is motivated by a Six Sigma program. No true Six Sigma Black Belt would dare show up to present a theory without data to back up the proposed actions. And that is one of the characteristics that makes Six Sigma unique. It is not any special set of magical tools that mathematicians have developed to change industry. Six Sigma is many things, but most importantly it is a philosophy to process improvement. It is a philosophy of how things are done and controlled in an organization. Some people claim it to be a lot of hype. Some people claim it as the be-all-end-all. Actually it is neither. Six Sigma is simply a program that some business leaders, who understood both the power of Quality Engineering and business needs, developed by combining traditional statistical tools with a very structured basic problem-solving methodology. Six Sigma methods can be used to improve nearly anything, from golf games to business operating plans.

What is "Six Sigma"

Six Sigma is many things to many people. This paper will consider three ideas:

1) Six Sigma as a Metric.

2) Six Sigma as an Initiative.

3) Six Sigma as a Philosophy.

As a *Metric*, Six Sigma is a method of measuring the robustness of a process. Process improvement is a goal in many activities, but how does one measure the efficiency at which they are functioning? Take, for instance, the job of laying shingles for a roofing company. A task that is very common in laying shingles on a house is that of hammering a nail through a shingle and into the roof. When a carpentry apprentice begins with a roofing company, that person moves slowly and makes many mistakes because they do not have much experience. They have not yet programmed their brain to complete this task with the speed and dexterity that will make the process efficient. However, as more time is spent at this task, that person masters the basic roofing skills by executing the task repeatedly and by learning better methods as they watch other experienced roofers who have developed quick and easy methods to reduce error in their work. After several years, this roofing apprentice has improved the process of hammering nails considerably. Now, instead of successfully nailing about 7 nails for every 10 attempts, this carpenter is successfully nailing about 94 nails for every 100 attempts. This roofer has moved the process efficiency of hammering roofing nails from a 2 sigma process to over a 3 sigma process. If this now experienced roofer eventually becomes good enough to only make about 6 mistakes for every 1000 nails attempted, then the process was improved to 4 sigma. This example shows how we can measure any process in terms of sigma efficiency. It stands to reason, then, that the lower the defect (error) rate, the more efficient the process becomes and hence more robust.

> The Greek letter σ (sigma) is used in mathematical statistics to represent the standard deviation of a distribution. In mathematical statistics, letters symbolized in Greek are used to represent parameters, and their values are always unknown. So, the value of sigma is always unknown, but it is estimated by calculating the standard deviation from a representative sample. [4, p181]

A review of some basic statistical theory will show the relationship of Six Sigma and the example above. Population standard deviation (Figure 1) is usually a theoretical number because most items we analyze are not finite. In other words, if one is dealing with a population that is finite, there is probably no reason to analyze it because it is no longer functioning. In practical statistical analysis, we use samples of a population to generate sample standard deviations. Standard deviation is simply a method of measuring the variation within a process, around the mean. In Figure 1, the formula under the square root sign is variance. Standard deviation is the square root of variation.

In Figure 1 x_i = sample mean, μ = theoretical mean, and N = population size. The equivalent formula for a process that is not finite is shown in Figure 2.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \mu)^2}{N}}$$

Figure 1. Population Standard Deviation

$$s = \sqrt{\dfrac{\sum\limits_{i=1}^{n} (\bar{x}_i - x)^2}{n-1}}$$

Figure 2. Sample Standard Deviation

One key goal in process improvement is to minimize variation, so you can predict outcomes of events.   This is the relationship of standard deviation to process improvement - variation metrics.

So what does this mean? Figure 3 shows a normal distribution of a process and how a defect is associated with the curve. Figure 4 shows that as the sigma number
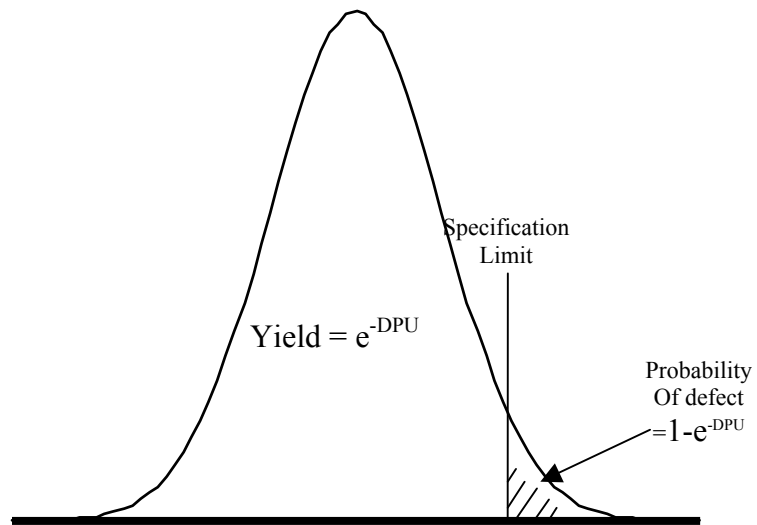
Figure 3. Normal Distribution, [3, p.139]

increases, the defect area to the right of the line gets smaller, hence the higher the sigma

the less likelihood of a defect.
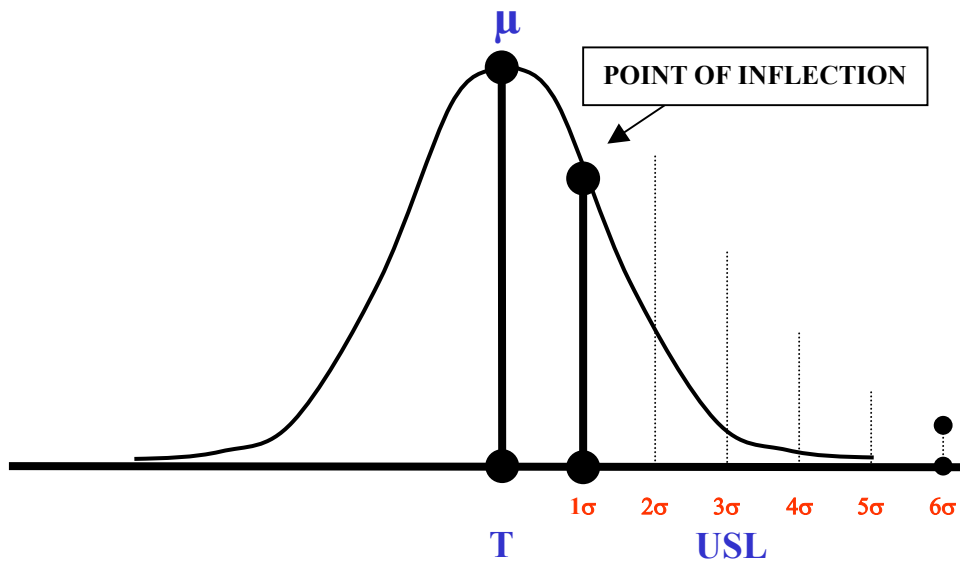
Figure 4. Sigma Relationship to a Normal Distribution

Table 1 shows the sigma value associated with the level of efficiency, measured in

Defective Parts per Million Opportunities (DPMO).

Table 1.

Defective Parts per Million Opportunity

σ	DPMO
	(Defective Parts per Million Opportunities)
2	308,537
3	66,807
4	6,210
5	233
6	3.4
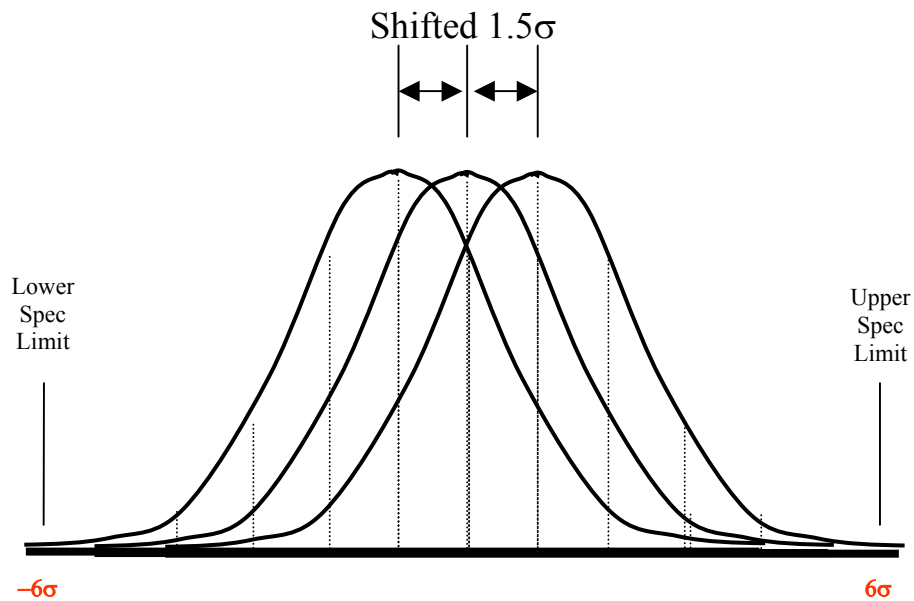
Figure 5. Effects of a 1.5σ shift where only 3.4 ppm fail to meet spec, [3, p.10]

Would the average person settle for a 95% confidence level that their airplane would not crash the next time they fly on a commercial airline? They probably would not, regardless of the price of the ticket. On the other hand, would that same person be

willing to take a chance that they would be that 1 of 20 people who buy a light bulb and it burns out at 500 hours instead of the advertised 1000 hours, if it meant that they could get the light bulb at $.50 instead of $2.00? There is generally a direct correlation between expected reliability, cost and consequences of failure. That 1 person out of 20 who buys the light bulb and it burns out early just buys a new light bulb. However, the person who gets on that 1 airplane that is going to crash, faces much greater consequences. From this example, it is easy to see why confidence intervals are so difficult to decide upon, because there is generally an added, up front cost associated with confidence intervals, as
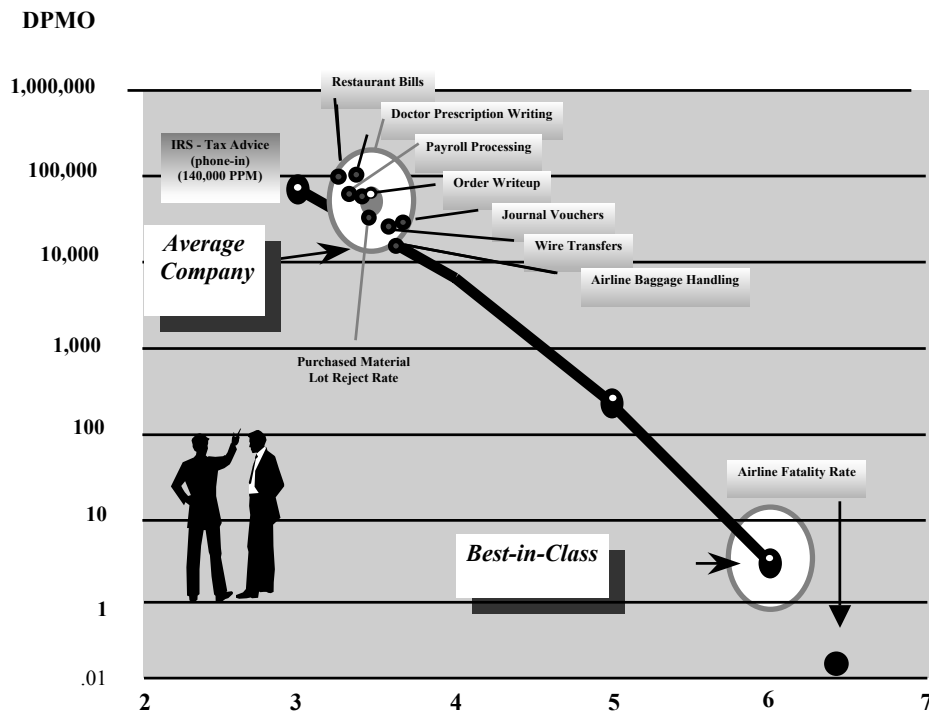
Figure 6. Sigma Rating per Industry, [27]

well as an added long-term cost. The aircraft industry is actually closer to seven sigma. In other words, the commercial aircraft industry has less than .43 fatalities per 1 million people who fly. They have to be that reliable because the average consumer would not fly and they would go out of business (not to mention the ethical issues). Certain

industries are not so demanding and therefore will probably never achieve Six Sigma because it doesn't justify the cost associated with improving it to Six Sigma. Figure 5 shows some common industries and their respective sigma levels. So would this mean that Six Sigma doesn't apply to these industries? For such industries, it may not be feasible to go for the metric of six sigma, however, the methodology can still be applied for continuous improvement and to improve as much as is financially, or ethically, practical.

As an *Initiative*, Six Sigma is a method in which a business will drive its continuous process improvement program, utilizing traditional analysis tools as the fundamental common language. Six Sigma does not necessarily require any new statistical analysis tools or methods. It generally uses traditional quality tools in a very methodical approach to achieve improvement. A unique characteristic about Six Sigma as an initiative is that it organizes people and their thoughts. It synchronizes employees, engineers, managers, and leaders to communicate with a standard method of accomplishing improvement. When a business decides to implement a "Six Sigma Program" or initiative, they are committing to their employees that they are going to focus on long term improvements. It must be led from the top down through the organization. Use of the "Six Sigma Tools" is enforced, but first the employees must be trained to use them. Hours are spent in meetings, training, experimenting, and in front of a computer analyzing data. Implementing a Six Sigma program into a business is "a cultural change" according to former CEO of GE, Jack Welch. The larger the business the more monumental the task becomes. According to Welch, "The training costs are astronomical. In

1997, GE will spend $400 million on training. But it is counting on $600 million in savings from Six Sigma improvements - for a net benefit of $200 million" [25 p.60]. The historical standard for most manufacturing has been somewhere around three or four sigma. In other words, every one million items produced generates between 6,000 - 60,000 defects. The variation is dependent upon the industry and there are exceptions. Six Sigma as a business initiative is no longer taken so literally as it began with Motorola, who eventually dropped their program as a failure because they could not achieve a point of only 3.4 DPMO.

As a *Philosophy*, Six Sigma does not focus on the metric but on the methodology. As a philosophy, Six Sigma is insisting that data drives decisions, almost to the point of being ridiculous. "Show the data" is a common phrase heard among Six Sigma "philosophers". There will always be a place for engineering intuition, but in a business that captures the Six Sigma philosophy, it should be the exception rather than the norm. Nearly all decisions are determined by what the data shows. It is not easy to gather data. However, Six Sigma philosophers always support, almost even insist, on data to drive their decisions. Even when discrete, objective data is not available, other methods like Brainstorming Sessions, Fishbone Diagrams, Cause-and-Effect Matrices, and Failure-Mode Effects Analyses are used to generate data with which to work. Six Sigma "philosophy" is simply using methodical means for achieving logical solutions to drive business decisions.

Motorola

Motorola introduced Six Sigma in the mid 1980s, as they were being severely impacted by Japanese competitors. Leaders within Motorola had concluded that the

quality of their products was very poor. A new initiative derived from Motorola's Communications Sector tracked performance by a sigma metric. Company CEO, Bob Galvin, initiated the "Six Sigma Quality Program" at the managerial and organizational levels, driving a zero-defects mentality through all facets of the organization - processes, products, services, and management. Galvin insisted on Total Customer Satisfaction (TCS) by improving on-time delivery, order completeness, order accuracy, and improved product quality. In return for this quality improvement, it was suggested that his business would receive a 5%-20% increase in business from many customers. The program was taken very seriously. The Motorola Corporate Policy Committee updated the company's quality goal to the following:

> Improve product and services quality ten times by 1989, and at least one hundred fold by 1991. Achieve Six Sigma capability by 1992. With a deep sense of urgency, spread dedication to quality to every facet of the corporation, and achieve a culture of continual improvement to assure Total Customer Satisfaction. …one ultimate goal: zero-defects - in everything we do. [4]

Motorola turned the business around with this new initiative. By 1988, Motorola won the first Malcolm Baldridge National Quality Award, presented by the US Congress for recognition of high quality standards in American Business. Along with their success came a newly invented concept, which was eventually accepted by GE and other businesses and has evolved into a comprehensive quality management system.

<div align="center">Honeywell/Allied Signal</div>

Allied Signal (now Honeywell) began their program in the early 1990s when their CEO realized the effect Motorola's program had on it's business. They applied the methods and tools to reducing cost of rework, but they also implemented the

methodology into design of their products. Designing quality into products is no new concept either, but Design For Six Sigma (DFSS) again forces methodical, data driven approaches to design.

<center>General Electric</center>

General Electric CEO, Jack Welch, drove the program through General Electric beginning in the mid 1990s. He still considers Six Sigma as one of GE's greatest initiatives, one of which they are still improving and driving throughout all GE businesses. While Motorola began a Six Sigma initiative to save the business, GE was already prospering and had been for years. So why would GE take on an initiative like Six Sigma? It is all about change.

> Six Sigma has forever changed GE. Everyone - from the Six Sigma zealots emerging from their Black Belt tours, to the engineers, the auditors, and the scientists, to the senior leadership that will take this Company into the new millennium - is a true believer in Six Sigma, the way this Company now works." - GE Chairman John F. Welch. [5, p4]

GE took the model from Motorola and Allied Signal, and began learning, training, and enforcing use of the methodology within the company. Goals were set, such as being a Six Sigma Company within 5 years. Demands of leadership involvement were enforced - all leaders were to be trained in Six Sigma methodology. Furthermore, individual leader involvement would be a primary metric for annual reviews, salary actions, bonuses, stock options, and all other benefits. Even today, all salaried employees have to become Six Sigma Certified in accordance with the standards of the General Electric Six Sigma Certification Program. Without certification, individuals will not receive salary actions or positive annual reviews. There is no choice if a person wants to work at GE. This

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kind of "lunacy", as Welch put it, is exactly the kind of leadership required when taking on this initiative and expecting results. Results were achieved. GE Medical Systems (GEMS) used Six Sigma to help redesign their medical scanning technology and reduce the amount of time it takes to conduct full-body scans. Furthermore, GEMS has increased the expected life of their CT scanner x-ray tubes 10X, again through design improvement (Design For Six Sigma - DFSS). GE Lighting (GEL) has made numerous process improvements and improved service with their biggest customer, Walmart, by reducing customer issues by 98%. GE Power Systems (GEPS) mended relationships with their utility customers by using Six Sigma to develop a better understanding of their requirements. These are just a few examples within GE. General Electric's newest endeavor is to force it deeper into the organization. Within GE, Six Sigma has gone from a nearly separate, autonomous group to an organization that is blending more and more with the manufacturing, engineering, and sales teams. Black Belts are no longer looked at as these outside, individual, process optimization gurus. They are team members, blending in with the daily operations. Most of the business leaders, starting at the plant manager level, are past Black Belts or Master Black Belts.

Other Programs

Other companies that have implemented successful Six Sigma programs including Sony, Bombardier Transportation, Asea Brown Boveri, Lockheed Martin, and 3M. This list is by no means inclusive. As some of the aforementioned companies and others have started their programs, they claim to have achieved the monetary benefits in Table 2 within the first several months of implementation.

Table 2.

Initial Savings

Company	Savings	Duration
Allied Signal	$1.2 billion	2 years
General Electric	$1.1 billion	9 months
Polaroid	$100 million	1 year
Lockheed Martin	$10 million	9 months
Siebe PLC	$100 million	9 months
Crane's	$10 million	1 year

CHAPTER III

THE PROGRAM

Overview

As stated before, a Six Sigma initiative is a method in which companies drive continuous process improvement- setting up an infrastructure, training their teams on standard analysis tools, and driving a program of customer centricity, data analysis, and control plans throughout their business. A company that is serious will always begin with the highest-level manager. Six Sigma is an initiative that will not survive unless it is completely supported by the highest levels of management and driven down through the organization.

So the first step is training and buy-off from higher management. Companies will generally do this by sending their senior managers to some type of a retreat, or workout, ranging from days to weeks. During this time, they will learn the methodology and higher-level implementation of Six Sigma as it applies to business strategy. It will involve lots of team building, role-playing, and hypothetical discussion and analyses. The main purpose is to ensure that everyone who is going to be driving this program through the business understands the capabilities and believes in the potential results for the business. Then those leaders will actually learn the basic tools and execute simulated projects, or case studies. It is not critical, although helpful, for the higher-level managers to understand all of the tools. It is critical, however, for them to understand what the

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capabilities and limitations are.

The second step is to train the full-time Black Belt team, Black Belts and Master Black Belts. This is also usually done by a professional consultant. There are several consulting companies that specialize in Six Sigma training at all levels. The list below is by no means inclusive.

Organization	Web Site
The Six Sigma Academy	www.6-sigma.com
Advanced Systems Consultants	www.mpcps.com
Six Sigma Qualtec	www.sixsigmaqualtec.com

Once the higher-level managers and Six Sigma team are trained, a company should have enough knowledge to start training their personnel internally. Consulting fees are quite expensive. Some businesses even try to lure formally trained Black Belts and Master Black Belts away from their companies to start new programs. The greatest risk in doing this is credibility. Companies need to be sure they are getting quality training in order for the program to be successful. Consulting firms are beneficial initially, until a company just starting out builds a foundation of knowledgeable leaders. However, eventually as the company grows it is more beneficial to train from within the company. One technique is to graduate into an internal training program. Train the upper-level management first through formal means. Then, send the Black Belt team to formal training. While the Black Belt team is at their training, the upper-level managers can be looking at their independent areas for opportunities. When the Black Belt team returns, they can immediately begin projects. Project team members do not necessarily all have to be formally trained up front, however it is a good long-term goal. Leaders who

understand Six Sigma methodology should be leading project teams. As the projects begin to take shape and the pace slows down for the Black Belts, then the company can gradually begin to train their mid-level key leaders and engineers through an internal training program, which should be led by the Black Belt team. The key is to get as many people trained in the tools as possible. The internal training can be tailored to the business needs. It does not have to be as long and drawn out as the consulting training.

The initial investment in consulting fees and training time required of key leaders is often enough to discourage businesses from initiation of a Six Sigma Program. Some businesses have succeeded and some have failed. If a company wishes to make the program a success, it requires total commitment, some risk, and quite a bit of up front money for training.

<div align="center">Infrastructure</div>

Six Sigma teams have several levels of responsibility. Some companies choose to keep their Six Sigma Black Belt team as a separate organization while others want the Black Belt team integrated into the organizational teams, ie Manufacturing, Sales, IT, etc. No matter what method is used, there are certain positions that must be present in order to have a successful program.

A *Six Sigma Champion* is usually assigned as a part-time additional duty to the top performing business leaders. Champions will mentor those who guide the projects, in relation to the business strategy. They mentor the entire team of Master Black Belts, Black Belts, and Green Belts and guide them so that the Six Sigma projects will stay focused on the needs of the customer and/or business. Champions also drive the overall Six Sigma program and commitment throughout the business at higher echelons. They

also resource the program, at all levels. They communicate in business terms what impact Six Sigma is having and they coordinate project report-outs to higher-level management. They must be trained on the basic tools and understand the methodology, but a Six Sigma Champion's true mission is to drive the program throughout the business - change the culture. Therefore, a Champion must fully understand and believe the philosophy. "Champions... successfully organize and effectively lead the deployment of Six Sigma across a large organization." [2, p.24.4]

Master Black Belts (MBBs) are full-time Six Sigma "experts" who are responsible for implementing Six Sigma methodology at the site level. They act as the liaison between the site team and the Champions, helping to resource the teams and knock down any roadblocks that are preventing project execution. They are usually highly involved with ensuring the team members are properly trained and certified. They mentor and guide Black Belts, enforcing good communication with site managers. MBBs coordinate for periodic site reviews with the Champions. They will often manage more than one site and oversee many Black Belts. They personally mentor Black Belts on their projects, both in the project management role and at the technical level. They are accountable to the Champions for achieving annual goals. Often, MBBs are past Black Belts. Although it is not required, this technique helps the MBB understand what a Black Belt is facing during project completion.

Black Belts (BBs) are the highest level at which projects are executed. They manage large-scale projects that are generally made up of many smaller projects. They coordinate and administrate all team activities, assigning tasks to team members. Black Belts track the team's goals, progress and benefits. They are the project executors and

internal site trainers. They are generally made up of a company's top-performing salaried employees. They are leaders. Black Belts generally have no command authority like other managers, so they have to lead through influence. This difficult task is just one reason a company should insist on the "crème-de-la-crème". If a company invests money in only one area, this is the place they should do it. They are by far the closest team members to the improvement projects and are the ones who are going to drive them to completion. A Black Belt understands business metrics and sees the "big picture". They must be well versed in the tools but they must never become tunnel-focused. It is critical that all Black Belts do not let boundaries get in their way, always thinking "outside of the box". Black Belts are the main driving force that ultimately determines whether or not projects are completed on time and on budget.

Green Belts (GBs) are formally trained employees who work as project team members, or leaders, while maintaining their normal duties ie. engineers, managers, supervisors, etc. Green Belts can be hourly or salaried. They usually take on projects of a smaller nature, both in scope and benefit. A robust Six Sigma program will organize their teams so that Green Belts are supporting projects that Black Belts are working on in the same area/department. This encourages synergies between GBs and their BB Mentors. The Black Belts will manage the larger, umbrella projects and the Green Belts will tackle smaller targets that fall under the umbrella projects. Green Belts are also accountable for their own project completion and annual benefit accomplishments. They are generally mentored by whatever Black Belt is supervising the umbrella project under which their project aligns.

Yellow Belts (YBs), also called *Associates*, are employees who have not been

formally trained on all of the Six Sigma tools, yet they have a working knowledge of the Six Sigma methods and tools. They have probably received a modified version of Green Belt training. They usually are not leading a project themselves (unless very limited scope), but at the same time they are key team members with the technical expertise that is critical to successful completion of a project. They are generally matched to projects inherent to their work areas.   Associate positions are critical to Black Belts and Green Belts during project execution.

<u>Project Identification, Organization and Execution</u>

The *Six Sigma Methodology* is nothing new to most technically trained people. It is simply a very methodical, organized, team approach at solving problems and improving processes. It follows a **D**efine, **M**easure, **A**nalyze, **I**mprove, **C**ontrol format. Prior to beginning the **DMAIC** process, projects must first be identified and assigned.

At the end of each fiscal year, site managers begin planning for the following fiscal year business plan. This Operating Plan (OP) includes expected opportunities in process improvements, to include Six Sigma. A Six Sigma project will formally be approved or disapproved by a Champion, MBB, and site manager. Ideas for projects are conceived by anyone, from business CEOs to subcontractors. No matter who comes up with the idea for a project, it must be carefully analyzed and determined whether or not it is going to be beneficial. Leaders must determine timeliness, cost, savings, resources required, benefit to the customer, and any other facet inherent to the project scope. Site managers usually formulate Six Sigma benefits into their normal Operating Plan. Champions and MBBs will formally analyze most projects to ensure that they are meeting the customer needs and that they offer some sort of benefit to the organization. The benefit is generally

monetary, however, sometimes project benefits are measured by non-quantitative means. For example, a project could be focused on fixing a process that will improve machine speed by 3 indexes per hour (definite monetary benefit) or it could be to improve the facility's safety training program (no underline direct monetary benefit to the facility but possible long term cost savings to the company). Regardless, the need for a project is identified usually through normal business analysis procedures ie. a department is missing on-time-delivery, or a particular machine group is only achieving 75% yields. These issues are usually formally brainstormed at the site level during some annual review (minimum) that involves the MBB, site managers/leaders, all BBs, GBs, and maybe select YBs. The key projects (usually the greatest or quickest benefits) are prioritized and assigned to Black Belts. These key projects will have smaller level projects that support them, which will usually be assigned to a Green Belt or maybe even an Associate. Any smaller scope projects that have not been covered will be assigned to Green Belts. This process will usually take place in the third or fourth fiscal quarter to ensure communication to all participants prior to fiscal year end. Once the annual project/benefit plan has been established, key leaders will review it with their respective departments and teams will be formed.

The first step of project execution is to *Define the Problem.* Usually not considered a time consuming portion of the project, here you are simply defining exactly what is going to be addressed, or improved upon, from a very high level and referred to as the "Big Y" (this term derived from an xy plot where "y" is the desired result). The mistake that most new project leaders make is they execute this process too quickly because they are anxious to start measuring data. Data collection is important, however, it is critical that

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the scope of a project is very clearly defined in order to optimize the potential of the team. There are many people involved with making a Six Sigma project successful, and all of those people need to understand very clearly what the full scope of the problem is. A key first step in this process is identifying valuable team members. Deciding who will be the leaders, who will be critical team members, and who will simply be needed to support the project is critical. All of these people will meet for an initial brainstorming session to define the full scope of the problem. There may be more to the issue than what was initially thought. With the assistance of all team members, the end result should be to identify issues outlined in Table 3.

Table 3.

Define The Problem

Topic	Description
Team members	who is needed to make this project successful
Customer	who is the customer, both internal and external
Macro statement of the problem	10,000 foot level
Micro statement of the problem	details, details, details
Critical To Quality (CTQ)	metrics on which you are trying to improve
Output	defects or characteristics which need focus, to improve CTQs
Inputs	what factors may impact the CTQs
Data type	what types of data will be needed
Data source	how/where will the data be collected
Time	estimated time to complete project, beginning to end
Projected benefits	expected end result of this project (be conservative)
Customer expectation	what is the customer expecting from this project
Risks	things that could affect how well the project is executed
Translation	has this or something similar already been done and/or could someone use this after I am finished

During the *Measurement* phase, the Six Sigma team gathers data. Some forms are in a simple manual data collection sheet like the one in figure 4 below, while others are much more sophisticated and usually involve some form of computer software package such as Cimplicity or Oracle, just to name a few.

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Table 4.

Sample Data Collection Sheet

<div align="center">

DATE: _____

Downtime Codes

Code	Reason	Code	Reason
1	Accumulator Full	11	Pick and Place
2	Bulb Conveyor & Transfer	12	Reflector Conveyor/ Transfer
3	Cementers	13	Sensors/ Electronics/ Series Six
4	Changeover Setup	14	Six Sigma/Engineer Test
5	Electrical Wiring	15	STA 10 & STA 23 Errors
6	Heads	16	STA 7 Rejects & STA 8 Nest
7	Heat Lamps	17	Startup/ Shutdow n
8	Miscellaneous (All Others)	18	Unload Transfer
9	Nest Opener	19	Vision/ Zenith/ Align
10	Overhead Units and Neat	20	Wire Lamp Feed

</div>

Downtime			Reason (use above codes)	Remarks
Start Time	End Time	Minutes		

Regardless of the method of data gathering, the user must ensure the data is as accurate as possible. This data is what will eventually be used to analyze the troubled area and formulate a solution to improve the process. So this is a critical part of any project. If something is found to be questionable, the data collection systems should be tested formally for accuracy. This is done by creating data sets and running them through the data collection system and then reviewing it to see if it generates the expected results. This is called a Gauge R&R and is one of the tools that will be reviewed in a later chapter. Once the data collection system is validated, it is safe to begin data collection, however, throughout the entire project the accuracy of data should constantly be scrutinized.

Analysis of the Data is where the real statistical work will be done and where most of the mistakes in projects are made. The key to data analysis is not just knowing how to use the statistical analysis tools, but when to use them. A technique for becoming proficient at this tool usage is to read books and reference them often. Some businesses develop "road maps" for tool usage. The references outlined at the end of this thesis are a good start, but by no means inclusive. Once the analysis is complete, it is sometimes desireable to have another person review the data and analysis. This can foster new ideas. Other than the final review, where the analyst may want a second opinion, analysis can pretty much be done alone. The analysis tools are already established (and have been for years). If the analyst does not know the tools, though, this process can lead to complete failure in the project. Some analysis tools are touched on in Chapter IV of this thesis. If correctly analyzed, the data analysis will generally point the team in the right direction to improvement.

Once again, it is time to get the team together to figure out how to *Improve* the process, based on the analysis results. This is where the term "out-of-the-box" thinking is key. The question must always be asked, "what is the bottom line?" The bottom line may be to reduce cost, maintain the best quality, or simply to do what is right. Companies keep customers by delivering quality products to them on time and at a reasonable price. But that's not it. All of this can be done and a company can still go out of business. Businesses have to turn enough profit to cover costs and generate revenue. If they aren't doing that, then they won't be in business for long. So the team must constantly be thinking creatively how to improve the process, based on whatever the data is pointing them to, and ultimately saving the company money. If the process is

improved but it costs more than the savings can justify, then that company will not be in business for long. The recommended approach for improvement is brainstorming. Get as many different types of people in a room and show them the data analysis. One should not underestimate the value an hourly operator can add during brainstorming sessions, to help resolve major process issues. The meeting facilitator should hold back nothing, invite ideas from everyone, and encourage people to think outside of the box.

While improving a process takes a lot of creativity, *Controlling* a process is pretty straightforward. There are two primary factors to process control - effective control systems (ie Manufacturing Control Plans, Manufacturing Process Instructions, Statistical Process Control, etc) and discipline. Some of the aforementioned controls will be defined in a later chapter. Control systems should be consolidated within the Quality Assurance department and should become part of the overall quality system for the facility. Control systems can be very simple to very complex. Many control systems today integrate complicated computer management systems or computerized Statistical Process Control. Other control systems are on a clipboard and updated with a pen. Either way, the most important aspects are that they work (ie when properly used do they keep the process in control) and do the employees using them understand how to use them. If these two factors are in place, then the only other issue is are they actually being used to maintain control. This can be audited on a regular basis, even included in an ISO facility's internal audit program. Control is generally viewed as the most important portion (if there is such a thing) of the DMAIC process, because it will determine whether the improvement continues in the future. Unfortunately, it is the step that is most commonly overlooked. If not careful, a team can be so busy celebrating after they

have improved a process, they can completely forget about control, and within no time the process is back to the same poor standards as before the project began.

CHAPTER IV

TOOLS

<u>Define</u>

Brainstorming   is nothing more than a meeting of people who may have knowledge on a subject to be discussed. The purpose is to come up with ideas around the subject. Brainstorming can be used to solve problems, create fishbone diagrams, come up with ideas for solutions, etc. This tool is a very important part of any problem-solving technique. It should be used throughout a Six Sigma project to gather information and create new ideas. A facilitator should keep the meeting on track. Ground rules should be established in the beginning of the meeting to encourage "out of the box" thinking and to discourage personal attacks or negativity.

The *Process Map*, Fig is a method of flowcharting processes. It is a graphical tool that shows what the flow is of any procedure. Generated during the early stages of a Six Sigma project, effective Process Mapping can explain to anyone how the system works. All projects should construct Macro-level and Micro-level process maps to use throughout the project for reference, explanation and analysis.

SYMBOL	NAME	DESCRIPTION
→	Connector Line	Symbolizes flow and direction of the process
START	Terminator	Sybolizes the Start and End points of a process
PROCESS A	Activity	Symbolizes the Start and End points of a process
PASS?	Decision	Symbolizes a point at which a decision must be made

START → PROCESS A → PROCESS B → INSPECT → PASS? → END

NO
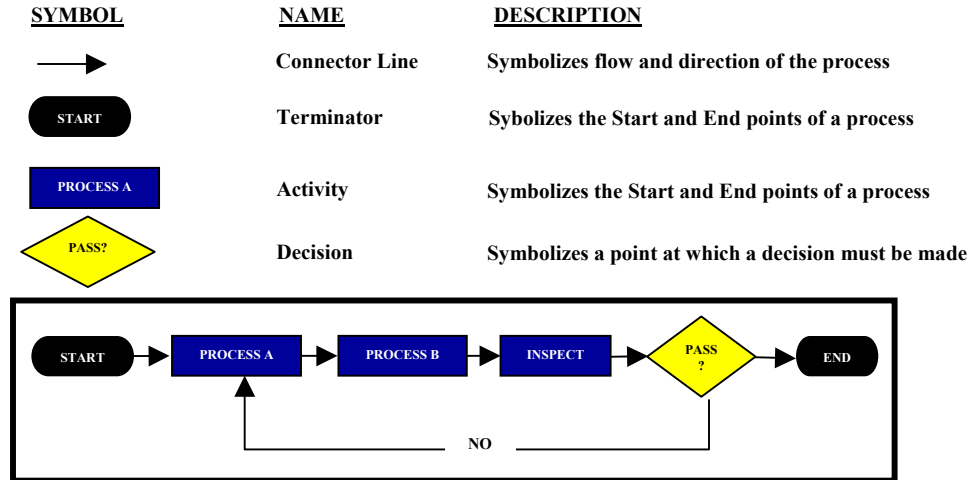
Figure 7. Process Map

Rolled Throughput Yield (RTY) focuses on a defect rate throughout a process rather than at the end of the process, and may be calculated by the formula in Figure 8.

$$RTY = Y_{RTP} = e^{-DPU}$$

Y=yield

RTP=Rolled Through Put

e^{-DPU}=probability of units with zero defects

Figure 8. Rolled Throughput Yield Formula, [3] p.137

If an organization focuses just on the end defect rate, it will lose site of all of the wasted effort throughout the process. RTY is a method of breaking down where different amounts are lost throughout a process. Rolled Throughput Yield can also be depicted graphically as in Figure 9.

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Figure 9. Rolled Throughput Yield

Measure

Gage Repeatability and Reproducibility (Gage R&R) is a method of evaluating

measuring systems and should be used throughout a Six Sigma project to check the

validity of measurements.

Gage repeatability and reproducibility studies determine how much of your
observed process variation is due to measurement system variation. Any time you
measure the results of a process you will see some variation. This variation comes
from two sources: one, there are always differences between parts made by any
process, and two, any method of taking measurements is imperfect—thus,
measuring the same part repeatedly does not result in identical measurements [30,
Gage R&R).

$$\sigma^2_{\text{error of measurement}} = \sigma^2_{\text{repeatability}} + \sigma^2_{\text{reproducibility}}$$

Figure 10. Gage Repeatability & Reproducibility
Gage R&R is used to measure both accuracy of measuring tools and the precision of the

people using the tools. Basically, a gage R&R is conducted by running samples of parts

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with known values through multiple tests and yielding results. It is critical that inspectors do not know what the correct measurements are until after the tests are completed. Gage R&R tests may be run without any inspectors even knowing it is being done, to eliminate the possibility of them changing their normal routine and potentially skewing results.

Process Capability/Performance Study is used in the initial phase of a Six Sigma project to baseline where the process is at that particular time and to determine the potential of the process.

Minitab has a function called Process Six Pack which is effective in conducting a quick Process Capability Analysis which will produce Xbar R charts for Mean and Range, Sub-group charts, Capability Histogram, Normal Probability Plot, and a Capability Plot all in one graph.
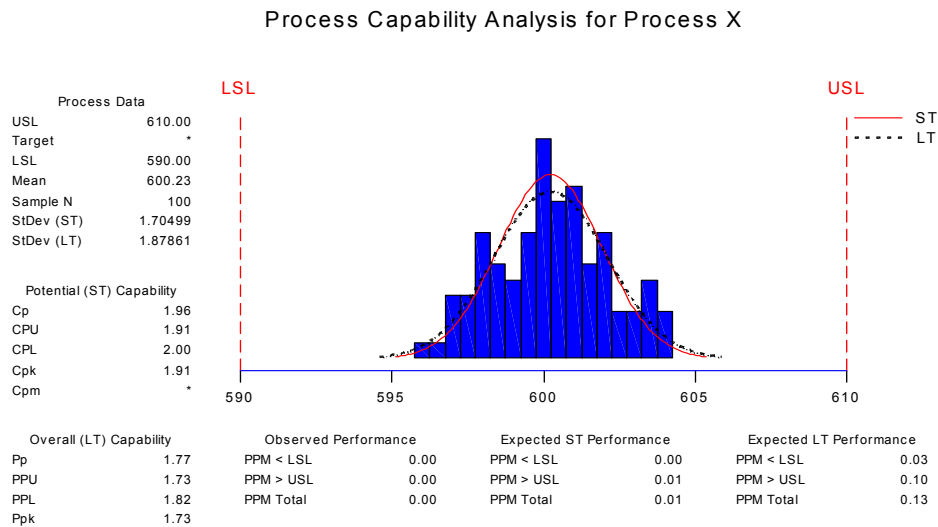
Figure 11. Process Capability from MINITAB

Process Capability Sixpack for C1

Xbar and R Chart

```
M    4.8 ─────────────────────────────────    3.0SL=4.949
E
A    4.2                                       =
N    3.6                                       X=4.000
S    3.0 ─────────────────────────────────    -3.0SL=3.051
    Subgr  1     2     3     4     5
```

```
R     6 ─────────────────────────────────     3.0SL=5.469
A
N     4                                        =
G                                              X=3.078
E     2
S     0 ─────────────────────────────────     -3.0SL=0.686
```

Last 5 Subgroups

```
V    6.5
A    5.0
L    3.5
U
E    2.0
S        1     2     3     4     5
           Subgroup Number
```

Potential (ST
StDev: 1
Cp: 0.33
Cpk: 0.33

Overall (LT)
StDev:
1.04514
Pp: 0.32
Ppk: 0.32

Capability Histogram

```
         2.0   4.5   7.0
```

Normal Prob Plot

```
         2.0   4.5   7.0
```

Capability Plot

```
      Process Tolerance
      ├────────┼────────┤   ST
      ┠────────┼────────┨   LT

              ├─┼─┤
              3   5
          Specifications
```
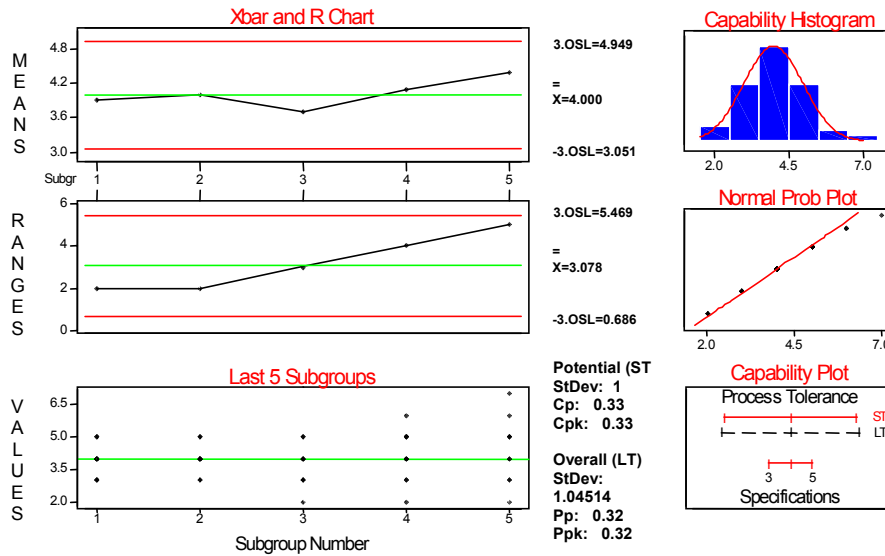
Figure 12. Process Capability Sixpack from MINITAB

The *Fishbone Diagram* (also called a Cause and Effect Diagram) is a tool used to identify input variables that impact the Key Process Output Variable (KPOV).   This technique can be used for any process. A fishbone diagram is a precursor to creating a Cause and Effect Matrix. The KPOV is recorded at the head end of the fishbone. The ribs depict six factors of discussion - Environment, Materials, Methods, Measurements, Machine, and Human factors. The purpose of the fishbone diagram is to get ideas onto paper. After the fishbone is completed, the person who called the meeting will take the diagram and organize it into a Cause and Effect Matrix, so it is not important to be organized or "final" while creating a Fishbone Diagram. The important thing is that all ideas are captured.

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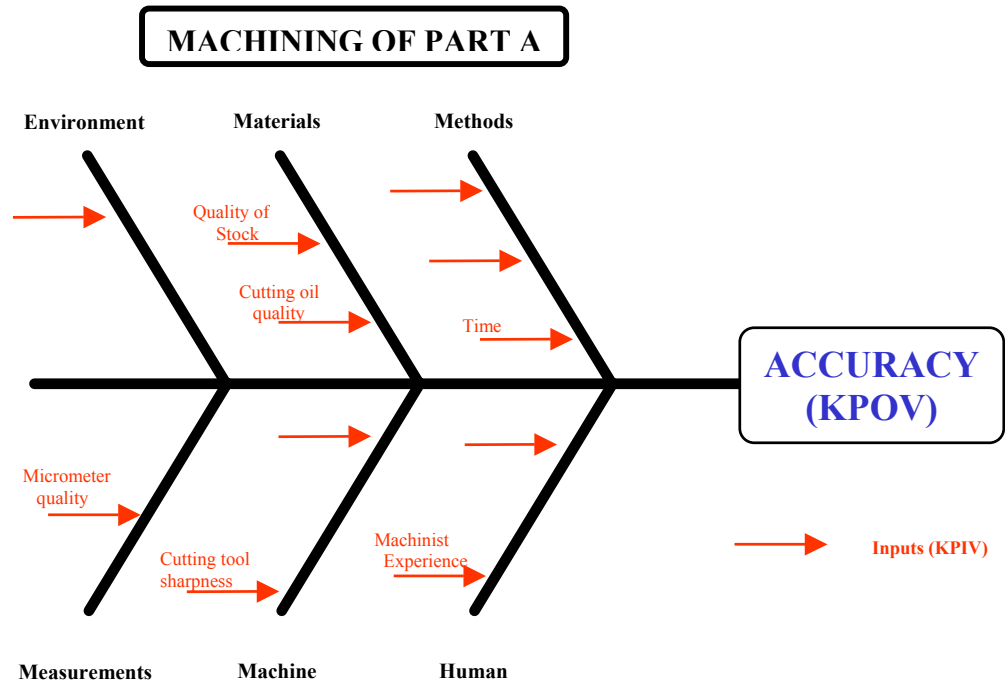
Figure 13. Fishbone Diagram

Analyze

The *Cause and Effect Matrix* is constructed after the Fishbone Diagram has been created. Input variables are assigned values in terms of what effect they will have on the Key Process Output Variable (KPOV). Again, team members who are especially close to the process and understand the impact of each input variable should assist in assigning these values. Output variables are also assigned values based on the impact they have on what is important to the customers' Critical to Quality (CTQ) requirements. The most important input variable that should be considered, as a general rule of thumb, is the highest number in the far right-hand column. This would be identified as a Key Process Input Variable (KPIV).

CAUSE AND EFFECT MATRIX Machining of Part A											
	OUTPUT VARIABLE AND VALUE (1-10) TO CUSTOMER CTQs										
	7	5	10	6							
INPUT VARIABLES/VALUE (1-10)	Accuracy	Appearance	Part Works	Hardness							TOTAL
sharpness of cutting tools	10	0	8	0	0	0	0	0	0	0	150
stock material quality	6	7	3	8	0	0	0	0	0	0	155
machinist experience	8	3	7	0	0	0	0	0	0	0	141
time	3	0	3	0	0	0	0	0	0	0	51
air moisture content	0	8	0	0	0	0	0	0	0	0	40
cutting oil quality	6	5	5	0	0	0	0	0	0	0	117
micrometer quality	5	0	8	0	0	0	0	0	0	0	115
post machine heat time	0	5	0	10	0	0	0	0	0	0	85
	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0

Key Process Input Variables (KPIVs)

Figure 14. Cause and Effect Matrix

The *Pareto Diagram* is an analysis tool that is used to sort sets of data from "highest" to "lowest" values. It is a tool that can be used to measure counts of defects. This is very important when deciding where resources should be focused. Excel and Minitab software are capable of generating Pareto diagrams. This tool can be used at the beginning stage of a project to baseline the process as well as throughout the project to monitor progress, or effects of the improvements.
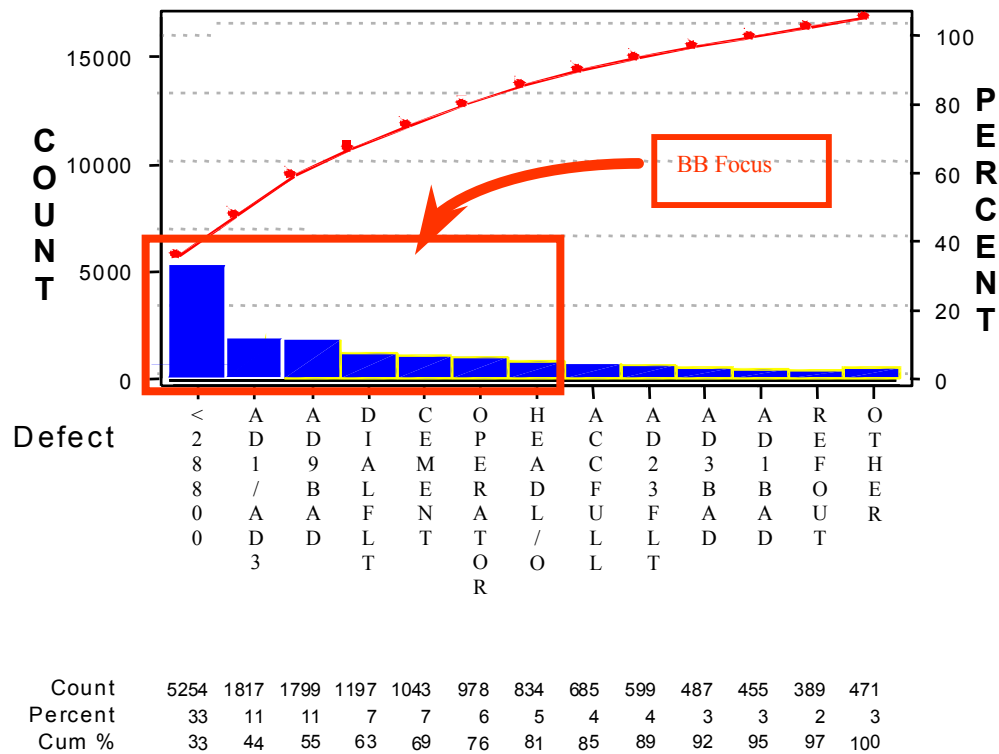
Figure 15. Pareto Diagram from MINITAB

Failure Mode Effects Analysis is a technique used to identify where a process can fail and therefore fosters process improvement. Again, the use of brainstorming with a good technical team is critical. Experienced and knowledgeable team members are also critical in developing FMEAs. The team works through the process map, step-by-step to determine where the process can fail, and then identifies what actions can be taken to prevent those failures. The form in figure 16 is filled out while working through this procedure. FMEA is a very effective tool that can be used for process or design.

FMEA Type (Design or Process):	Project Name:											Original Date:				
Responsibility:												Revised Date:				
Team Members:																
Design FMEA (Item/ Function) Process FMEA (Function/ Requirements)	Potential Failure Mode	Potential Effect(s) of Failure	S e v	C l a s s	Potential Cause(s)/ Mechanism(s) of Failure	O c c u r	Current Controls	D e t e c	R P N	Recommended Actions	Responsibility & Target Completion Date	Actions Taken	S e v	O c c u r	D e t e c	R P N

Figure 16. Failure Mode Effects Analysis

Benefits of a properly executed FMEA include [3, p256]:

- Improved product functionality and robustness

- Reduced warranty costs

- Reduced day-to-day manufacturing problems

- Improved safety of products and implementation processes

- Reduced business process problems

Regression Analysis is method of determining the statistical relationship between a response variable (output) and its predictors (inputs) ie. $Y = f(x)$. The objective of a regression analysis is to yield an accurate regression function, which is representative of the process being analyzed. The difference between regression and simple correlation is that regression can be used to develop relationships that help with predicting results.

Regression Plot

Y = 2.59740 + 0.188312X
R-Sq = 80.3 %
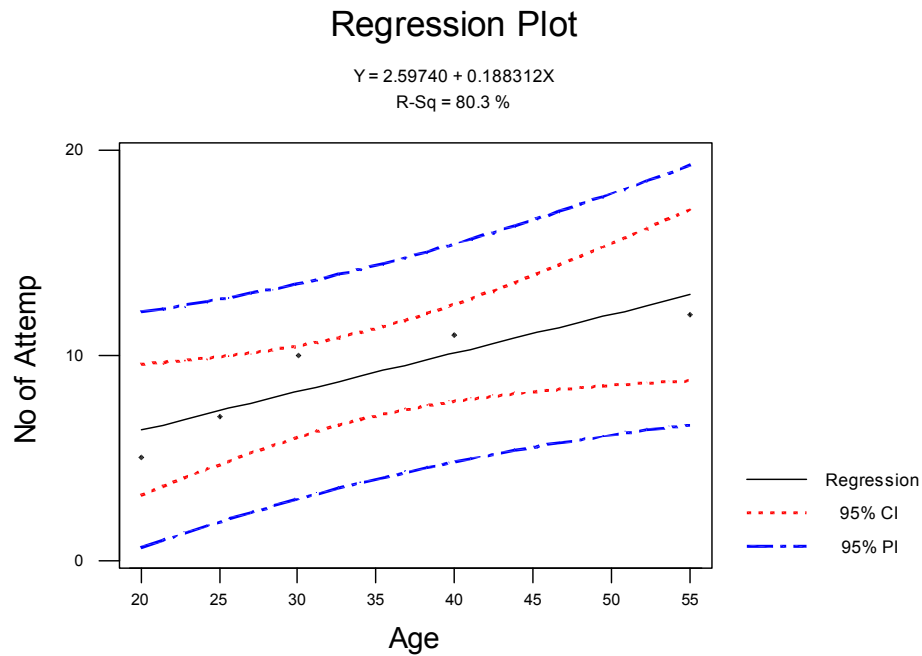
Figure 17. Regression Plot from MINITAB

Models can be Simple (one predictor), Multiple (more than one predictor), Linear and

non-Linear. In depth regression analysis is a college course in itself, so for practical

purposes, this these will examine only the very basics of Simple Linear Regression. The

easiest way to show what regression is all about is graphically. The chart below shows a

Simple Linear Regression of number of attempts required by individuals to complete a

difficult task (Y response variable) to the age of the individual completing the task (X

predictor variable) [9, p17]. The legend to the right shows the regression line (depicted

by the formula above Y = 2.59740 + 0.188312X) and the red dotted line depicts the

confidence at which it will fall within on the chart, based on the number of data points.

From this model, one could predict how efficient a person may be at these particular

tasks, prior to possibly hiring or even interviewing them.

Simulation is "the process of designing a model of a real system and conducting

experiments with this model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system" [8, p3].

There are many software packages used to simulate processes. Simulation is a very powerful tool where the designer builds a model of what is being analyzed. Sub-processes are characterized through input blocks. The blocks are placed in a cumulative model to represent an entire process. The user can then use that model to run variations of the sub-processes to determine the expected outcome. Although not generally used for optimization, it is very helpful for numerous "what if" applications. A well-built model can be used to predict, evaluate, compare, troubleshoot, schedule, and analyze systems. Probably the most useful aspect of a simulation is that it gives you nearly instantaneous results, in comparison to the actual process, with no commitment (except the time spent building the model). There is some risk involved. If a model is not built to truly represent the actual process, it can render false results, which can result in erroneous assumptions, decisions, and ultimately actions by the user. Detailed models of complex processes are not built without much research and work. It is critical that all sub-processes are examined and analyzed to define accurate results prior to modeling. The model is only as accurate as the data that was used to build it. A very powerful tool, simulation is not for the beginner. Simulation modeling takes patience, knowledge, and understanding, both of the process being modeled and of the concept of simulation itself.

<u>Improve</u>

Design of Experiments is a very powerful tool used for process improvement. The basic method of DOE is to observe improvements and degradations of a process as levels of input variables are changed. This will show a level of significance of each

variable as well as show the interactions between the variables. Analysis of the responses will ultimately result in a prediction model. This tool takes all of the input variables of a given process, or sub-process, and formulates various experiments using different levels of each input variable. Design of Experiments requires an in depth understanding of design philosophy, interaction analysis, and noise effects. However, when used effectively, DOE can render a truly robust system. The DOE looks at all factors (variables) and performs a series of tests at different levels for each factor. Each test will yield results that will be analyzed until the prediction model can be formulated and a truly robust system generated. One disadvantage to DOE is the amount of resources required for some tests. For instance, a simple DOE requiring testing of just 4 factors at 2 levels would require 16 trials (2^4) as shown in Table 5.

Table 5.

Design of Experiment

TRIAL NO	FACTOR			
	A	B	C	D
1	+	+	+	+
2	+	+	+	-
3	+	+	-	+
4	+	+	-	-
5	+	-	+	+
6	+	-	+	-
7	+	-	-	+
8	+	-	-	-
9	-	+	+	+
10	-	+	+	-
11	-	+	-	+
12	-	+	-	-
13	-	-	+	+
14	-	-	+	-
15	-	-	-	+
16	-	-	-	-

DOE, like Simulation, is a very powerful tool that can yield outstanding, robust, accurate results. However, it requires dedication, understanding, and commitment.

Design for Six Sigma is simply a matter of applying the Six Sigma methodology to engineering design application rather than process improvement. The idea is to design equipment to a Six Sigma standard before it goes into manufacturing. Again, to take this literally is sometimes not practical, but the real benefit of this process is that it forces the engineering designers to consider all aspects of getting the part out to the customer through a methodical approach to design. The chart below shows how the normal DMAIC method of the Six Sigma process parallels DFSS.

PROCESS

Define → Measure → Analyze → Improve → Control

DESIGN

Define → Measure → Analyze → Design → Verify and Control

Define	Measure	Analyze	Design	Verify and Control
•Define Project Scope •Overall Vision •Commit Resources/Team •Steering Committee •Appoint Sr. Mgmt Champion	•Define CTQs •Document Current Process •Develop Technical/ Process Design •Risk Assessment (RPN)	•Establish Capability •Capability Gap Analysis •Root Cause Analysis •Value Add Analysis •Risk Assessment •Status on Deliverables	•Solution Selection •Process Design •System Design •Capability Predicted •Simulate New Process •Control strategy	•Pilot -> Production •Verify Permitting •Validate Process Performance •Robust Control Plans •Transition to Process Owners •Audit Plan •Project Autopsy & Celebration

Figure 18. Design For Six Sigma

Control

Manufacturing Process Instructions are used to control processes. They are actual instructions for a procedure on the manufacturing floor. They are used to define exactly how tasks are to be completed for that process. A MPI will identify the purpose

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of the instruction, responsibilities of individuals, equipment required, safety issues, and it will give detailed instructions on how to perform the task. The instruction section should include a process map of the task and step-by-step, detailed instructions of what is to be completed.

Manufacturing Control Plans are used to control processes as the operation is actually running. Manufacturing Control Plans are in chart format and identify step-by-step instructions, in a procedure, of where the control points are. At each control point a measurement, or check, is taken to ensure the process is in control. Control limits will be identified at these points. If the measurement is not within the specified limits, then a corrective action will be identified on the control chart. Manufacturing Control Plans are very useful in maintaining control of a given process and serve as an excellent aid in training new operators. The MCP will generally have one or more control documents associated with it to record the checks and corrective actions taken.

A summary of a control plan can include, in spreadsheet format, the following items: process, process step, input, output, process specification (lower limit, target, and upper limit), Cpk/Ppk (describe sample sizze and methodology to obtain), MSA (include system, %R&R, and % of tolerance), current control method (include sample size and sample frequency), and reaction plan [3, p555].

Statistical Process Control (SPC) Charts are tools used for measuring the stability of a process and assisting the personnel in reacting to out-of-control conditions. It is becoming common in the manufacturing work place with much more sophisticated means using computer readout in most cases. SPC measures data points of a process as time elapses. Measured against an upper control limit (UCL) and a lower control limit (LCL) the chart will tell you immediately when the process is out of control (after it

meets certain criteria ie. a certain number of data points outside the control limits, etc.
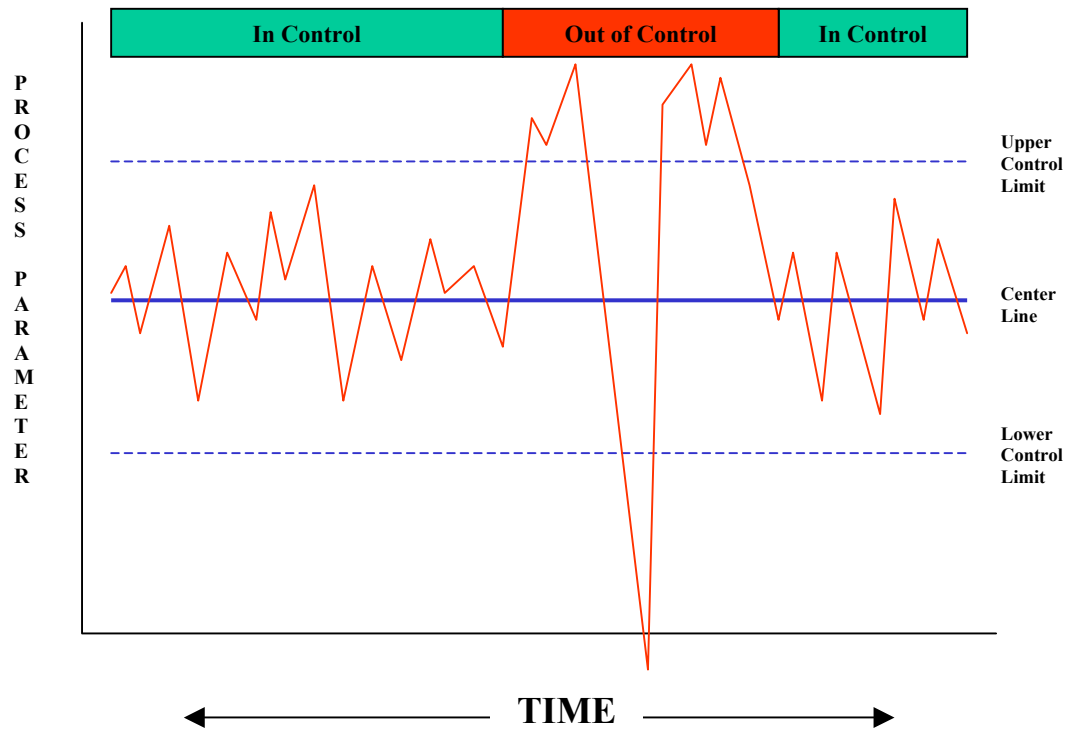
Figure 19. Statistical Process Control Chart

CHAPTER V

CASE STUDIES

Case Study I - Preventative Maintenance

1	Load filament
3	Load reflector
5/6	Cement filament in reflector
8	Align filament in reflector
10-21	Cure cement
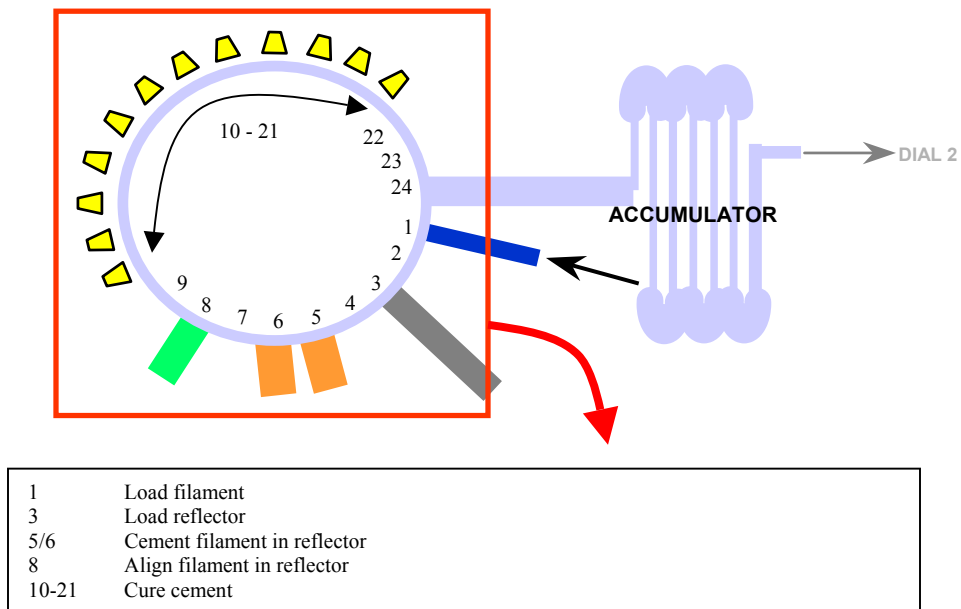
Figure 20. Index Machine Process Map

A lamp assembly machine is operating poorly - only about 75% efficiency. It is a critical machine in the plant and basically costs the facility $.50 each time it misses an index. Theoretical index speed is 3 seconds, which means that it is capable of making a finished lamp every 3 seconds. Since the machine indexes every 3 seconds and it costs $.50 for each missed opportunity, the overall rough estimate for Cost Of Poor Quality

(COPQ):

[24(hrs/day) x 60(min/hr) x 60(sec/min)] / 3(sec/index) = 28800(theoretical indexes/day)

[365(days/yr)-11(holidays)-52(proposed weekend days off) = 302(days of operations/yr)

[28800(theor indexes) x 302(days opn/yr) = 8897600(theor indexes/yr)

[8(hrs/wk PM) / 5(days/wk cap) x 1200(indexes/hr) = 1920(indexes/day PM)

302(theo days/yr) x 1920(indexes/day PM) = 579840(indexes/yr PM)

8897600(theo indexes/yr) - 579840(indexes/yr PM) = 8317760(act indexes/yr)

75% eff➔ 8317760(act indexes/yr) x .25(defect rate) = 2079440(missed indexes/yr)

COPQ ➔ 2079440(missed indexes/yr) x .50(per index) = $1039720 Annual Opportunity

Using a combination of automated data collection and manual data collection, a defect chart was created and analyzed in a rolling 30-day format. Each day a new row of data was collected. The data showed overall production and how many opportunities were missed each day due to respective defect. When data became 31 days old, it was placed in an archive for later analysis of long-term data. At the bottom of the table was recorded the Q1, Q3, stability factor, and mean for each column. After several weeks of analysis, it was obvious that the greatest problem was reacting to downtime caused by maintenance issues. A Pareto Chart was created. It clearly showed that the main issue was downtime due to reactive maintenance.

Table 6.

Downtime Data

Date																													
08-Sep-99	23575	20	53	0	3	462	20	3268	157	78	400	63	0	115	0	0	128	0	163	55	240	0	0	0	0	0	0	0	100
22-Sep-99	20667	749	53	16	17	785	105	3567	75	0	1069	218	49	215	0	0	120	0	103	32	400	0	0	0	560	1	2	0	37
30-Sep-99	20420	481	71	15	59	758	57	4301	258	44	735	115	220	140	85	0	74	0	0	7	560	0	0	0	400	1	2	0	42
20-Sep-99	20362	344	139	0	5	718	446	3157	50	0	820	395	68	60	0	0	81	0	75	0	2080	0	0	0	0	0	0	0	100
12-Oct-99	20156	211	53	0	58	772	315	3020	0	0	881	74	744	122	129	0	205	0	50	10	1040	0	0	960	0	0	0	0	84
29-Sep-99	19732	275	181	6	55	852	121	3200	466	271	965	71	141	188	0	0	284	0	194	38	120	0	0	0	640	1	3	3	84
21-Sep-99	19697	422	228	0	5	954	470	2967	62	66	1337	405	0	168	0	0	345	0	0	10	1520	0	0	0	144	0	1	0	100
13-Oct-99	19575	284	67	46	105	746	79	3674	185	91	802	31	149	61	191	0	16	0	18	0	800	0	0	400	480	0	0	0	0
28-Sep-99	19231	536	29	13	82	600	172	4326	9	331	740	130	3	128	26	0	60	0	308	76	1760	0	0	0	240	0	2	8	0
27-Sep-99	19167	682	45	3	28	533	5	4710	85	227	1080	98	0	232	0	0	122	0	23	0	1200	0	0	0	560	0	3	0	0
08-Oct-99	18061	613	100	2	86	1177	75	2729	205	12	1297	91	164	19	134	0	298	0	105	92	2400	880	0	0	160	0	1	0	100
11-Oct-99	18061	873	77	1	82	1792	858	2856	255	53	939	249	102	166	55	0	413	0	0	48	960	0	0	0	960	0	2	0	100
23-Sep-99	18037	692	68	15	18	867	9	4470	78	0	898	131	281	212	0	0	412	0	40	12	880	0	1200	0	480	0	3	0	0
01-Oct-99	18028	659	125	70	93	1395	232	4942	180	145	417	210	0	211	34	0	100	0	27	12	400	800	0	0	720	0	2	0	0
04-Oct-99	17720	644	42	62	95	1294	333	4870	851	143	568	37	650	51	97	0	293	0	30	60	640	0	160	0	160	0	2	0	0
09-Sep-99	17575	515	107	27	133	1054	312	4171	318	280	1338	84	865	250	0	0	70	0	11	10	160	0	0	0	1520	1	3	0	42
06-Oct-99	17546	766	67	27	139	1328	243	4325	763	1002	462	40	191	56	98	0	174	0	0	53	1280	0	0	0	240	0	4	8	0
07-Oct-99	17511	686	70	20	97	1335	353	3687	859	7	526	250	267	579	0	0	887	0	10	216	160	0	0	0	1280	1	2	0	29
17-Sep-99	17240	171	29	37	20	935	267	5092	137	435	386	277	128	0	0	0	212	0	63	183	1268	720	0	0	1200	1	2	0	33
10-Sep-99	17162	755	15	22	37	1320	345	3776	182	0	306	287	1098	146	0	0	0	0	62	7	1600	960	0	0	720	0	2	0	0
05-Oct-99	16038	705	116	101	87	1344	309	4669	464	396	731	381	227	141	0	0	565	0	458	68	1600	0	0	0	400	0	4	4	0
03-Sep-99	14943	644	117	29	14	692	242	4826	4016	512	315	636	43	102	114	0	423	0	12	0	240	880	0	0	0	0	1	3	0
15-Oct-99	14882	1451	119	31	260	1390	128	4881	399	145	734	280	463	66	183	0	447	0	126	255	1360	640	0	0	560	0	4	5	100
24-Sep-99	14178	471	38	12	9	801	255	4445	660	839	453	80	303	475	0	0	347	0	425	49	1680	1040	0	0	2240	0	3	7	0
14-Oct-99	13552	549	126	291	161	1298	232	3648	0	101	1422	586	0	60	59	0	681	0	99	95	5600	0	0	0	240	0	3	4	0
13-Sep-99	13168	406	82	14	34	1921	849	4128	2900	122	254	636	850	242	0	0	567	0	68	0	1440	0	960	0	0	0	3	0	0
07-Sep-99	13168	673	35	49	9	798	12	3661	672	0	218	534	558	99	299	0	929	0	12	14	4960	0	0	0	2000	1	0	10	15
16-Sep-99	13027	430	30	48	109	1816	950	3804	604	255	640	74	1600	163	0	0	174	0	50	151	3835	0	0	0	1040	0	3	0	0
15-Sep-99	7014	198	76	27	82	1678	918	2920	942	982	4816	71	121	173	0	0	659	0	0	26	8097	0	0	0	0	0	1	0	0
14-Sep-99	1861	7	74	0	19	342	159	1000	0	845	0	12	0	0	0	0	535	0	0	323	23623	0	0	0	0	0	0	0	0
Q1	14706	329	44	3	18	755	10	3189	77	11	413	73	33	65	0	0	115	0	11	9	620	0	0	0	108	0	1	0	0
Q3	19606	688	116	39	96	1337	347	4520	695	347	991	311	487	211	97	0	469	0	104	80	1840	0	0	0	780	0	3	3	84
sf	0.75	0.48	0.38	0.07	0.19	0.56	0.32	0.71	0.11	0.03	0.42	0.24	0.07	0.31	0.00	####	0.25	####	0.10	0.12	0.34	0.00	####	####	0.14	0.00	0.33	0.00	0.00
Mean	16717	530	81	33	67	1059	299	3836	561	246	852	218	310	158	50	0	321	0	84	63	2430	197	77	45	565	0	2	2	32

When data became 31 days old, it was placed in an archive for later analysis of long-term data. At the bottom of the table was recorded the Q1, Q3, stability factor, and mean for each column. After several weeks of analysis, it was obvious that the greatest problem was reacting to downtime caused by maintenance issues. A Pareto Chart was created. It clearly showed that the main issue was downtime due to reactive maintenance.

Pareto Chart for Assembly Machine 2

Defect	MAINTENANCE	AD BAD ALIGN	OP STOP MACH	CHANGEOVER	ACCUMULATOR	BAD BULB	STA 23 FAULT	SEL SW OFF	HEAD LOCKED	CEMENT INOP	OTHERS
Count	2430	1059	852	565	561	530	321	310	299	246	218
Percent	32.9	14.3	11.5	7.6	7.6	7.2	4.3	4.2	4.0	3.3	2.9
Cum%	32.9	47.2	58.7	66.4	74.0	81.1	85.5	89.7	93.7	97.1	100.0

Figure 21. Pareto Chart of Defects

The next step was to examine the variation in the sub-processes. Another consideration from a business standpoint, was to identify any "quick hit" projects. Quick hits are anything that the project manager feels they can resolve immediately or with little effort. By examining the variation in the data collection chart and identifying the primary issues, the Box Plot charts were placed beside each other to examine, graphically, to see if there were other issues that were not obvious from simply looking at the data. The high mean demonstrated the company was losing considerable opportunity from that defect. The high variation suggested that some days were good and some days were bad, so the machine did have the capability of having a good day. If the good days could be modeled and duplicated, then the mean would naturally improve as well.

Box Plot of Defects

REDUCE SPACING BETWEEN LOTS

REDUCE SHUTDOWN TIME

DRIVE CURRENT GREENBELT PROJECT

PURCHASE SPARE HEAD ASSEMBLY

TRANSLATION FROM QAF1

M/O per Day — 3000, 2500, 2000, 1500, 1000, 500, 0

Defects (see chart below) 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

1	A D 9 Bad Alignment	11	Operator stopped the machine
2	Reactive Maintenance	12	A D 23 Sta Fault
3	Head locked out at station 1	13	A D 3 Bad Reflector Load
4	Changeover	14	A D 22 Sta Fault
5	Accumulator between dial 1 and 2 is full	15	A D 6 Sta Fault
6	Neither cement machine is operating	16	A D 1 Sta Fault
7	A D 1 or A D 3 selector switch turned off	17	A D 5 Sta Fault
8	A D 1 Bad Bulb Load	18	A D 6 Bad Cement
9	A D Dial Index Fault	19	A D 5 Bad Cement
10	Reflector supply out		

Next step to look for any QUICK HITS!!!

Figure 22. Box Plot of Defects

Quick hits were identified and assigned to Green Belts while more data was collected on the root cause of maintenance downtime. It was interesting to see the amount of difference made in the process simply by analysis after the quick hit projects were introduced. Figure 24 shows a Chi Squared test of the mean, Homogeneity of Variance, and Box Plot which all demonstrate a significant difference simply after a few quick hits.
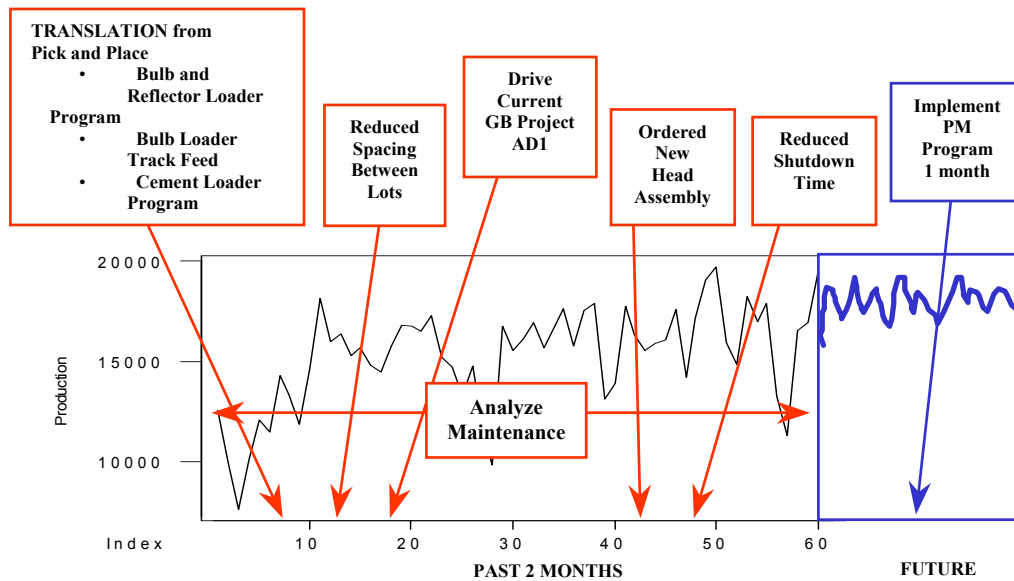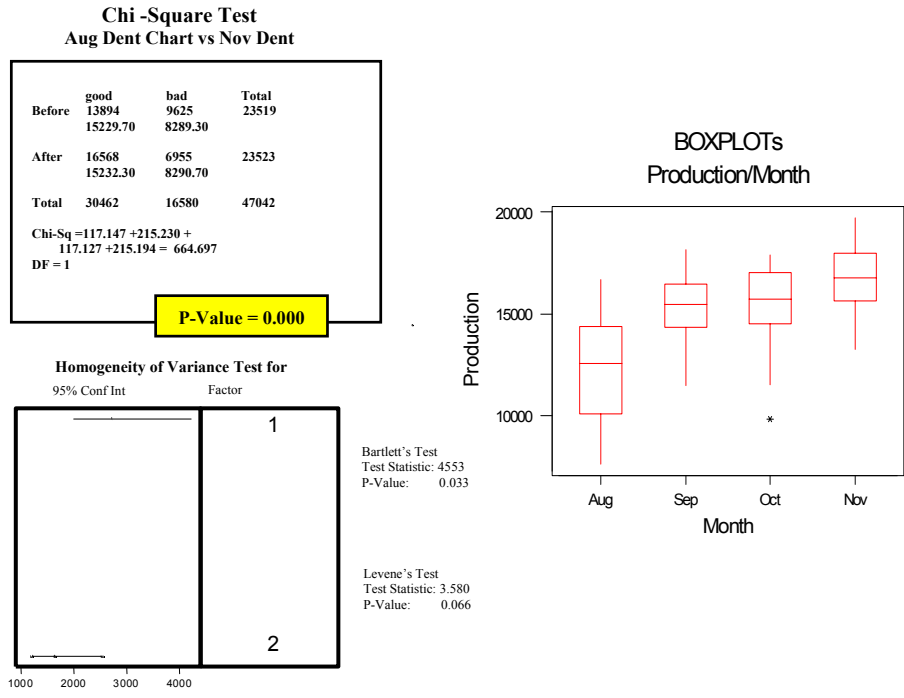
Figure 23. Timeline of Events

The next step was to identify what issues were causing maintenance downtime. A maintenance log was designed that required the operator to record detailed data each time they shut down the machine for any kind of reactive maintenance. The operator would need to log their name, time, duration, what went wrong and how they corrected the problem. Every second of downtime would be accounted for. After several weeks of collecting more data, another cause and effect matrix was generated. Two stations were causing most of the maintenance downtime - reflector loaders and alignment (alignment)station maintenance should not be confused with actually aligning the bulb, which was identified as a separate issue). Each issue was brainstormed on how this downtime would be reduced. The answer was stopping periodically and conducting some maintenance on the stations before they would break down.

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Chi -Square Test
Aug Dent Chart vs Nov Dent

	good	bad	Total
Before	13894	9625	23519
	15229.70	8289.30	
After	16568	6955	23523
	15232.30	8290.70	
Total	30462	16580	47042

Chi-Sq =117.147 +215.230 +
117.127 +215.194 = 664.697
DF = 1

P-Value = 0.000

Homogeneity of Variance Test for

95% Conf Int   Factor

1

Bartlett's Test
Test Statistic: 4553
P-Value: 0.033

Levene's Test
Test Statistic: 3.580
P-Value: 0.066

2

1000   2000   3000   4000

BOXPLOTs
Production/Month

Statistical Improvement in both Variation and Mean

Figure 24. Significant Difference After Quick Hits

Table 7.

Cause and Effect Matrix for Reactive Maintenance

		7	5	
	Inputs	Loaders Not Enabled	Alignment	**Total**
11	gripper assembly repair	90	0	630
9	complete head repair	84	0	588
17	bad contact	0	100	500
25	head/nest alignment	0	89	445
10	contact repair	60	0	420
22	head opener/closer	0	80	400
3	gap between lots	56	0	392
12	neat 203h box assembly	54	0	378
26	debris under ball slide assembly	0	60	300
19	low light level (Zenith)	0	50	250
8	notification	35	0	245
2	change cups	31	0	217

The main result from the brainstorming session and data analysis was that more time

needed to be spent during the normal planned down time to prevent unplanned down time. Several brainstorming sessions were conducted with all operators to create a Preventative Maintenance control plan. The control plan consisted of a one-line entry into the overall Control Plan for the machine that stated PM would be conducted in accordance with the Maintenance Schedule form. The maintenance schedule was given a form number within the facility document control procedure, and the schedule was implemented. An extract of the maintenance schedule shows that it identifies specific tasks for each shift. These tasks were rotated periodically to ensure each mechanic would stay proficient at the task.

Table 8.

Maintenance Schedule

Proactive Maintenance Schedule

Legend: ■ 1st Shift (red) = R ■ 2nd Shift (blue) = B ■ 3rd Shift (green) = G

Job#	Station	Item	Action	Fr	Time	January 1-3	4-10	11-17	18-24	25-31	February 1-7	8-14	15-21	22-28	March 1-7	8-14	15-21	22-28
1	Stock Rm	Parts for next months PM	Order	M	30	R					R				R			
2	001	clutch brake (pick-n-place)	replace	A	120	R					B				R			
3	001	cam follower	inspect	M	5	R					B				R			
4	001	cam follower	replace	Q	45	R					B				R			
5	001	sensor	inspect	M	5	R					B				R			
6	001	hopper	clean out	M	30	R					B				R			
7	001	gripper sensor	inspect	S	5													
8	001	pick and place pads	replace	S	20													
9	003	clutch brake (pick-n-place)	replace	A	120													
10	003	brushes	inspect and blow out	M	20		G				R					G		
11	003	p & p pads	replace	S	30													R
12	003	conveyor	grease	M	15	R	G	B	R	G	B	G	B	G	R	B	G	R
13	003	orienter	inspect	W	5	R	G	B	R	G	B	G	B	G	R	B	G	R
14	003	orienter	replace	M	30	R												
15	003	clutch brake (accumulator)	replace	A														
16	005	chiller antifreeze	inspect	M	5			B					G				B	
17	005	chiller antifreeze	replace	A	60													
18	005	vibrator	rebuild	A	15						B							
19	005	end assembly, vibrator	replace	Q	60				G									
20	005	bushings, (plw blk), vibrator	replace	Q	60									R				
21	005	brushes (12 on machine)	replace	2wks	30	G		R			B			R		B		G
22	005	tubes	replace	W	30	G	B	G	G		R	G	B	R		R		G
23	006	chiller antifreeze	inspect	M	5	G					R							
24	006	chiller antifreeze	replace	A	60		B											
25	006	vibrator	rebuild	A	15			R										
26	006	end assembly, vibrator	replace	Q	60	G												
27	006	bushings, (plw blk), vibrator	replace	Q	60		B											
28	006	brushes (12 on machine)	replace	2wks	30		B		G		R		B		G		R	
29	006	tubes	replace	W	30	G	B	R	G		B	G	B	R		B	R	G
30	009	glass plate	replace	S	30					G								

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Case Study II - Reflector Haze

Clear glass reflectors must be coated with a reflective material in order to be effective

in creating the proper lumens and beam of a lamp. It is critical to quality that the

Figure 25. Macro Process Map – Reflector Process

reflector coating meet specific criteria. The coating department ran excessive defects due

to haze.   Several projects had attempted to resolve issue, but none had been successful.

Batches of reflectors for certain runs were resulting in a haze in the reflector coating.

Table 9.

Baseline Cost of Poor Quality

BASELINE			
	Ave # Ref Lost/Month to Haze	Cost/ref	Total Cost/Month
Foam 7	7880	$0.30	$2,364.00
Foam 8	8217	$0.30	$2,465.10
Foam 11	9066	$0.30	$2,719.80
			$7,548.90
Annualized Opportunity			$90,586.80

Coating machines are known as FOAMs. The first step was to define the scope of the

problem. A team was formed to begin brainstorming what types of haze were being

created and what were potential causes of the haze. Three FOAMs were dedicated to

reflector coating. All 3 coaters were having issues with haze, but it would not happen on

every batch.   The causes of haze were identified and a Cause and Effect Matrix

generated. There were several different types of haze, however, the defects being generated in these cases fell into two categories - Light Haze and Other Haze. Because Light Haze was causing less than 1/10 of the overall defects, it was given a CTQ value of 1 and Other Haze was given a CTQ value of 10.

Table 10.

Cause and Effect Matrix of Haze Defects

| | 1 | 10 | |
Inputs	Light Haze	Other Haze	Total
defective reflector molds	3	4	43
dirty molding machines	8	8	88
poor raw reflector cleaning	8	8	88
poor coating mixture	2	2	22
dirty packaging of raw reflectors	7	8	87
exposure to debris in warehouse	7	8	87
hand residue/oil	7	8	87
too much time in coater	2	2	22

From the Cause and Effect Matrix, it was apparent that the root cause could have been happening at the facility where the raw reflectors were being molded into shape or at the facility where the raw reflectors were being coated. The molding facility was notified with all of the details and they claimed they were not the cause of the problem because all of their controls to ensure cleanliness were in place. Packaging that arrived at the coating facility was not very clean, neither was the warehouse in which the reflectors were stored. The operators used white cotton gloves whenever handling the raw reflectors and
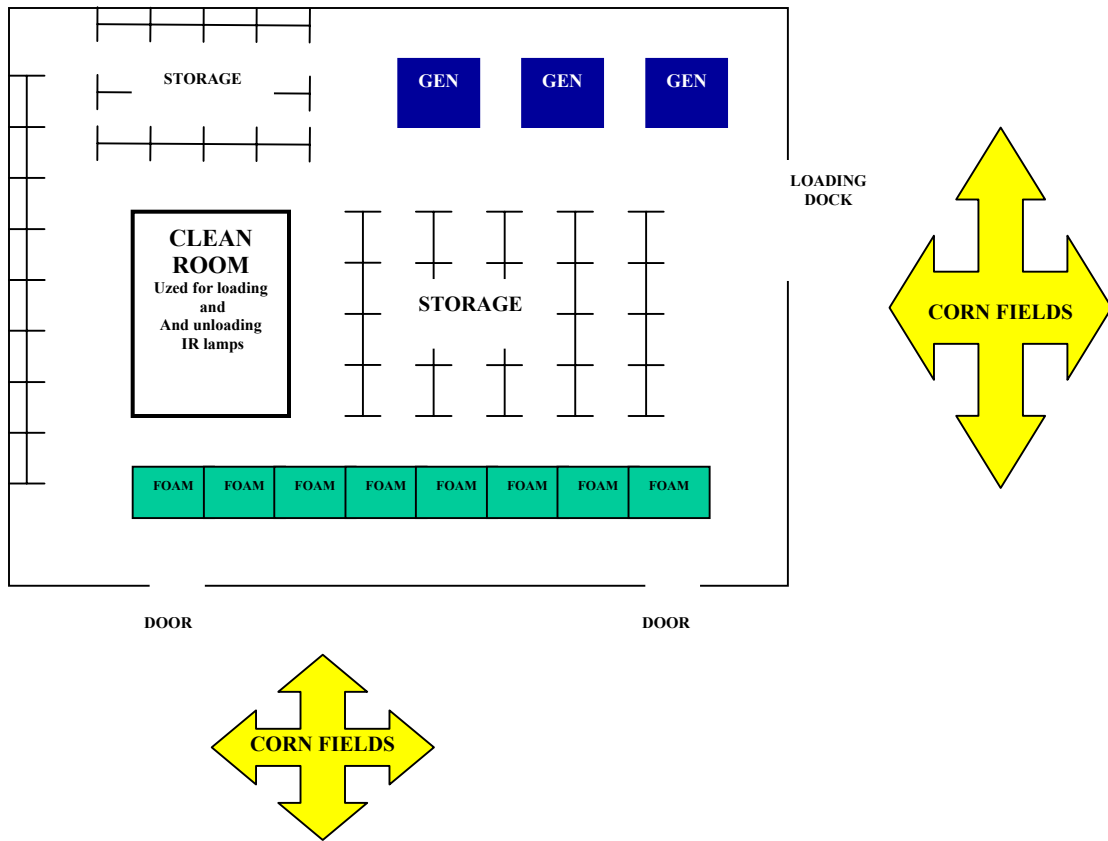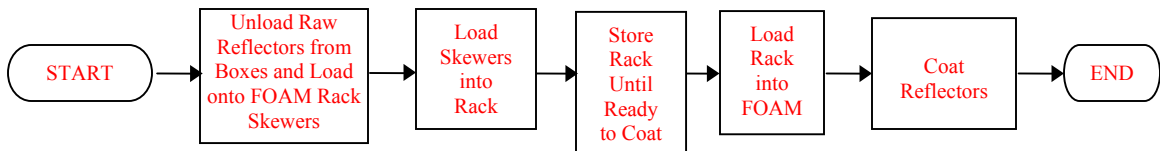
Figure 26. Warehouse Layout

Figure 27. Process Map - Reflector Coating

changed them out for new gloves regularly. Since the team could have more direct impact over the inputs of the warehouse, the team decided to focus on the warehouse first. If that did not turn out to be the root cause, then they would look at the packaging.

The team turned to what was causing the warehouse to be so dirty. Warehouses are generally not very clean. This warehouse was exceptionally dirty, however, mainly because a cornfield surrounded the facility. When the corn was growing and being harvested, they would get residue from the corn stalks blowing in from the wind. After the corn was harvested, the wind would blow dust from the soil in through the doors. They could not keep the doors shut because is was the shipping and receiving area. Looking back at the process map, the question was raised as to why they needed to load and unload in the warehouse. There was a clean room environment in the middle of the warehouse for other operations. Perhaps there was enough room in the clean room to conduct this operation. A facility layout and redesign was conducted and it was determined that is would be feasible, however, it would take much work. It would be necessary to conduct an experiment to ensure that this would resolve the problem prior to improvement. The team needed to construct a DOE to determine if the warehouse cleanliness was the real issue. Due to the potential expense of testing (creating defects essentially), the experiment needed to remain limited. There were several conditions that affect debris in the warehouse such as temperature, amount of work going on, whether the doors are opened or closed, time of the year in regards to harvesting the corn, etc. However, there was little control over any of these factors. A 2 factor, 2 level design was all that was needed. The two factors would be loading the reflectors into the coating racks and storing the reflectors until coated. The levels would be in the warehouse (dirty) and in the clean room (clean). Since $n = 2^k$, and $k = 2$ this experiment would require 4 runs (or 4 separate experiments).

	Load Rack	Store Rack
1	+	+
2	+	-
3	-	+
4	-	-
	Clean (+)	Dirty (-)

Figure 28. DOE for Reflector Coating

Because it had been proven that there was variation in the quality of raw reflectors from the reflector mold facility, this noise had to be eliminated. The 4 experiments would require a total of 54,000 raw reflectors, or about 3.5 pallets. Four pallets were immediately pulled aside. Four empty pallets were placed beside them, and 4 new pallets of reflectors were build by randomly mixing even amounts of reflector cases from each of the original pallets. This would eliminate the noise, because no matter what the defect rate, it would then be relative across each pallet. Again, the purpose of this experiment was not to show that the experiment using the clean room came out much lower than the baseline, but to prove that under the same conditions there was a significant difference between the warehouse and the clean room and that it did have an effect on the haze. And yet another noise factor was the amount of time it took to load and the amount of time it was stored prior to coating. It was determined that these noise factors would have to be controlled during the experiment, even if it meant slowing down production to expose a rack of raw reflectors longer than normal. So the experiments were conducted

NOISE REDUCTION

Original Pallets of Raw Reflectors each pallet has variation in defect rate

P1	P2	P3	P4

(P1+P2+P3+P4)/4	(P1+P2+P3+P4)/4	(P1+P2+P3+P4)/4	(P1+P2+P3+P4)/4
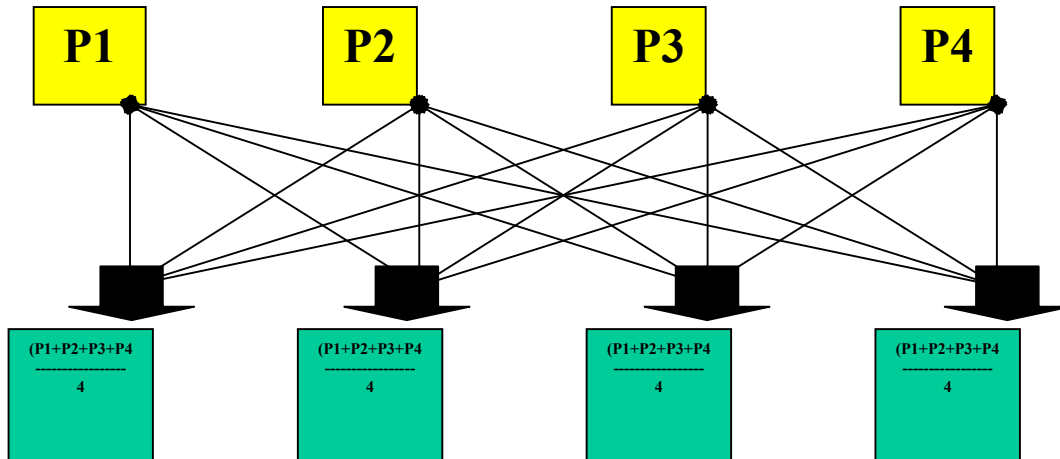
**New Pallets Built for Experiment
to reduce noise from variation in
in raw reflectors – each pallet now
has equal variation of
(P1+P2+P3+P4)/4**

Figure 29. DOE Raw Reflector Variation Reduction

all within a few days during a time that the temperature and weather were the same, to eliminate any of these possible noise factors. Figure 30 shows the results of this experiment.

	Load Rack	Store Rack	% Yield
1	Clean	Clean	98
2	Clean	Dirty	93
3	Dirty	Clean	95
4	Dirty	Dirty	61
	Clean (+)	Dirty (-)	

Figure 30. Reflector Coating DOE Results

Based on these results, the clean room was reconstructed to make room for loading and storing of raw reflector racks prior to coating. The following 8 months savings resulted.

Table 11.

Reflector Coating Project Results

	Lt Haze	Other Haze	Yield
FOAM 1			
Baseline defects	**550**	**7330**	**8120**
May	22	3	15975
Jun	0	0	16000
Jul	15	0	15985
Aug	0	0	16000
Sep	0	58	15942
Oct	0	0	16000
Nov	0	0	16000
Dec	0	0	16000
FOAM 2			
Baseline defects	**567**	**7650**	**7783**
May	0	70	15930
Jun	0	0	16000
Jul	0	24	15976
Aug	0	0	16000
Sep	0	0	16000
Oct	33	21	15946
Nov	0	0	16000
Dec	0	0	16000
FOAM 3			
Baseline defects	**634**	**8432**	**6934**
May	350	18	15632
Jun	0	10	15990
Jul	203	33	15764
Aug	0	0	16000
Sep	0	0	16000
Oct	0	0	16000
Nov	0	5	15995
Dec	0	0	16000

Baseline was established using 4 months of historical data

Table 12.

Annualized Savings

TOTAL SAVINGS		
Month	**Ref Saved**	**$$$**
May	24700	$7,410
Jun	25153	$7,546
Jul	24888	$7,466
Aug	25163	$7,549
Sep	25105	$7,532
Oct	25109	$7,533
Nov	25158	$7,547
Dec	25163	$7,549
Estimated Annualized Savings		**$90,198**

CHAPTER VI

SUMMARY, CONCLUSIONS, RECOMMENDATIONS

During this thesis, an overview was given of the basic principles and methods used in Six Sigma projects. Two areas that were functioning poorly in a lamp manufacturing facility were observed. These areas were analyzed using the same methods taught in General Electric's Six Sigma program.

The processes were improved using a define, measure, analyze, improve, control approach. Teams were gathered to define the initial problems. Data was gathered by various means to analyze. Using data gathering tools, statistical analysis, design of experiments, and process control measures, both processes were improved significantly.

The preventative maintenance project outlined in this document resulted in an annual savings of $140,000. The reflector haze project resulted in an annual savings of $121,000.

Six Sigma is a program that takes some common industrial and quality engineering tools and applies them as common language across a business. The methods and tools used in Six Sigma projects are nothing new. Industrial engineers and quality engineers have used the methods for decades. Six Sigma is a unique program in that it drives these well-known processes across a business to improve any kind of issue and brings these

tools as common language for all team members to understand. This fosters teamwork and ultimately results in a better-trained work force who is looking to improve their processes.

One can expect Six Sigma to become more and more popular among businesses - a common language. It is already a part of the curriculum of numerous programs in universities. General Electric is integrating their Six Sigma program into the business more and more every day - not just manufacturing, but all businesses. The principles can be applied to anything, from manufacturing airplanes to improving a golf game. If a business wants to become certified to ISO 9001:2000, they're going to have to adopt a process improvement program. During the last several years General Electric's program has evolved from a very focused, process-oriented program, to a very broad, all-encompassing philosophy of daily business. There are two characteristics that have helped General Electric's Six Sigma program to become successful. First, they focused more on Six Sigma as a philosophy rather than a metric. It would be great to get to a Six Sigma level of quality, but not everyone can do that. Metrics are not the most important thing about this program. The most important thing is that it fosters continuous improvement. It gives everyone a common language to understand. The philosophy of Six Sigma is to keep improving. The second input to GE's success is that it was driven from the top down, with total commitment, throughout the business. This is not a program that can be partially implemented. There are always going to be a few engineers and managers in any business that understand some of the common tools used in driving process improvement. The difference with a well-implemented Six Sigma program is that most of an organization's population understands and uses the tools. If implemented

properly, with total commitment and focus, Six Sigma can render excellent long-term benefits.

REFERENCES

(1) Harry, Mikel J., <u>The Vision Of Six Sigma: Tools And Methods For Breakthrough</u>, Sigma Publishing Company, Arizona, 1994.

(2) Harry, Mikel J., <u>The Vision Of Six Sigma: A Roadmap For Breakthrough</u>, Sigma Publishing Company, Arizona, 1994

(3) Breyfogle, Forrest W. III, <u>Implementing Six Sigma: Smarter Solutions Using Statistical Methods</u>, John Wiley & Sons, Inc., New York, 1999.

(4) Perez-Wilson, Mario, <u>Six Sigma: Understanding The Concept, Implications, And Challenges</u>, ASC Press, Arizona, 1999.

(5) Pande, Peter S., Neuman, Robert P., Cavanagh, Roland R, <u>The Six Sigma Way: How GE, Motorola, and Other Top Companies Are Honing Their Performance</u>, McGraw- Hill, New York, 2000

(6) Eckes, George, <u>Making Six Sigma Last: Managing The Balance Between Cultural And Technical Change</u>, John Wiley & Sons, Inc., New York, 2001

(7) Kiemele, Mark J., Schmidt, Stephen R., Berdine, Ronald J., <u>Basic Statistics: Tools For Continuous Improvement</u>, Air Academy Press & Associates, Colorado, 1997

(8) Pegden, C. Dennis, Shannon, Robert E., Sadowski, Randall P., <u>Introduction to Simulation Using Siman</u>, McGraw -Hill, Inc, 1995

(9) Neter, John, Kutner, Michael H., Nachtsheim, Christopher J., Wasserman, William, <u>Applied Linear Regression Models, Third Edition</u>, Times Mirror Higher Education Group, Inc, 1996

(10) Schmidt, Stephen R., Launsby, Robert G., <u>Understanding Industrial Designed Experiments</u>, Air Academy Press & Associates, Colorado, 1998

(11) Chase, Nancy, "Six Sigma Blackbelts Stamp Out Tough Quality Problems," Quality, August 1999

(12) Godfrey, A. Blanton, "Six Sigma Quality," Quality Digest, May 1999

(13) Perez-Wilson, Mario, "Six Sigma Strategies: Creating Excellence in the Workplace," Quality Digest, December 1997

(14) Advanced Systems Consultants,"What is Six Sigma?," September 17, 1999

(15) Maguire, Miles, "Cowboy Quality: Mikel Harry's riding tall in the saddle as Six Sigma makes its Mark," Quality Progress, October 1999

(16) Six Sigma Qualtec, "Pilkington Libby Owens Ford," Momentum, 1998

(17) Six Sigma Qualtec, "GE Capital Mortgage Insurance Canada," Momentum, 1999

(18) Kendall, Jenny and Fulenwider, Donna O., "Six Sigma, E-Commerce Pose New Challenges," Quality Progress, July 2000

(19) Munro, Roderick A., "Linking Six Sigma with QS9000," Quality Progress, May 2000

(20) General Electric Company, Annual Report, 1998

(21) General Electric Company, Annual Report, 1999

(22) General Electric Company, "Six Sigma," May 1999

(23) General Electric Lighting, "What is Six Sigma? Understanding GE Lighting's Quality Initiative," 1996.

(24) Stewart, Thomas A., "America's Most Admired Companies: Why Leadership Matters," Fortune, March 2 1998

(25) Walmsley, Ann, "Six Sigma," Business Magazine, October 1997

(26) Reinvigorating Six Sigma - Lighting Leads the Way, May 23 2001

(27) GE Six Sigma Partnering with Customers Workshop Pitch

(28) http://www.sixsigmaqualtec.com

(29) http://www.sixsigmaacademy.com

(30) http://www.ssqc.ge.com (Six Sigma Quality Coach)

(31) MINITAB Release 12.2, Help Section

CIRRICULUM VITAE

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                   Voluntary Protection Program (VPP) Core Team Training
                   Don Day Ergonomics Course
                   GE Advanced Manager Course

MILITARY: Engineer Officer Advanced Course (Distinguished Graduate)
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AWARDS &
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                   Student Marshal, Applied Sciences Curriculum Committee

Sigma Pi (Pledge Class President)
Army ROTC Distinguished Military Student (academic award)
ROTC Federal/State Scholarships

PROFESSIONAL
SOCIETIES: American Society for Quality
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