Applying Six Sigma to Tenneco Automotive Manufacturing

by
John Kang

S.B. Materials Science and Engineering, Massachusetts Institute of Technology, 1994

Submitted to the Sloan School of Management and the
Department of Materials Science and Engineering
In partial fulfillment of the requirements for the degrees of

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and
Master of Science

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Abstract

Product Quality, broadly defined as the ability of a company's product to meet specific conformance requirements as defined by the customer, is the subject of this thesis. Specifically, this thesis will explore how product quality can be improved in the context of Tenneco Automotive's (TA's) manufacturing process. A brief survey of these processes indicate the following:

- **Quality Gap:** Company data suggest internal defect rates as measured by factors such as rework and scrap may be higher than external defect rates as measured by factors such as customer returns and warranty costs. Decreasing internal defect rates could potentially reduce TA's internal manufacturing cost.

This thesis attempts to evaluate whether Six Sigma can, as stated in the popular literature, improve internal product quality while reducing manufacturing costs.

The thesis contains three major sections:

- **Benchmark Study:** This section reports and summarizes the experiences different Fortune 500 companies have had with Six Sigma. The information was obtained through a series of interviews with people, mostly senior managers, who have had direct experience leading a portion of their company's Six Sigma efforts.
- **Six Sigma Models:** This section reports the financial and product quality improvement that TA could potentially achieve on both a company-wide and plant level basis through the application of Six Sigma. The two quantitative models that were used to come up with these findings are also shown and explained. These two models, although specifically designed for TA, can be easily broadened to apply to almost any general manufacturing enterprise.
- **Six Sigma Integration:** This section attempts to identify the major issues and barriers that need to be overcome to successfully implement a Six Sigma program in TA manufacturing.

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Professor Stephen Graves, Sloan School of Management

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INTRODUCTION

1.1 Problem Statement

Tenneco Automotive (TA) is a $3.2B automotive parts supplier. Its primary products are shocks marketed under the Monroe^{TM} brand name and exhaust systems marketed under the Walker^{TM} brand name. Both products, were are marketed and sold to both original equipment (ie. the "big 3" automakers) and after market (ie. Midas, Pepboys) customers. Historically, the Monroe and Walker products have been very popular among both original equipment (OE) and after market (AM) customers and currently maintain a number 1 or number 2 position in terms of market share in their respective markets. These products have also enjoyed a reputation among customers as being, in general, high quality products. Recent data analysis, however, of company-wide data and data collected from select TA factories reveal the following:

- **Quality Gap:** The data seems to indicate that internal defects, as measured by such things as scrap and rework, are relatively high compared to external defects, as measured by such things as customer returns and warranty costs. This suggests the possibility that TA may be incurring extra manufacturing cost to prevent internal defects from becoming external ones. This hypothesis assumes, of course, that the internal defects being identified by TA are ones that are truly of direct concern to the customer.

Any plan that attempts to address this issue needs to incorporate the following elements:

- **A focus on reducing internal defect rates:** There must be a focus on getting it right the first time. Such an effort should result in lower internal manufacturing costs as the extra resources and effort needed to catch and eliminate internal defects are eliminated.
- **A plan to continuously improve critical to quality processes:** Factories need to improve only those processes that will truly impact product performance as perceived by the customer.

1.2 Project Motivation

According to articles found in several reputable quality journals such as Quality Digest, and Quality Progress and the popular literature such as the Wall Street Journal, one very powerful approach that can be used to reduce internal defect rates to nearly zero is Six Sigma, a methodology which focuses on achieving breakthrough results in product quality. Product quality being defined, in this case, as a product's ability to meet or exceed customer specified requirements. What is "claimed" by the popular literature, and what is reality, however, can sometimes be two very different things. Hence, the focus of this thesis is to gain from primary sources detailed information on Six Sigma, what it really means to different companies, and its effectiveness as a tool to improve product quality. Other goals will include quantifying the benefits that TA could potentially receive by implementing Six Sigma and suggestions on how it could be integrated into TA's current business structure.

1.3 Thesis Overview

The thesis is organized in the following manner:

- **Background Sections:** Chapter 2 provides the raw material to help the reader come up to speed on the basic terminology, concepts, and principles related to the old principles of quality management. Chapter 3 gives a brief overview of TA's current quality system and Chapter 4 provides a brief introduction and overview of the new principles of quality management as embodied in Six Sigma.
- **Analysis Sections:** Chapter 5 consists of a summary and analysis of several interviews with Fortune 500 managers who have been significantly involved with their respective Six Sigma programs. Chapter 6 provides a description of the analytical models that were used to quantify the benefits TA could potentially reap by implementing Six Sigma. This section also includes a small case study that attempts to analyze the potential benefits that could be realized by the systematic application of Six Sigma to a manufacturing line.
- **Integration Section:** Finally, chapter 7 highlights barriers that may need to be overcome as well as a general guideline on how Six Sigma should be implemented at TA or any other company.

1.4 Executive Summary

The primary conclusion that can be drawn from the data collected in this study, especially the material from the company interviews, indicates that careful application of Six Sigma tools and principles could potentially significantly improve Tenneco Automotive's product quality while lowering its manufacturing cost.

Furthermore, the analytical models that were developed to help quantify the benefits that could potentially be derived by implementing Six Sigma corroborated this conclusion. The first model, called the macro-model, showed how TA could realize real increases in EBIT, and decreases in COQ over its current 5 yr. Plan. The second model, the micro-model, showed the cost and quality impact that Six Sigma could potentially have on a particular Tenneco Automotive manufacturing line. This analysis verified the number projected by the macro-model and identified 3 potential projects that could each result, on average, about $569,000 in cost savings.

Lastly, the data gathered indicates that successful implementation of Six Sigma requires careful attention to such details as getting full management support for the initiative, selecting the right Six Sigma training provider, monitoring the completion of high impact process improvement projects, and coordinating the initiative with any other major efforts (ie. Lean Manufacturing) which the company may be currently supporting.

2 TRADITIONAL QUALITY THEORY

2.1 Definition of Quality

Before we can set out to meet the objective established at the outset of this paper, namely "to determine if Six Sigma can really improve product quality," the definition of "quality" must be established, something which is not easy to do since it can mean many different things depending on the context in which it is used. Dr. Neil Hardie, a quality guru and author of the book The Consequences of Quality (1997) stated that most definitions of quality could be put in one of the following categories[1]:

- **Conformance to Requirements:** Quality, in this sense, is defined as the extent to which a product meets certain defined specifications and is free of deficiencies/defects. The closer a product conforms to the specified requirements, the higher is its overall level of quality.
- **Fitness for Purpose:** Quality is defined as the extent to which a product properly performs the functions for which it was intended. Dr. Genichi Taguchi made this definition of quality famous. Dr. Taguchi defined quality in terms of a loss function that assessed the amount of loss that a society suffered from a product of imperfect quality. Hence, the higher the product quality, the lower the associated loss to society. The loss function is minimized by varying, through special statistical procedures, all the significant variables that could effect product performance.
- **Meeting Customer Expectations:** Quality is defined as the extent to which the product satisfies or delights the customer
- **Exceeding Customer Expectations:** Quality is defined as the extent to which customers believes a given product surpasses their minimum needs
- **Superiority to Competitors:** Quality is defined as the extent to which a given product's characteristics surpass those of one's competitors as perceived by the customer

The definition of quality which will be used from this point on and which comes closest to what can be applied to the manufacturing process is that which defines quality as conformance to requirements.

2.2 Cost of Quality Model

By examining all the above definitions for quality, conventional wisdom dictates that there must be a certain cost to achieving higher and higher levels of quality. These costs are captured in a metric called Cost of Quality (COQ). In general, the COQ metric tries to capture all the costs associated with identifying and then fixing defective work. Why is it important to quantify quality costs? The answer is simple, as stated by Frank M. Gryna, co-author with J. M. Juran of Quality Control Handbook (1988) in section 4.4, "money is the language of upper managers." By translating defects into dollar figures, upper management is better able to track, understand, and reduce the costs associated with producing products of poor quality. Without a dollar figure, it is sometimes difficult to get senior management to take quality costs seriously and spur them to take action to reduce them.

Most of the major costs that are roll-up into the COQ metric can be characterized in one of four categories [2]:

- **Internal Failure Costs:** These are the costs associated with finding and preventing internally generated defects from getting to the customer. Examples of common costs included in this category include scrap, rework, failure analysis, 100% sorting inspection.

- **External Failure Costs:** These are the costs associated with addressing and remedying defects that somehow reach the customer. Examples of these costs include warranty charges, returned material, and complaint adjustments.
- **Appraisal Costs:** These are the costs associated with ensuring product is meeting the required product specifications. Examples of these costs include incoming, in-process, and final inspection and test, and test equipment calibration.
- **Prevention Costs:** These are the costs associated with efforts aimed to keep failure and appraisal costs to a minimum. Examples of these costs include process planning and control, supplier quality audits, and training.

As can be seen, these costs can be directly linked to the manufacturing process. Other potential "hidden" costs include the extra effort and resources needed to be spent to redesign a product or process due to poor quality. These costs, although more subtle, need to potentially be weighed, in addition to COQ, when making decisions regarding efforts to improve quality.

Once quality costs in the form of COQ have been quantified, management needs to know how much it should spend to reduce these quality costs. Obviously, if the future benefit that will be derived from addressing a particular quality issue is less than the resources and costs that will be incurred, management should look for other opportunities that will make better use of the resources at hand. One qualitative framework that can help managers decide whether to invest more resources into quality improvement efforts is the Prevention Appraisal Failure (PAF) Model shown in figure 2-1.

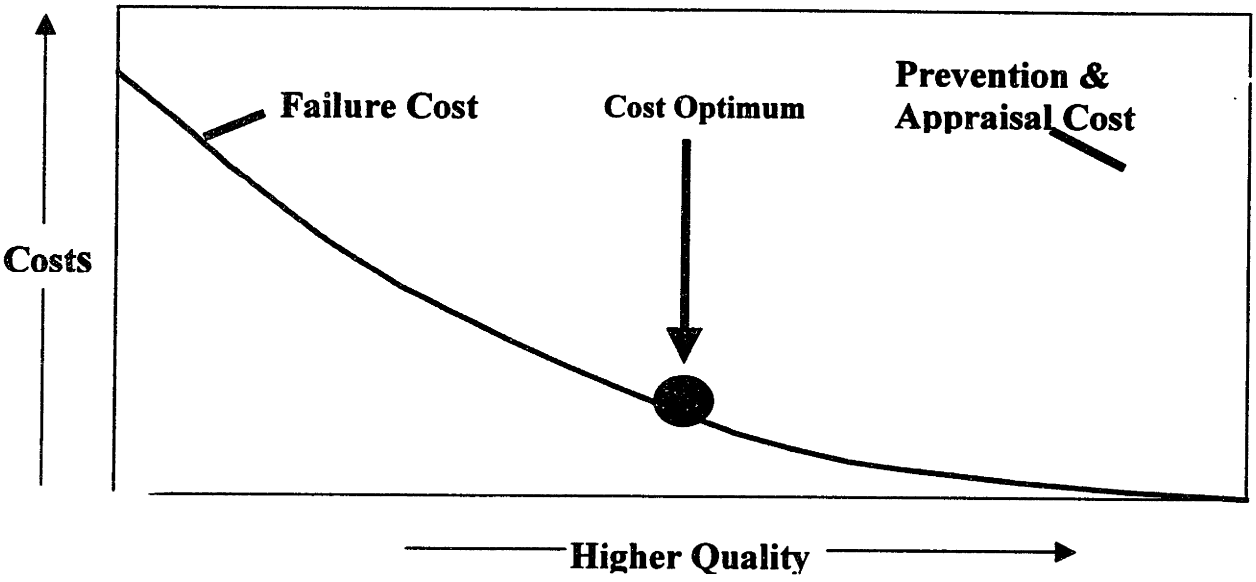

Figure 2-1 PAF Quality Model

In the model pictured above, both external and internal failure costs are summed together to form the failure cost curve while the prevention and appraisal costs are added together to form the prevention & appraisal cost curve. The two curves flow in opposite directions showing that increased spending on prevention & appraisal costs are necessary to decrease costs associated with internal/external product failure. In this model, the cost optimum occurs at the point where the absolute value of the slopes of the two curves is equal to each other. Going beyond this optimum point results in increasing instead of decreasing quality costs since the extra resources spent on prevention/appraisal far outweigh the benefits that can be expected to be realized through decreased costs associated with internal/external product failure. One important implication of the PAF model is that reducing failure costs to zero is undesirable since, at the cost optimum, a certain number of failures must be tolerated[2].

2.3 Quality and Business Performance

While the direct benefits of increasing quality, such as reduced manufacturing cost, is easy to see, the indirect business benefits, such as increased sales or customer satisfaction, is much more difficult. Currently, there is much in the literature that attempts to empirically quantify the indirect business benefits that can be potentially realized by increasing quality. One such model, which attempts to combine all the current literature studies together, is presented below[1]:

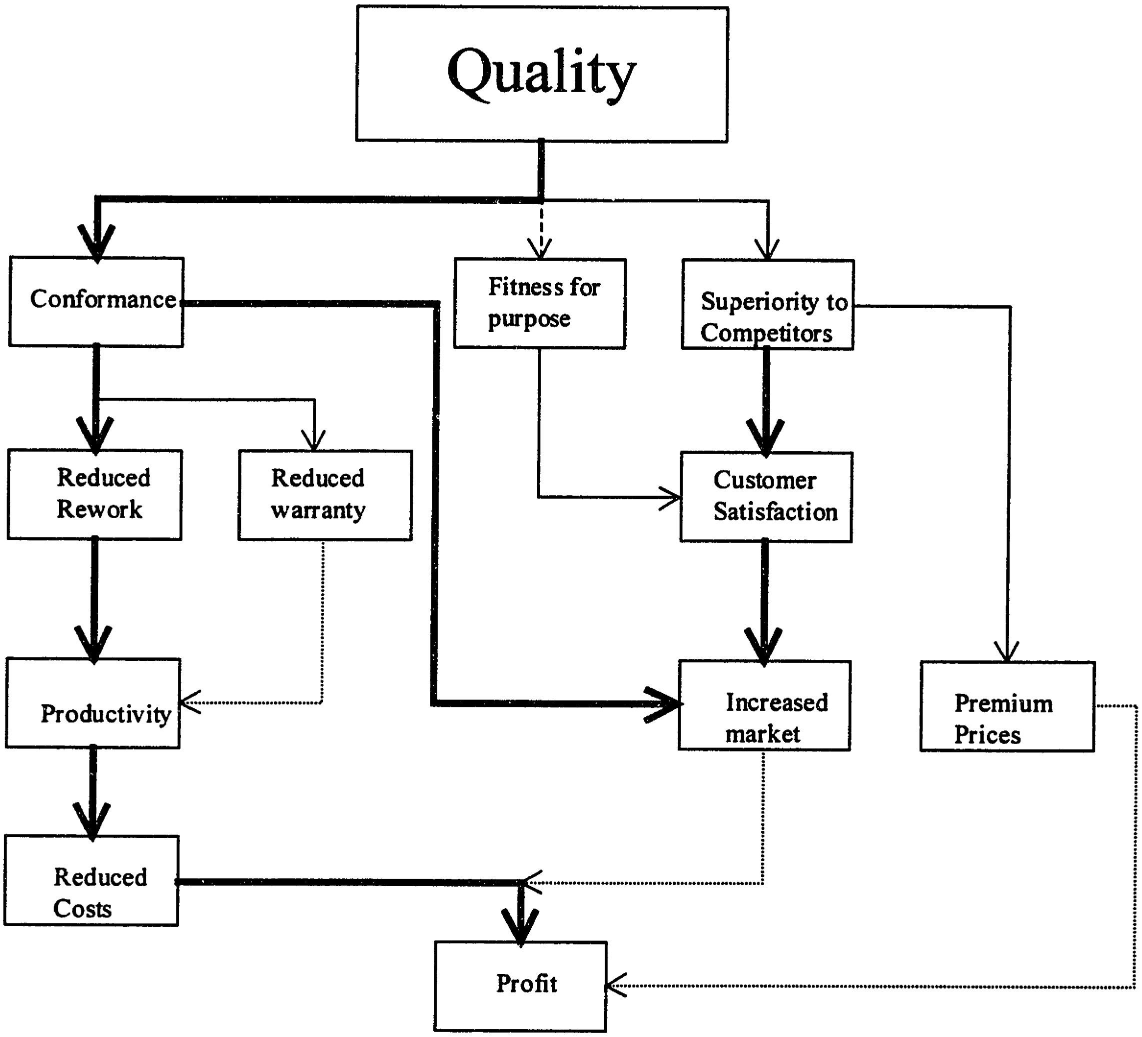

Figure 2-2 Empirical Relationship between Quality and Key Business Performance Metrics

In figure 2-2, the bold lines indicate strong correlation. The thin lines indicate weak correlation, and the dotted lines represent correlations which can logically be concluded but not supported by any formal studies. A quick glance at figure 2-2 shows how improving quality with respect to product conformance and with respect to the product quality of one's competitors leads to increased profits and market share.

3 TENNECO AUTOMOTIVE'S APPROACH TO QUALITY

TA's current quality management system called Total Cost Management (TCM) uses Cost of Quality as the primary driver to reduce costs and improve product quality. Under this approach, plant managers are expected to come up with and complete a certain number of improvement projects that will reduce the cost of quality metric. Cost of Quality, as defined by TA only include the "hard costs" that are incurred as a result of producing bad quality product. Thus, appraisal and prevention costs are not counted as being part of TA's COQ. Each quarter, a new COQ figure, represented as a % of sales, is calculated and sent out to various managers.

TA's TCM system has, up to this point in time, produced mixed results. On the positive side, the system has sharply focused both the OE and AM business units on cost reduction. All of TA's factories have generated lists of cost reduction projects and have been held strictly accountable to meet certain cost reduction goals. On the flip side, however, most of the cost reduction that has currently been realized has fallen mainly under the categories of "productivity improvements" (ie. labor savings) or "material savings" (ie. switching from one raw material type to another). Both of these categories do not directly belong to any one of the categories that comprise Cost of Quality.

Consequently, though TCM drives down costs, it does not necessarily drive down costs associated with bad quality. A possible explanation for this lack of correlation between TCM cost reduction and Cost of Quality stems from the fact that the goal of cost reduction far outweighs the goal of improved quality. Whereas it is possible to identify products to improve both cost and quality, it is much easier to go after projects that just reduce cost. Projects that involve improving quality usually are very difficult to achieve since these typically involve improving the underlying process or machine. Consequently, projects associated with quality are easily neglected, especially in light of the pressure to get short-term cost reduction results. Another issue is that the COQ statistic is, in a sense, much too general to be acted upon by a particular factory unit. Because COQ is a rolled-up figure, it is very difficult to pinpoint why it goes up or down at any given point in time.

4 A NEW APPROACH TO QUALITY: SIX SIGMA

4.1 Historical Perspective

Six Sigma has its roots in Motorola in 1979 when a senior manager at the company declared that the company's quality "stunk." With this realization, Motorola formally established a corporate quality officer in 1980 and, in

1981, Bob Galvin, chairman of Motorola, challenged the company to achieve a 10x improvement in quality over the next 5 years. In 1985, the Communications Product Sector began to use Total Defects/Unit (TDU), a basic unit for measuring process capability, as the primary driver for improving manufacturing quality. (The Communications Product Sector, incidentally, was led by George Fisher who would later become CEO of Motorola). In 1987, Motorola formally adopted Six Sigma, a system to drive down TDU's to zero, and again was challenged by its chairman to achieve new aggressive quality targets (100x quality improvement over 4 years). As a result of its intense focus on quality, Motorola became the first Malcolm Baldridge Quality Award winner. The business results over the 1987-1997 time span which Motorola claimed to be a direct result of its Six Sigma Quality efforts were staggering. Results claimed included[3]:

- Elimination of 99.7% of all in-process defects corresponding to a 5.6 sigma level.
- Reduction in COQ of 84% per unit of product.
- Cumulative Manufacturing Cost Savings of $13 Billion.

Results such as these were soon noticed and other companies including Kodak, AlliedSignal, and, most notably General Electric began implementing their own respective Six Sigma programs in the early to mid-1990. The financial results reported by these companies in the popular literature were almost as equally impressive as those reported by Motorola:

- AlliedSignal reported direct cost savings of over $1.2 Billion since program inception in 1994[4].
- General Electric reported a small net loss due to implementation of Six Sigma in 1996 due to high training costs but reported net savings of $250MM and $800MM in 1997 and 1998, respectively[5].

As further evidence of the belief that Six Sigma can achieve real improvements in company operations, Wall Street analysts started taking notice of companies that implemented Six Sigma and even started giving them higher valuations. One analyst from Morgan Stanley, Jennifer Pokrzywinski, estimated "that by the year 2000, GE's gross annual benefit from six sigma could be $6.6 Billion."[4] A series of stock price graphs provided courtesy of Six Sigma Qualtech, a leading Six Sigma provider, shows evidence of firms whose stock price have gone up dramatically in response to future expectations that the firms, as a result of their Six Sigma efforts, will be much more profitable.

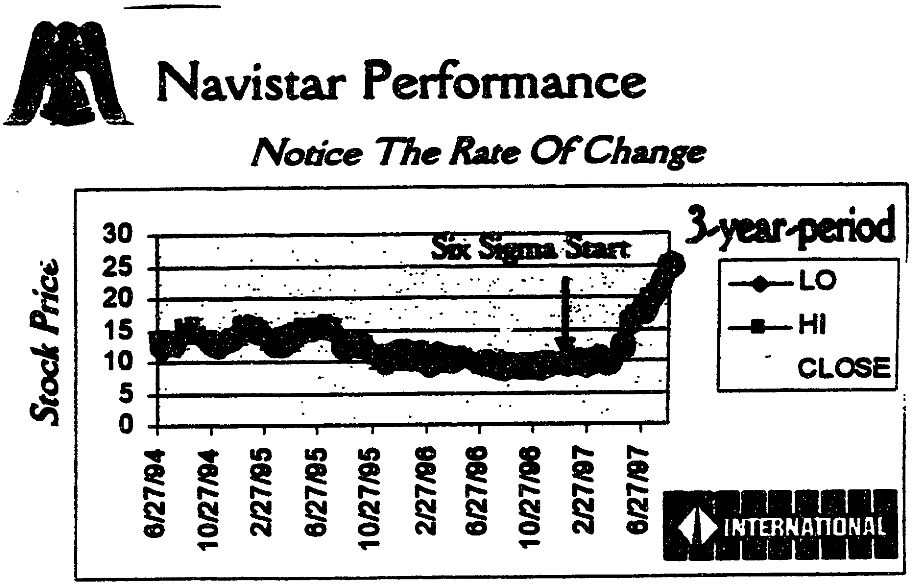

Figure 4-1 Navistar's Stock Performance

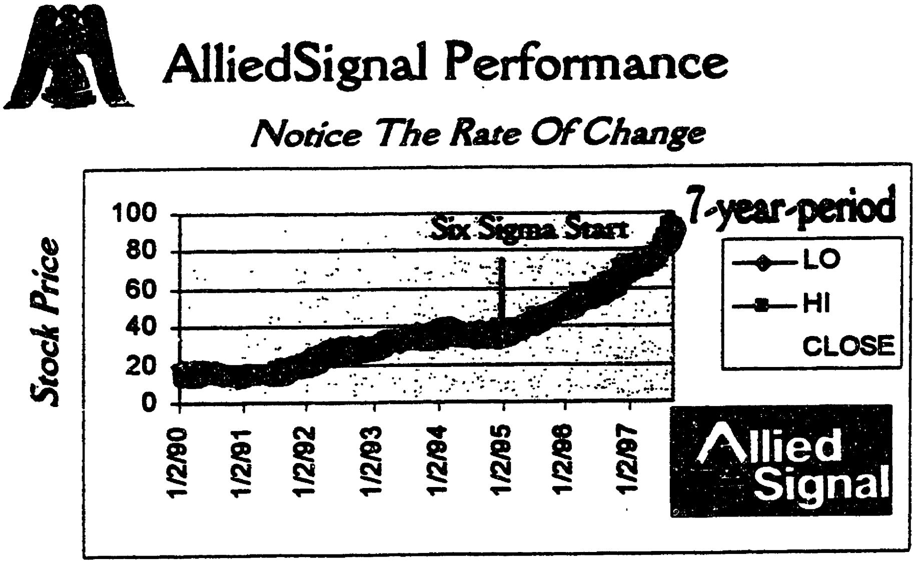

Figure 4-2: AlliedSignal's Stock Performance

4.2 Theory and Application

Much of the theory and practice of Six Sigma as formulated and developed by Motorola is captured in a seminal article "The Nature of Six Sigma Quality," (1997) by Mikel J. Harry, Ph.D. published by Motorola press. The Six Sigma quality model is shown below in figure 4-3.

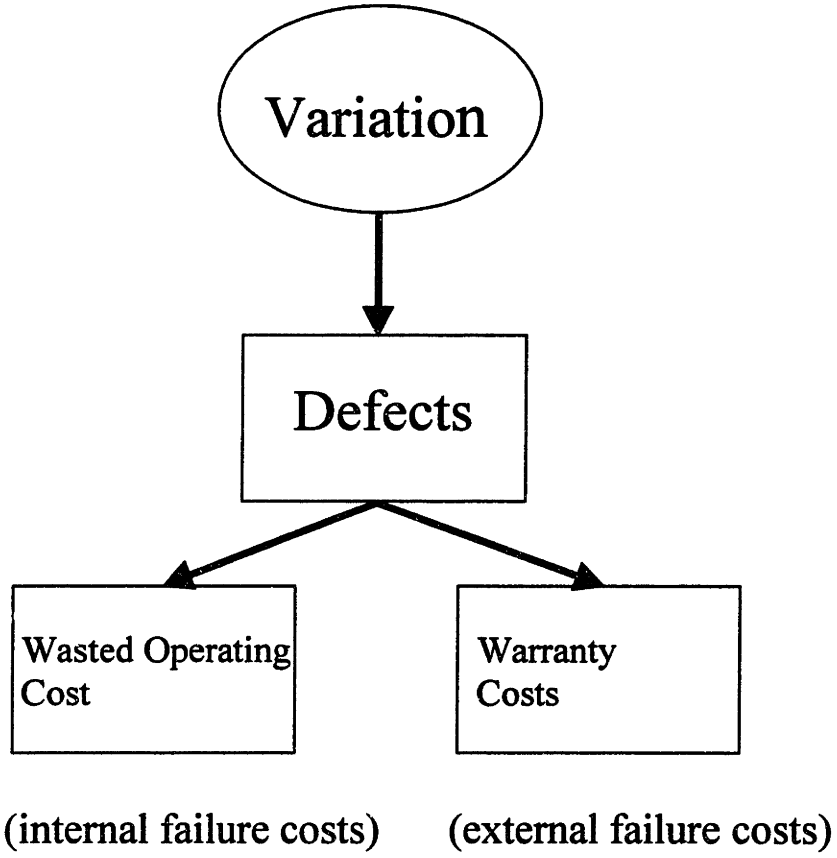

Figure 4-3 Six Sigma Quality Model

According to the model, process variation is the original source of all manufacturing related quality costs. Variation causes defects (ie. a non-conformities) which, in turn, lead to unwanted internal and external failure costs. Consequently, reducing variability, through the tracking and elimination of defects, is the key to product quality improvement.

One way to determine the extent to which a certain process is prone to producing defects is to characterize its sigma level. What do we mean by "the sigma level of a process?" For any given process, let us assume that it has a key measure or attribute that is normally distributed with a mean u, and standard deviation, sigma (σ). Furthermore, let us say that the process is in control as long as this key attribute is observed to be within the interval (u – 3σ, u + 3σ). Now, that we have established these definitions, we can now define the "sigma level of a process" as the distance, measured in units of σ, between the attribute mean u and its upper (or lower) specification limit. As the distance between the attribute mean and either specification limit gets larger, (ie. as the σ level of the process increases), the number of defects the process produces goes down. A 3σ process, for example, one in which the attribute process width and specification width are exactly the same distance away from the attribute mean, will produce defects at a rate of 2700 ppm. In contrast, a 6σ process, one in which the process width is only half the size of the specification width, as depicted in figure 4-4, will only produce defects at a rate of .002 ppm [6].

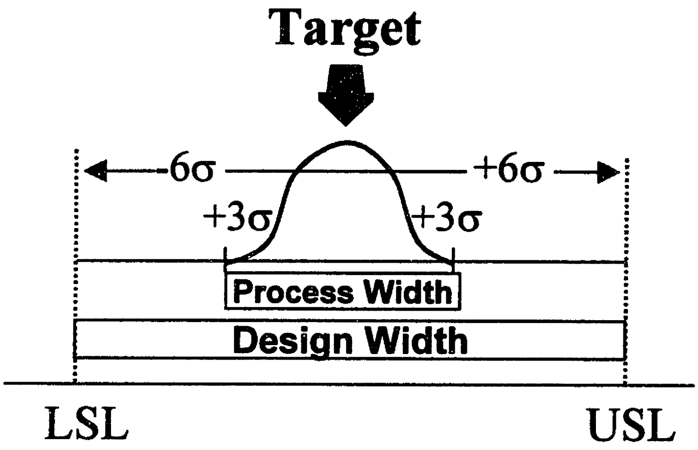

Figure 4-4 Six Sigma Capable Process

According to Harry's article, "The nature of Six Sigma Quality," most manufacturing processes are 4σ. These types of processes, on average, produce defects at a rate of 63 ppm. At first glance, this may look extremely low since such a process, in percentage terms, has only a .0063% chance of producing a defect. Considering this to be the case, is a 6σ level of process control really necessary?

To answer this question, we must consider two things. First, we must keep in mind that we should not look at any given process by itself, rather we must look at it as one process step among many that are needed to produce a given product. If we look at a process in this way, any incremental gain in process capability, even if very small, could have a potential large effect on the total number of defects generated since any such gains (or losses) will be passed down to other processes involved in the production of a given product. Another important thing to keep in mind is that the theoretical rate at which defects are be produced might actually be much different from the actual rate. Indeed, empirical data from Mikel Harry's article strongly suggests that most manufacturing process will naturally drift +/- 1.5σ from its mean during the course of normal operations. The implications of both of these factors in determining whether 6σ quality is really necessary is best illustrated using a relevant example.

In the illustrative example, let us assume that 1000 process steps are required to produce a given product. Let us also assume that 1000 units of this product are produced and sold to customers every year. To complete the analysis, we need at our disposal the following equation [6]:

$$Y = (d/u)^r e^{-d/u}/r!$$

Figure 4-5 Defect Probability Equation

Figure 4-5 gives the expected probability that a given unit of product will have a certain specific number of defects r. The term d/u is defined as the total number of defects generated per unit of product (TDU). The basic assumption underlying figure 4-5 is that defects are randomly distributed and follow a Poisson distribution. In the special case where r= 0, figure 4-5 simplifies to [6]:

$$Y = e^{-d/u}$$

Figure 4-6 Rolled Throughput Yield

The equation shown in figure 4-6, called the Rolled Throughput Yield (RTY) is the probability that a given unit of product is produced with no defects[6].

Let us now assume that all our manufacturing process steps, nominally, operate at 4σ. Let us also assume that we can produce product under one of the following four scenarios:

- Scenario 1: Manufacturing steps operate at 4σ. (Process does not drift under normal operating conditions). Inspection is not used to catch and prevent defects from reaching customer.

- Scenario 2: Manufacturing steps operate at 4σ. (Process does not drift under normal operating conditions). Inspection is used to catch and prevent defects from reaching customer. Inspection is 99% effective at catching these defects.
- Scenario 3: Manufacturing steps operate at 4σ +/- 1.5σ (Process drifts from its mean during course of normal operation). Inspection is not used to catch and prevent these defects.
- Scenario 4: Manufacturing steps operate at 4σ +/- 1.5σ (Process drifts from its mean during course of normal operation). Inspection is used to catch and prevent defects from reaching customer. Inspection is 99% effective at catching these defects.

By using the two equations shown in figures 4-5 and 4-6, we can now calculate what the defect distribution would be among the 1000 product units produced under each of the above 4 scenarios. A summary of the results of this exercise is shown below in Figure 4-7.

Number of defects (r)	**4σ process Scenario 1 (no drift w/o inspect).**	**4σ process Scenario 2 (no drift w/ inspect)**	**4σ process Scenario 3 (drift w/o inspect)**	**4σ process Scenario 4 (drift w/ inspect)**
0	939	999	2	940
1	59	1	12	58
2	2	0	38	2
3	0	0	79	0
4	0	0	124	0
5	0	0	154	0
6	0	0	160	0
7	0	0	142	0
8	0	0	111	0
9	0	0	77	0
10+	0	0	101	0
Total Product Produced	1000	1000	1000	1000

Figure 4-7: Product Defect Distribution under 4σ Process Capability

Under scenario 1, 4σ process capability seems adequate since most of the product produced have no defects. Under scenario 2, in which we are able to "inspect in" quality, only 1 defective unit of product ultimately ends up in the hand of the customer. Under scenario's 3 and 4, however, in which mean drift is assumed to occur, the defect distributions look dramatically worse. In scenario 3, for example, we only obtain 2 units of defect-free product. The rest contain multiple defects with most products exhibiting 4 or more. Even under scenario 4, in which the product is inspected, 60 units of defective product still end up in the hands of the customer.

Figure 4-8 shows what the defect distribution of the product would look like under scenarios 1-4 assuming, however, in this case, that the process capability of the individual manufacturing process steps is 6σ instead of 4σ.

Number of defects (r)	**6σ process Scenario 1 (no drift w/o inspect)**	**6σ process Scenario 2 (no drift w/ inspect)**	**6σ process Scenario 3 (drift w/o inspect)**	**6σ process Scenario 4 (drift w/ inspect)**
0	1000	1000	997	1000
1	0	0	3	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10+	0	0	0	0
Total Product Produced	1000	1000	1000	1000

Figure 4-8 Product Defect Distribution under 6σ Process Capability

Under scenarios 1-2, as we may expect, all 1000 units of product are produced free of defects. Under scenarios 3-4, however, in contrast to what was shown in figure 4-5, most of the product, 997 in scenario 3 and all in scenario 4, respectively, are still free of defects as a result of higher process capability. In fact, even if we lower the inspection efficiency from the original 99% to 86% in scenario 4, we still end up with 1000 units of defect-free product.

From this relatively simple example, we can see why 6σ process capability can be attractive to a manufacturer from both a quality and cost perspective. By being able to absorb the 1.5σ mean drift which, as Mikel Harry asserts, is prevalent in most manufacturing processes, a manufacturer can produce a given product with less defects, less cost (due to reduced need to spend extra resources on extensive inspection, testing, and catching defects), and less probability of shipping bad product to customers. The results obtained here help corroborate the six sigma quality model proposed in figure 4-3.

How do we go about increasing the sigma level of a given process? Mikel Harry, in pages 17-20 of "The Nature of Six Sigma Quality" article explains that such increases can be achieved by carefully applying the proper statistical tools in a four phase approach involving defining the process, establishing initial process capability, optimizing the process through design of experiments, and setting the proper controls for the few key "critical" variables (these were determined in phase 3) that effect the process. A depiction of the results that can be achieved by increasing process capability is shown in figure 4-9 [3].

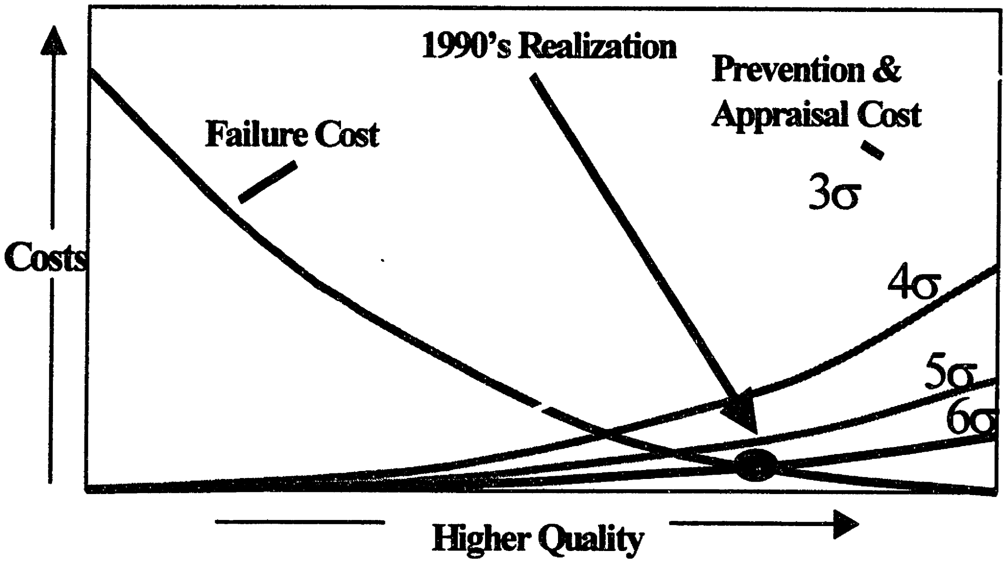

Figure 4-9 PAF Quality Model Applied to Six Sigma

The above PAF model is quite different from the original one shown in figure 2-1. Under this new depiction, an ideal cost minimum target no longer exists since failure, appraisal, and prevention costs can be continually reduced by increasing the sigma level of one's manufacturing process ultimately allowing one to achieve near zero cost of quality along with zero failure costs. What the model is showing us is that quality and cost are not trade-offs as the old PAF quality model would have us believe, but, instead, are complementary to each other so that the producer of highest quality can also be the producer of lowest cost.

Moving towards zero failure costs, however, is not a "cost-free" process as the above model, at first glance, might indicate. Going from one sigma level to another will require some level of investment. The actual level of investment will depend upon a company's cost saving and sigma level target. The rate at which a company wants to reach this target will also be a factor in the investment decision. A higher investment level, for example, will be required for a company that wants to reach 4 sigma in two years versus one that wants to get there in five years. Whatever the investment level, the associated expected financial benefits, should be attractive.

5 SIX SIGMA BENCHMARK STUDY

5.1 Study Overview

The following benchmark analysis is based on a series of interviews conducted during the July and August 1998 timeframe with seven Fortune 500 companies. The companies represent a good mix of different industries, revenues, and products. The individuals interviewed include many senior managers closely involved with their respective Six Sigma programs. Due to the sensitive nature of some of the material being reported, company names have been omitted. They will be identified from this point forward as companies A, B, C, D, E, F, G, respectively. Most of these companies launched their Six Sigma programs within the past five years.

Company	Revenue	People Interviewed	Basic Manufacturing	Launch Date
A	$89 Billion	Product Manager, Six Sigma Business Unit General Manager	Aerospace Plastics Durable Goods	1995
B	$29 Billion	Product Engineer,	Communications Semiconductors	1987
C	$15 Billion	Business Unit General Manager, Six Sigma Business Unit Leader	Automotive Chemical Aerospace	1994
D	$15 Billion	Manufacturing Manager, Six-Sigma Business Unit Program Manager	Chemical	1994
E	$7 Billion	Director of Quality	Automotive	1997
F	$2 Billion	Six Sigma Corporate Program Manager, Master Black Belt	Chemical	1997
G (BU of Fortune 250 Firm)	$1 Billion	Six Sigma Business Unit Program Manager	Agricultural Products	1998

Figure 5-1 Summary of Companies Studied

This report was designed to attempt to get behind all the "six sigma hype," and to assess whether the Six Sigma Business Strategy would really be an effective means to improve the overall quality of the Tenneco Automotive manufacturing process. It provides an analysis of the Six Sigma programs launched by companies A through G and the results which Tenneco Automotive might achieve by implementing its own program.

5.2 Definition of Six Sigma

The data collected from the company interviews suggest that there is no clear-cut definition of "Six Sigma". However, the interviews do indicate that, depending on the context in which it is used, Six Sigma can be viewed as a statistical measure, a special methodology to bring about process improvement, or business initiative. Each of these views is describe below:

- **Six Sigma as a Statistical Measure:** In the classic sense, six sigma is used to describe a process which has reached six sigma process capability, the details and characteristics of such a process are described in detail in section 4.2.

- **Six Sigma as a Methodology and Toolset:** In many cases, the term Six Sigma is used to describe the process of identifying customer needs and then linking them back to "critical to quality" (CTQ) processes. By using the Six Sigma problem solving methodology and toolset, these CTQ processes are improved and controlled to yield dramatic improvements in customer satisfaction as measured by warranty costs, customer returns, and operational performance as measured by productivity and reduced manufacturing costs.

  The Six Sigma Methodology consists of four phases:

  - Measure: Identify and map relationships between process inputs and outputs
  - Analyze: Determine the "critical few" inputs which have the most effect on customer satisfaction, product quality, and manufacturing cost
  - Improve: Increase the process capability of the "critical few"
  - Control: Sustain the gains made on the "critical few" through the establishment of long term controls

A representation of this improvement process is shown below:

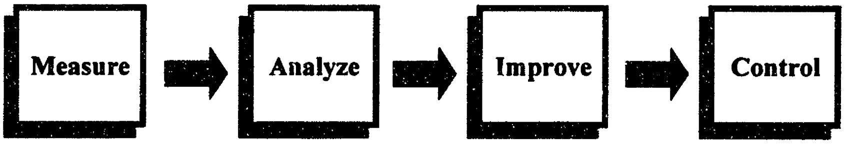

Figure 5-2 The six sigma breakthrough strategy

The major tools used in the four phases include:

Measure Phase:

- Process Mapping: Identify key inputs that significantly affect the characteristics of key outputs as defined by final customer requirements
- Cause and Effects Matrix: Relate key inputs to key outputs
- Failure Mode Effects Analysis (FMEA): Among key inputs, identify those that could cause the most harm if not properly controlled
- Measurement Capability Analysis: Determine how accurately key inputs and outputs can be currently measured by performing Gage Repeatability and Reproducibility studies

- Process Capability Study: Establish short and long-term capabilities of key inputs as measured by Cp and Cpk

Analyze Phase:

- Multi-variable Studies: Identify major sources of variation and eliminate "noise" variables from those that may be truly critical to the process by using statistical screening experiments, hypothesis testing, and correlation/regression
- Process characterization: Determine the statistical nature/distribution (ie. poisson, Normal) of key inputs

Improve Phase:

- Design of Experiments: Optimize and improve process capability of those key inputs which have the biggest effect on key outputs
- Response Surface Experiments: Finely tune/optimize setting for a particular key input.

Control Phase:

- Control Plans: Identify and establish control systems for key inputs which were optimized in the improve phase. Control systems can include the establishment of precontrol plans (monitoring of inputs), control charts/spc (monitoring of outputs), mistake proofing, and the development of support systems such as maintenance plans, system to track special causes, required critical spares lists, and trouble-shooting guides.

- **Six Sigma as a Business Initiative:** On an even higher level, Six Sigma is the name given to many corporate-wide programs. These corporate-wide initiatives tend to be less concerned with Cpk and sigma levels than with reducing errors and variability in all company processes and transactions.

  The data suggests that most of these programs usually focus on one of two objectives:

  - Increase Product Conformance: Six Sigma packaged as a "Quality" Initiative
  - Reduce Base Business Costs: Six Sigma packaged as an "Operational" Initiative

The structures put in place to manage these corporate programs can range from informal to formal as shown in figure 5-3.

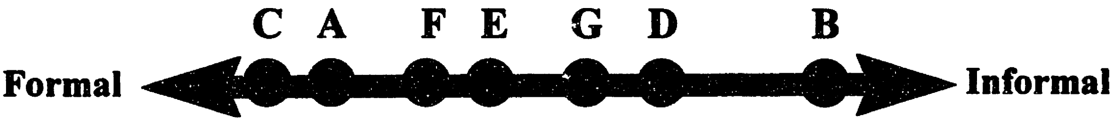

Figure 5-3: Distribution Of Organizational Structures Among Companies Interviewed

Companies with informal program structures have people perform improvement projects within the context of their current job responsibilities. Formal training is also not specified. Informal structures tended to arise in companies which already had highly valued quality and internal training departments with a firm grasp of quality tools.

Companies with formal program structures have people perform improvement projects within the context of roles dedicated to Six Sigma. Standardized training, metrics, and methodology are used throughout the organization. Formal structures tended to arise in companies that did not have any previous formal quality initiatives or programs, and which had a basic understanding of quality tools. An example of a formal Six Sigma program structure is shown in Figure 5-4.

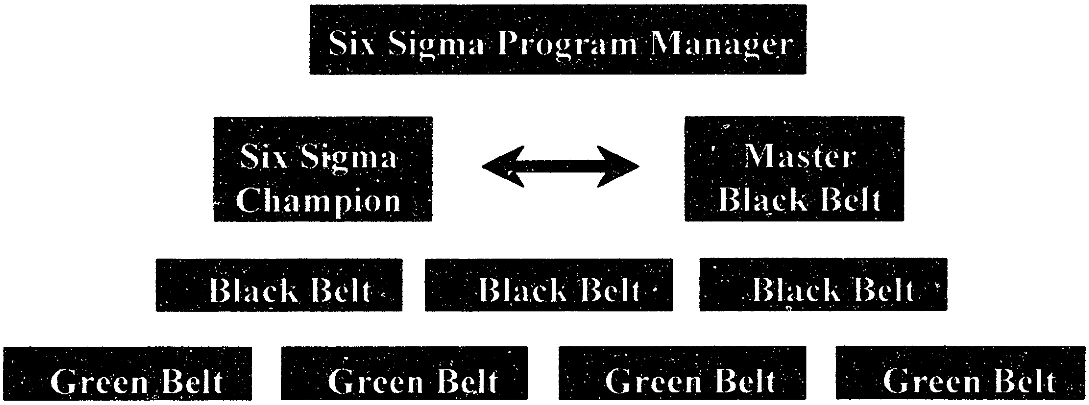

Figure 5-4 Example of Highly Formal Structure

5.3 Definition of Six Sigma Roles

The roles and responsibilities of those individuals involved in formal Six Sigma programs as shown in figure 5-4 are described in detail below:

- Six Sigma Program Manager-This individual is responsible for providing strong leadership and direction for the company's Six Sigma efforts. He or she is the recognized formal head for the Company's Six Sigma program and usually is someone who has already established a strong reputation in the company. The Program Manager usually reports directly to the CEO.
- Champion- These are individuals who hold key leadership roles in the organization and ensure that the Black Belts have the resources and support to get projects done. Champions are especially pivotal for clearing up road blocks and breaking down barriers for Black Belts who may experience resistance by individuals within the organization. Black Belts are defined further below.
- Master Black Belt- These are individuals who have made significant impact to and gained the respect of the organization as a Black Belt. They are responsible for being technical mentors to Black Belts as well as identifying projects for them to work on. Experienced Master Black Belts spend most of their time training new Black Belts.
- Black Belts- These individuals form the most important part of the Six Sigma program. Black Belts are responsible for identifying and working on high impact process improvement projects that will significantly impact the company's bottom-line as well as product quality. These individuals undergo intense training in statistical tools that they then learn to apply in a very deliberate systematic manner to achieve process improvement breakthroughs. Most of these breakthroughs are achieved in small teams led by the Black Belt. Because these resources are so critical to program success, ideal Black Belts are individuals who are highly capable, have great leadership skills, and are well respected within the organization. Black Belts can be both full-time, in which they dedicate all their time to Six Sigma, or part-time, in which they do improvement projects on top of their current job responsibilities.
- Green Belts- These individuals primarily work on small process improvement projects. They get a scaled down version of the Black Belt training and many times assist Black Belts on process improvement efforts. In contrast to Black Belts, Green Belts typically have other responsibilities in addition to Six Sigma.

5.4 Implementation of Six Sigma

5.4.1 Obtaining Support for Six Sigma

For Six Sigma to succeed, an organization must embrace its tenets and be willing to commit time and resources to it at every organizational level. Data from the company interviews indicate that program support was achieved by different means as shown in figure 5-5.

Company	Source of Motivation	Key Program Champion
A	Mandate from CEO.	CEO
B	Recognition of poor quality.	CEO
C	Margins eroding.	CEO
D	Quality important part of Company Culture.	Quality Director/CEO
E	Quality important part of Company Culture.	Director of Quality
F	Margins eroding because of poor quality.	Senior VP/Director of Quality
G	Company in financial crisis because of poor quality.	Director of Quality

Figure 5-5 Gaining Internal Company Support

The above data shows us the key factors which can generate company-wide support for Six Sigma are:

- Direct CEO support
- Recognition that the business is not doing well because of poor quality
- A culture which highly values quality

5.4.2 Rolling Out Six Sigma

Training forms the major portion of most Six Sigma roll-out plans. Executive, champion, and Black Belt training are key parts of the roll-out plans for companies that want to establish formal structures. In these cases, Black Belts are trained in "waves" of 25 to 50 people. Key elements of such a roll-out are shown below:

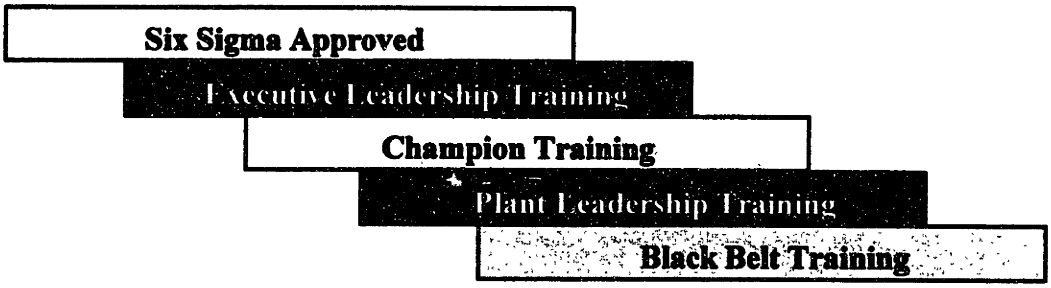

Figure 5-6: Typical Formal Six Sigma Roll-Out Plan

Companies that have informal structures rely heavily on internal training resources to transmit Six Sigma tools and principles to the appropriate individuals

5.4.3 Monitoring Six Sigma

Sustaining program results and momentum is achieved through periodic, formal project reviews by champions, plant managers, and senior management, and through the monitoring of key metrics at both a project and overall program level. Metrics used at companies A through F are summarized in Figure 5-7.

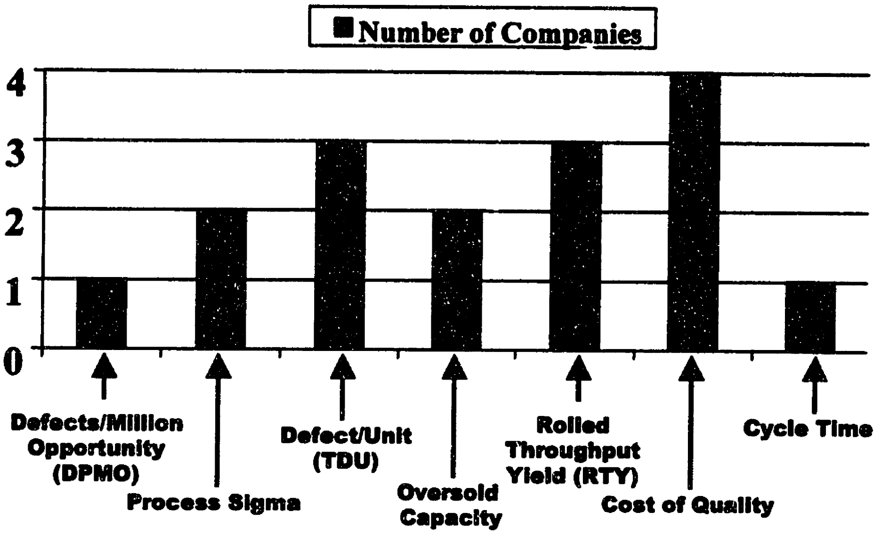

Figure 5-7 Summary of Metrics Used to Measure Six Sigma Program Success

The top three metrics cited by these companies were Cost of Quality, RTY, and TDU. Definitions for each of these metrics are given below:

- Defect/Unit (TDU): Total number of defects created by a given process and all previous processes, divided by the total number of units of a particular product produced. The TDU is calculated by adding up all the defects per unit associated with each individual process step of a given process as shown in Figure 5-8.

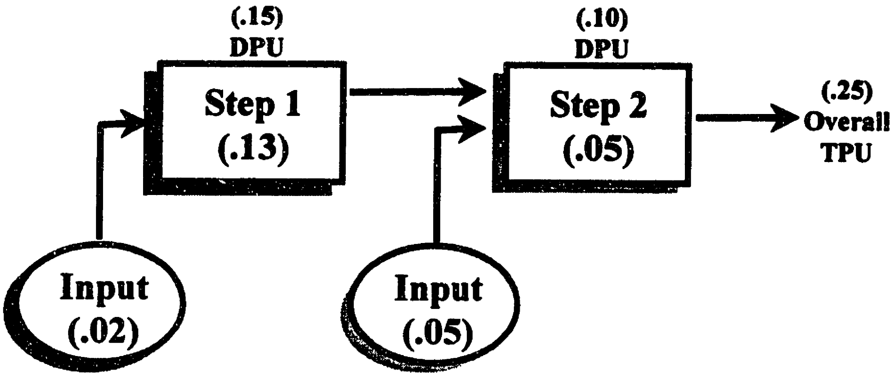

Figure 5-8 Calculating the TDU for Given Process

- Defects/Million Opportunity (DPMO): TDU/Total Opportunities Per Unit where an opportunity is defined as a step or procedure in a given process, which has the potential to create a defect if not performed correctly. A DPMO can be converted to a sigma level.
- Rolled-Throughput Yield (RTY): A measure of process yield calculated by multiplying the first pass yield of all the individual steps which make up a given process. Figure 5-9 pictorially describes how RTY is calculated.

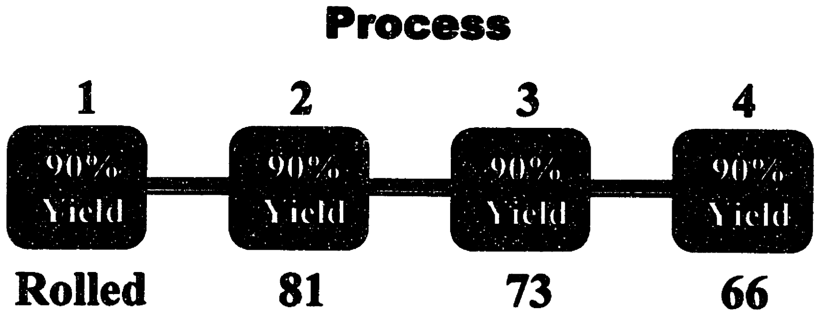

Figure 5-9 Calculating RTY

- Cost of Poor Quality: Costs of failing to produce and deliver 100% quality first time through. The key elements of this metric include rework, warranty, customer returns, and scrap. Prevention and appraisal costs, which are soft costs, are sometimes not included in this metric.
- Cycle Time: The time required to produce one unit of first pass quality through a given process step.
- Oversold Capacity: Equipment for which there is more demand than actual capacity. Utilization of oversold capacity is targeted to be as close to 100% as possible.

5.5 Manufacturing Benefits of Six Sigma

As Figure 5-10 indicates, the companies interviewed believe that Six Sigma is effective at reducing cycle time, scrap, rework, product recalls, and "other" manufacturing costs. This "other" category includes items such as capital expenditure, inventory levels, inspection costs, and additional waste incurred due to rework.

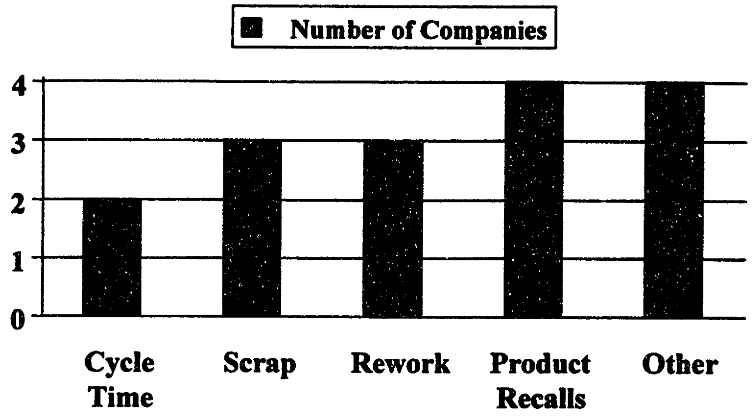

Figure 5-10 Items Cited as having been improved through six sigma

5.6 Financial Benefits of Six Sigma

5.6.1 Reported Savings

As mentioned before, Black Belts determine the level of cost savings that can be achieved in a Six Sigma program. Figure 5-11 shows the effectiveness of Black Belts at companies A, C, E, and F.

Company	Percent of Time Devoted to Improvement Projects	Average Savings* Achieved per Project	Average Annual Number of Projects Completed per Black Belt	Average Annual Savings per Black Belt
A	100%	$112,000	3	$ 336,000
C	100%	$350,000	3	$1,050,000
E	50% 100%	$ 75,000 $ 75,000	2 4	$ 150,000 $ 300,000
F	50%	$ 70,000	3	$ 210,000

*Savings refer to "hard" dollars, which can be added to company bottom-line

Figure 5-11 Productivity/output of Different Company Black Belts

From figure 5-11, we can calculate the average savings for dedicated Black Belts (ie. those who spend 100% of their time working on improvement projects) to be $318,000. In this calculation, we do not include Company C, which seems to be an outlier. We can also calculate that the average savings for non-dedicated Black Belts (ie. those who spend about 50% of their time on improvement projects) to be $180,000. Thus, it looks like dedicated Black Belts save about twice as much money as non-dedicated ones.

Figure 5-12 summarizes the percent annual reduction in cost of quality, base manufacturing cost, and internal defects that were realized by companies A, B, C, and D

Cost Item	Reduction/Yr
Cost of Quality (as % of sales) (Company C)	20%
Cost of Quality (as % of product cost) (Company B,C)	17-30%
Base Manufacturing Cost (as % of sales) (Company A,D)	0.7-2.5%
Internal Defects (Company B, D)	13-60%

Figure 5-12 Reported savings from Six Sigma

The data shows that the potential cost savings could be significant. For example, by launching a Six Sigma program, a $3 billion company could conservatively reduce base manufacturing cost (as a % of sales) by a 0.7% which would translate to a savings of about $21 million per year.

5.6.2 Reported Costs

The major cost items of Six Sigma as indicated by companies C, E, F, and G are shown in figure 5-13.

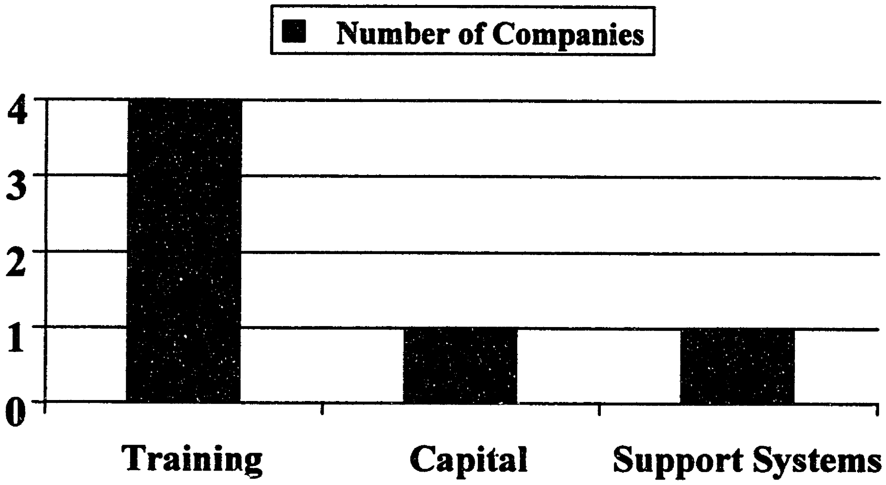

Figure 5-13 Major Costs as Identified by Companies C, E, F, G

Training by far, was mentioned as the predominant program cost. Although company F mentioned there might be some need for capital expenditure, depending on the project type, other companies indicated that Six Sigma is able to generate cost savings without investments in capital.

5.7 Additional Benefits

Other benefits of Six Sigma that surfaced from the various interviews but that could not be neatly put into any sub-sections of its own include:

- Culture of perfection in product quality
- A technical methodology for root cause analysis
- Improved operating performance
- Leadership bench strength
- Standard languages, metrics, and approach across business units
- An initiative that is simple, proven, and becomes institutionalized

Reaping these benefits will require:

- <u>Significant investment in training</u>: Getting a critical mass of process improvement leaders, or Black Belts, into the organization is the key to achieving breakthroughs in product quality and financial performance.
- <u>Sustained commitment from top management</u>: Top management must show strong visible support for Six Sigma.
- <u>Integration of Six Sigma into Tenneco Automotive's Current Business Processes</u>: Six Sigma must become a seamless part of the way Tenneco Automotive currently does business.

A more detailed discussion regarding the critical factors that must be considered and addressed to make Six Sigma a success are further explored in chapter 7.

6 SIX SIGMA ANALYTICAL MODELS

6.1 Six Sigma Macro-Model

6.1.1 Model Overview

To determine whether Six Sigma would be a good investment for Tenneco Automotive, we built a financial model that took into account all major program costs and savings that were reported in the benchmark study. The basic framework for the financial model is shown in figure 6-1.

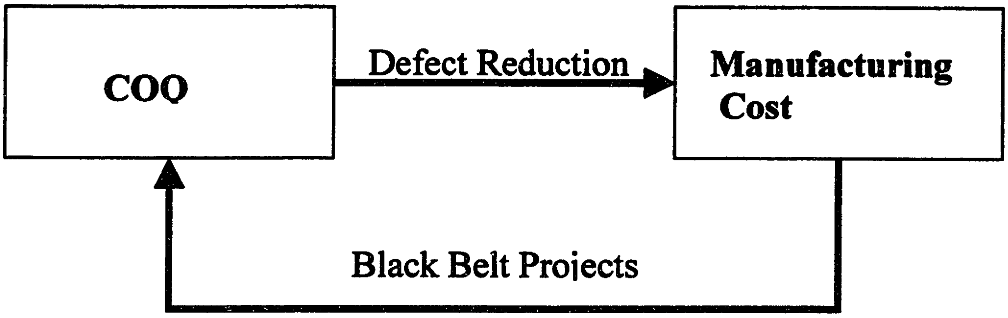

Figure 6-1 Six Sigma Cost Reduction Model Framework

In this framework, we assume that Tenneco Automotive adopts a formal six sigma program structure as described in section 5.2 in which specialized process experts known as "black belts" work on projects to reduce manufacturing defects.

The key inputs required by the model include:

- Number of Full-time Black Belts (BB) deployed/yr.
- Number of Part-time BB deployed/yr.
- Training Cost/BB (training fee paid to six sigma consultant)
- Cost to Backfill Full-time BB
- Cost Savings/BB
- Six Sigma License Fee (Up-front fee paid to six sigma consultant. This expense is capitalized and amortized over 3 yrs.)
- Tenneco Automotive Financial Projections (including target earnings before interest and taxes (EBIT), cost savings, impact of cost savings on company net income, cost of goods sold, revenue, cost of poor quality)

Given these inputs, the Six Sigma macro-model will calculate, as shown below, the following numbers for the first three years of program implementation:

- Six Sigma Costs = [Total BB training costs] + [BB Back-fill cost]
- Six Sigma Cost Savings = [# of BB]*[Cost Savings/BB]
- Incremental Cost Savings = [Six Sigma Cost Savings] – [Original TA Cost Savings target]
- Additional Operating Income = [Incremental Cost Saving] – [six sigma costs] - [amortized portion of six sigma license fee]
- Additional Cash Flow = [Additional Operating Income]*(1-tax)
- New EBIT = [Projected EBIT] + [Additional Operating Income]
- Percent Increase (decrease) in EBIT: [Additional Operating Income]/[Original target EBIT]

The overall value of the investment opportunity is quantified by calculating:

- NPV = [Additional Cash Flow, year 1] + [Additional Cash Flow, year 2] + [Additional Cash Flow, year 3] + [Terminal Value]. Each term is discounted at Tenneco Automotive's appropriate Cost of Capital. Terminal value is estimated to be [Additional Cash Flow, year 3] + [Amortized portion of license fee] since beyond year 3 the entire value of the license fee has been amortized. Also, terminal value growth is assumed to be a perpetuity with zero growth.
- IRR = calculated from cash flows
- Payback (undiscounted) = calculated from cash flows.

An example of the macro-model is shown in Appendix A. The numbers in the model are there for illustrative purposes only and in no way reflect Tenneco Automotive's actual operating characteristics.

6.1.2 Base Case Scenarios

Two scenarios that Tenneco Automotive could pursue were analyzed. Both scenarios assume that Tenneco Automotive launches a Six Sigma program at the beginning of 1999.

In scenario 1, we assume a non-aggressive implementation strategy. We train 100 Black Belts in year one and 150 more in year two. A total target of 250 Black Belts is chosen to maintain an approximate ratio of 1 Black Belt: 100 employees, a ratio recommended by some of the companies we had interviewed. We also assume that these Black

Belts will be non-dedicated, that is they will work on Black Belt projects in addition to their current job responsibilities. Based on benchmark data, we will then assume that each Black Belt will save about $180,000/yr. Out of the Black Belt pool, we will train 10 Master Black Belts in year 1 and 25 in year two for a total of 35 Master Black Belts. We are assuming here that we need 1 Master Black Belt: 10 Black Belt, a ratio again recommended by certain companies that we had interviewed. Since the Master Black Belts will have to work on projects as well as mentor Black Belts, we will assume that they will not have time to perform any other "non" Six Sigma duties. Consequently, these individuals will have to be back-filled by outside resources. Furthermore, we assume we do not have any Green Belts and that Champions are cost-free and require no special training or back-filling.

In the aggressive implementation scenario, scenario 2, we make the same assumptions that we made before for scenario one except that, in this case, we assume that all Black Belts are 100% dedicated to Six Sigma activities. Consequently, all Black Belts need to be back-filled by outside resources. Because Black-Belts are 100% dedicated to Six Sigma, however, we will assume that they will save $318,000 instead of $180,000/yr. as was projected for scenario 1. The projected $318,000 savings/Black Belt is estimated from benchmark data.

Summaries of both scenarios are given below:

Scenario 1, nominal case:

	1999	**2000**	**2001**	**Time Dedicated to Six Sigma**
Total Black Belts	100	250	250	50%
Total Master Black Belts*	10	25	25	100%
Total backfill requirement for Master Black Belts	10	25	25	0%
Projected Savings/Black Belt**	$180,000			

*Master Black Belts come out of original Black Belt pool
**Average savings achieved by companies E and F who deployed part-time Black Belts

Scenario 2, aggressive case:

	1999	2000	2001	Time dedicated to Six Sigma
Total Black Belts	100	250	250	100%
Total Master Black Belts*	10	25	25	100%
Total backfill requirement for Black Belts and Master Black Belts	100	250	250	0%
Projected Savings/Black Belt**	$318,000			

*Masters come out of Black Belt Pool

**Average savings of companies A and E who deployed full-time Black Belts

The projected financial results in terms of additional operating income for both the nominal and aggressive cases are shown in figure 6-2. The actual y-axis values are not shown due to the proprietary nature of the analysis.

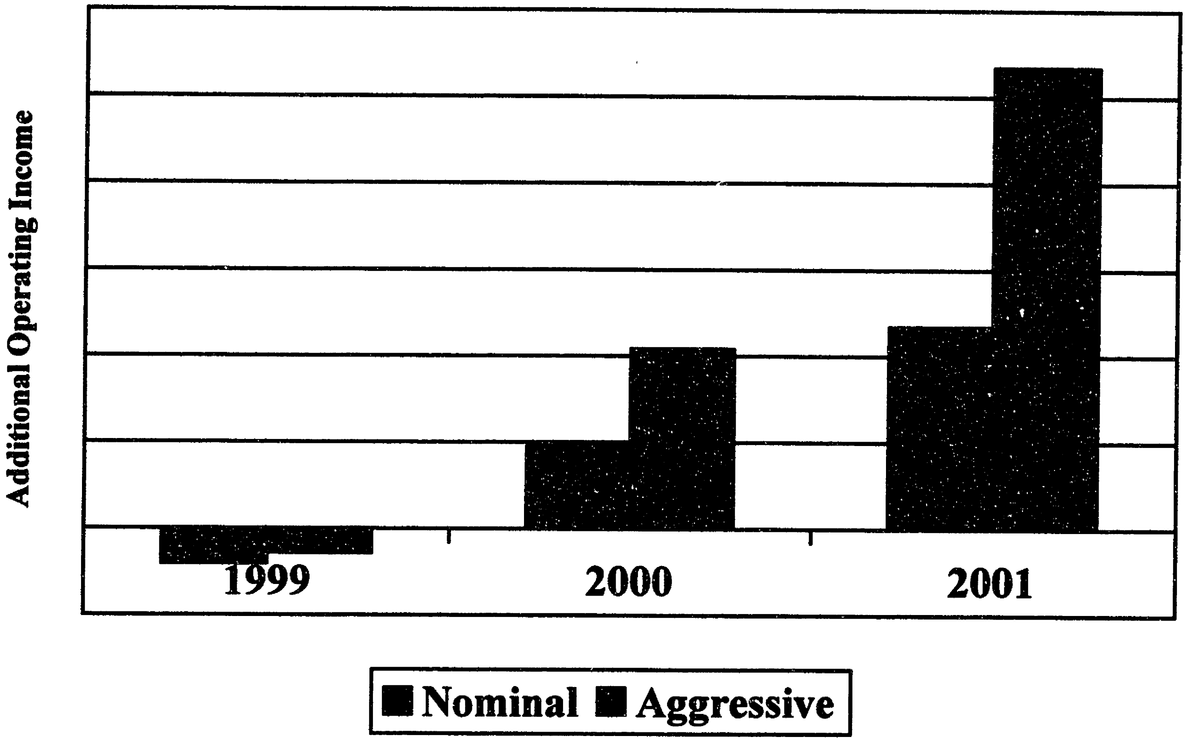

Figure 6-2: Additional Operating Income due to Six Sigma

As figure 6-2 shows, a slight loss in operating income occurs during the first year of Six Sigma implementation. In all three years, however, the aggressive case outperforms the nominal in terms of additional operating income that is added to Tenneco Automotive's bottom-line. The reason this is the case is that the annual cost savings per black belt is about twice as high ($318,000 vs. $180,000) in the aggressive case versus the nominal. This higher black belt cost savings more than offsets the higher investments costs that are required in the aggressive case due to the need to backfill all Six Sigma Black Belts.

Figure 6-3 shows what the COQ, as it is currently defined by Tenneco Automotive, would be as a percent of sales at the end of 1999, 2000, and 2001 for the nominal case, for the aggressive case, and for the current plan (the case in which Six Sigma is not implemented). These COQ projections are calculated in the macro-model by applying projected six sigma costs savings against Tenneco's beginning and ending projected COQ numbers for any given year. The major assumption in this analysis is that all the projected incremental six sigma costs savings can be directly applied against Tenneco's COQ projections. Again, y-axis numbers are omitted due to the proprietary nature of the analysis.

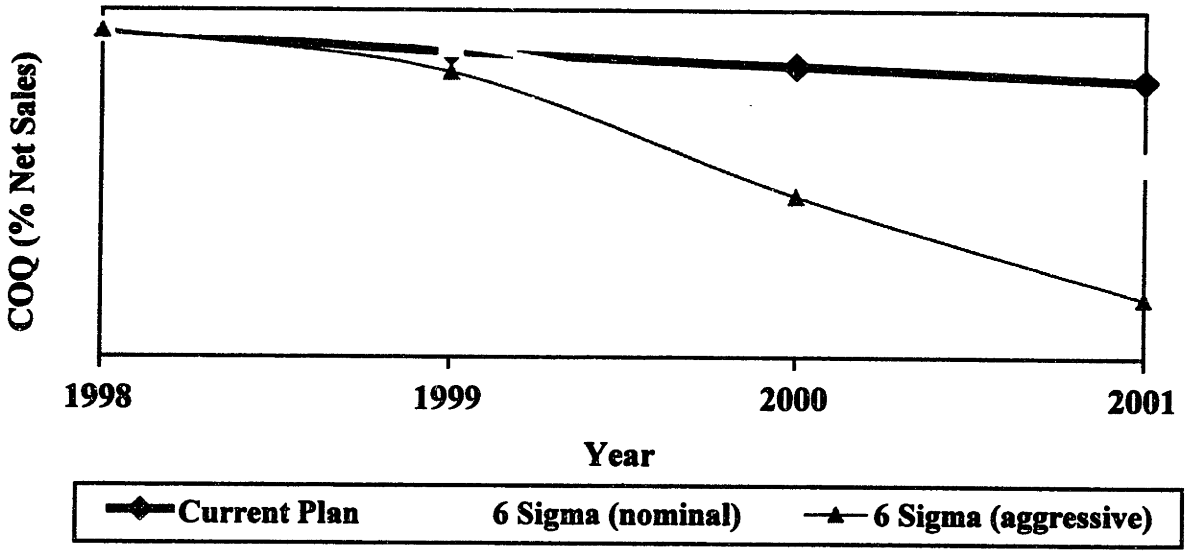

Figure 6-3: Cost of Quality Projection

From figure 6-3, we can see that COQ decreases at a much faster rate for the nominal and aggressive cases than for the current plan. The biggest reductions in Cost of Quality for the nominal and aggressive cases occur in 2000, and 2001. In 1999, due to the limited number of trained Black Belts and high investment costs, Cost of Quality for the nominal and aggressive cases are not much lower than for the current plan. In fact, during this year, Cost of Quality for the nominal case actually ends up being slightly higher than for the case in which Six Sigma is not implemented.

6.1.3 Sensitivity Analysis

Any model, no matter how well crafted, is only as good as the assumptions on which it is grounded. In this case, determining the cost savings per Black Belt is critical to knowing the overall attractiveness of the Six Sigma investment. Obviously, the higher the savings target, the higher the potential investment payback. Ultimately, though, one must ask the hard question of how much cost savings/Black Belt one really thinks is achievable. The benchmark data shows that higher cost savings/Black Belt can be realized by employing a dedicated team of Black Belt specialists whose sole job is process improvement vs. a team that does Black Belt projects "on the side" as part of their current job. Going this route, however, is not all that obvious since the higher cost savings/Black Belts that can be realized by using a dedicated Black Belt force could potentially be offset by the increased cost which could be incurred due to the need to hire and train new personnel to back-fill the jobs for which the Black Belts were previously responsible.

In any rate, one must make sure that a certain minimum savings/Black Belt is realized regardless of whether one does or does not use a dedicated Black Belt force since training costs under both scenarios are relatively high. Otherwise, if the minimum savings target is not realized, there is the danger that NPV of one's six sigma investment may actually be negative. To ensure that this does not happen, many companies, for example, have strict performance contracts that black belts must sign which pledge that a certain dollar savings for the given fiscal year will be achieved. Selecting only the best and brightest to be black belts is another way to better ensure that minimum savings targets will be met. Figure 6-4 shows, f or Tenneco Automotive's case, the potential NPV value of its six sigma investment as a function of Black Belt savings.

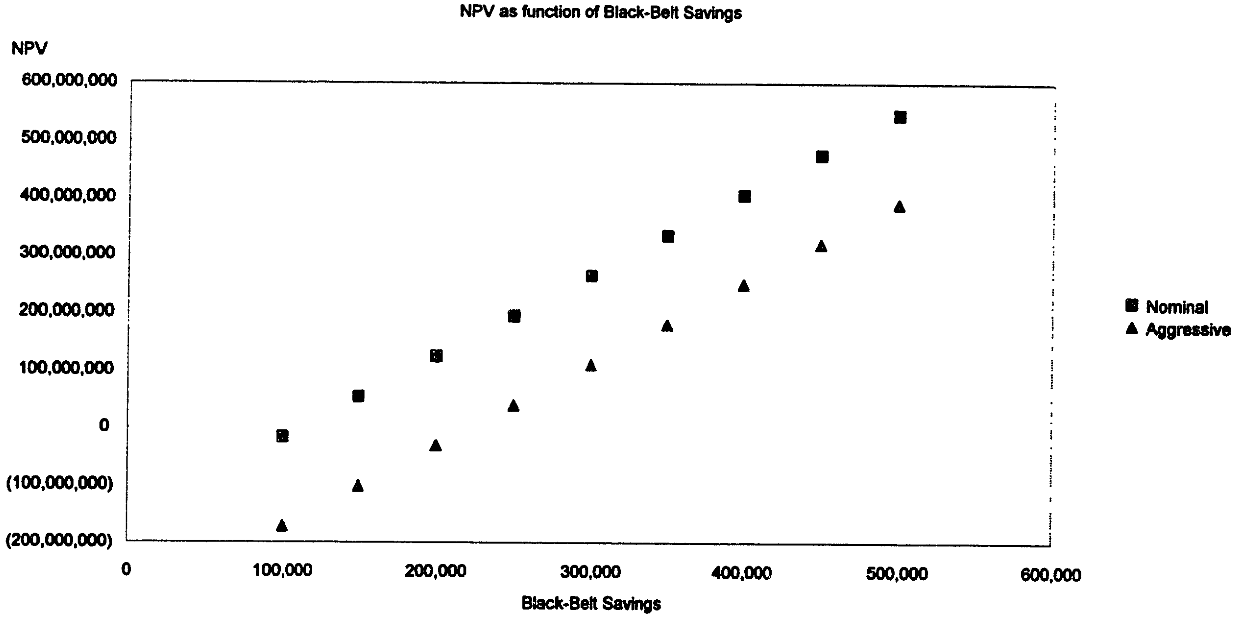

Figure 6-4 NPV as function of Black Belt Savings

We can make two important observations from figure 6-4. First, there are points along both curves, nominal and aggressive, which correspond to the same NPV. For example, a non-dedicated Black Belt work-force which is able to achieve, on average, about $200,000 savings/Black Belt produces the same results, in terms of NPV, as a dedicated Black Belt work-force that, on average, saves about $300,000/Black Belt. This illustration reinforces the fact, as mentioned previously, that determining whether one wants a dedicated versus a non-dedicated Black Belt workforce is a strong function of how much each savings each Black Belt will actually bring in to an organization. The second thing to notice is that, for both scenarios, there is a "minimum" savings hurdle rate/Black Belt that must be realized in order to keep the NPV of the six sigma investment positive.

6.2 Six Sigma Micro-Model

6.2.1 Model overview

The macro-model presented in section 6.1 provides a method to evaluate whether a six sigma investment would be an attractive investment to a given company. It does not, however, provide a way to identify which processes should actually be improved at the plant level. In order for the macro-model to be valid, Black Belts must have the means to identify the highest leverage process improvement opportunities so that their respective cost savings targets can be met. Given this need, the micro-model presented here was developed as a tool to help Black Belts achieve their quality and cost target goals.

On a general level, the model requires the Black Belt to characterize the process capability of each manufacturing process step for a given manufacturing line. As output, the model quantifies the current COQ for the line and the cost savings that could potentially be realized by improving one or more of the manufacturing process steps to a six sigma process capability level. Going through this analysis should help Black Belts decide exactly what process improvement projects should be tackled.

The general inputs required by the model for a given manufacturing line include:

- Manufacturing Operating Schedule (Number and length of Manufacturing Shifts, number and type of operators, total number of days/year line is in operation)
- Yearly production goal (units/year)
- Actual Cycle time (minutes)
- Theoretical Cycle Time (minutes)
- Revenue Generation/year ($/year)
- Material Cost ($)
- Wage rate (regular and overtime) ($/hour)

For each given process step of the line, the following inputs are needed:

- First-Pass Yield (number of product units which complete the process with no rework)
- Scrap Rate
- Unscheduled Machine Downtime.

Given these inputs, the micro-model will generate the following outputs:

- Rolled Throughput Yield (RTY) = [First Pass Yield]$_t$*[First Pass Yield]$_{t+1}$*[First Pass Yield]$_{t+2}$... for all processes t in the manufacturing line.
- [TDU]$_t$ = [1-First Pass Yield]$_t$
- [Total TDU] = Σ[TDU]t for all t.
- [PPM] = [Total TDU]/[# of process steps t]*1,000,000.
- [Sigma] = Calculated using PPM to Sigma conversion chart.
- [Required Production]t = [Required Production]$_{t+1}$/[Scrap Rate]$_t$
- [Required Labor]t = [Cycle Time]*[Required Production]$_t$ + [1-First Pass Yield]*[Rework Cycle time]
- [Theoretical Required Labor] = [Theoretical Production Requirement]*[Theoretical Cycle time]
- [Available machine time]$_t$ = [Total Available production time]*(1-[Machine Downtime]$_t$)
- [Scrap Cost] = ([Beginning Production Requirement] –[Theoretical Production Requirement])*[Raw Material Cost]

- [Extra Labor Cost] =([Required labor]- [Theoretical Required labor])*[wage rate] at bottle-neck operation
- Total Cost = [Scrap Cost] + [Extra labor Cost]
- COQ (as % of revenue) = [Total Cost]/[Total revenue]

A version of the full model is shown in appendix B. The required model inputs have been filled in for illustrative purposes only.

6.2.2 Case study: Model Application to Tenneco Automotive's Manufacturing Line

The example documented here illustrates how the micro-model can be used to characterize a manufacturing line, quantify the process costs, and identify high leverage process improvement opportunities that can be worked on by Black Belts.

The plant selected to do the study was located in Marshall, Michigan and produced mufflers for the OEM's (essentially the big 3 automakers). It was certainly one of Tenneco Automotives's more progressive facilities and had been experimenting with the principles of lean manufacturing. The plant senior leadership, Leonard Hartford, plant manager, and Brian Cole, manufacturing manager, put together a team for me comprised of operators, a manufacturing supervisor, senior engineer, plant controller, and materials manager to help me with the study.

The line that was selected for the study was the "Cell 08" muffler line which, historically, was one of their lower performing lines in terms of process stability, equipment breakdowns, and rework. The Cell 08 line can be essentially characterized as an assembly line in which the various muffler components, comprised of the muffler body/shell, various sub-assemblies made up of tubes (louvers) and plates (partitions), and the two muffler end piece (heads), are assembled together through a series of manual and automated processes involving various compression, bending/forming, and welding activities.

Among the several product families defined by muffler cross-section that were currently being produced, two product families, the 313058 and 192748 models, were singled out for more detailed analysis. The 313058 family (5.5"x11" cross-section size), which comprises about 64% of the total production volume of cell 08, is sold in high volume to OEM's. The 192748 family (5"x9.25" cross-section size), which comprises about 17% of production, is a low volume product sold to retail repair outlets.

The line analysis included the following series of steps:

- **General Data Gathering:** The general inputs (see section 6.2.1) that would be needed by the model were collected.
- **Process Map:** For both product families 313058 and 192748, respectively, the process steps and the equipment needed to complete them were mapped out. Both families essentially required the same process steps and equipment to produce. Upon completion of the map, the equipment associated with each process step were input into the micro-model. A summary of the process map is shown in figure 6-5:

Equipment	**Process**
Shell Laminator	Two sheets of steel spot welded together
Shell Lock Seamer	Welded sheets compressed and "locked" together
Walking Beam	Welded sheets conveyed to next equipment
Preflair	Welded sheets heat treated
BTM Press	Welded sheets deformed to form muffler body shell
Spot Weld	Shell is spot welded together
Front Stuff	Sub-assembly 1 (2 louver tubes + bushing (liner) + partition) and Sub-assembly 2 (1 louver tube + partition) "stuffed" into shell.
Infeeder Hydro #1	Hydro-welding operation performed on sub-assembly 1.
Infeeder Hydro #2	Hydro-welding operation performed on sub-assembly 2.
Stuffer #2	Another sub-assembly (partition + 2 louver tubes) "stuffed" into shell
Infeeder Hydro #3	Hydro-welding operation performed on sub-assembly 3.
Cover Lock Seamer	Entire shell is compressed and "locked" into place
Walking Beam	Entire shell transported to next equipment
Re-flange	Assembly heated and ends bent to form rim/rib all along the two ends of the shell
Head Press	2 end (head) pieces pressed and crimped into shell
Spinner and Walking Beam	Heads are spun and flattened
Size and Walking Beam	Inspect size of bushings located on two ends of shell
Final Inspect	Inspect entire muffler body

Figure 6-5 Muffler Assembly Process Map

- **Process Characterization:** For each of the process steps defined in the process map, the first-pass yield, scrap, and unexpected equipment down-time were input into the model. Although ideally, we wanted to pull this data directly from the factory databases, this was not possible since individual process step data were not available. For example, scrap data in aggregate were available but not on a process by process basis. Consequently, the team had to estimate what these values were for all the process steps in question. The operators who actually ran the cell08 line proved very helpful during this stage of the line analysis.
- **Data Analysis:** At this stage, the model outputs such as Process Sigma for the line, PPM's, and COQ were discussed and analyzed. Scrap costs, in particular, looked relatively high and a possible area to focus on in the near-term.
- **Project Selection:** All the process steps were carefully examined to determine which ones were the least process capable as defined by first-pass yield, scrap, and unexpected equipment downtime. Careful analysis seemed to indicate that, for both the 313058 and 192748 product families, the processes associated with the BTM's, Cover Lock Seamer, and Spinner/walking beam were the least process capable.

To calculate the financial benefit that Tenneco Automotive could potentially realize by improving the above three processes is relatively easy. In general, a six sigma process will have the following characteristics:

- First-pass yield = .999997
- Scrap = (1-.999997)
- Unexpected downtime = (1-.999997)

Plugging these numbers into the micro-model at any given process step will lower the COQ of the entire manufacturing line. The financial benefits, therefore, of any process improvement can be represented by the equation shown in figure 6-6:

$$\text{Financial Benefit} = [\text{Old COQ}] - [\text{New COQ}]$$

Figure 6-6 Benefits to be Realized through Process Improvement

Using the above equation, the benefits of improving the BTM, Cover lock Seamer, and Spinner/walking beam to a six sigma level were calculated, the result of which are shown in figure 6-7.

Process	**Potential Savings**
BTM	$629,000
Cover Lock Seamer	$774,000
Spinner/Walking Beam	$305,000

Figure 6-7 Project Opportunity Savings

Running the numbers indicated that any one of these three process steps could justify a Black Belt project. As we can clearly see, process improvement through Six Sigma can achieve substantial cost savings that was also alluded to earlier in the Six Sigma benchmark study (section 5.5.1).

- **Project Refinement:** To narrow the scope of the three project opportunities identified in the project selection phase, a comprehensive brainstorming session was held to identify, for each of the project opportunities, the top process problems and their potential underlying root causes. The results of the brain-storming session are shown in figure 6-8.

Project Improvement Opportunity	Top Process Problems	Potential Root Causes
BTM	• Muffler Body of inappropriate length formed • Muffler Body crushed/smashed during process	• Worn Tooling • Unstable mechanical locking mechanism • Variable Air Pressure • Water in Air lines
Cover Lock Seamer	• Lockseams do not lock • Wrong cover gets loaded • Vacuum System at out and in-feed breaks down • Cover gets stained with oil	• Vacuum Pressure Variation • Variation in material dimension • Drift in Roller/bushing alignment • Variation in oil level found in cup area
Spinner/Walking Beam	• Head (end pieces) of muffler misaligned and crushed • Burrs formed on end pieces • Bad seam formed between end head and muffler body	• Hydraulic fluid temperature variation • End piece dimension variation • Spinner speed variation • Variation in amount of crimp on head press • "Saddle shape" mechanism not adjusted properly • Inappropriate amount of lubrication/grease

Figure 6-8 Process analysis of Top Three Project Opportunities

This concludes the case study. The procedure outlined here, although specific to the Cell08 muffler line, can certainly be generalized and used to help other manufacturers analyze their processes and identify the process improvement opportunities that will have the most potential to impact two important elements of COQ, labor and material costs.

6.3 Comparison of Macro and Micro Models

The macro-model, presented in section 6.1, is a tool primarily geared to corporate planners while the micro-model, presented in section 6.2, is a tool primarily geared to the senior plant leadership. Both tools, however, try to achieve similar objectives, namely, to estimate the cost savings/financial benefit that can be achieved through process improvement efforts. A great way to validate the models is to compare the inputs/outputs generated by one against the inputs/outputs generated by the other. A big discrepancy between the two may indicate a fundamental flaw with how one or both of the models were constructed. Along these lines, a comparison of some key model inputs/outputs between the two models are shown in figure 6-9.

Variable	**Macro-model**	**Micro-model**	**Model correlations**
Process Sigma	Required as model input. Value calculated based on corporate data.	Calculated as model Output.	Values similar to one another.
COQ (% of sales)	Required as model input. Value calculated based on corporate data.	Calculated as model Output.	Micro-model value about 2x macro-model value
Cost Savings/Project	Required as model input. Average based on benchmark data $83,000	Calculated as model output. $569,000	Micro-model about 7X macro-model

Figure 6-9 Comparison of Macro and Micro Models

Figure 6-9 indicates two discrepancies between the two models. The first discrepancy is that the COQ value calculated in the micro-model is much higher than the COQ value used in the macro-model. There are two potential reasons for this discrepancy. First, the corporate cost database may not be capturing all the quality costs thereby underestimating the company COQ. Second, the estimated amount of scrap being generated by the 192748 and 313058 product families that were input into the micro-model may be higher than the real scrap rate. As mentioned in section 6.2.2, we must keep in mind that operators estimated the majority of the micro-model input values.

The second discrepancy is that the estimated cost savings/project between the two models are different. One reason for this discrepancy may be due to the fact that the values input into the micro-model were too high. If this were the case, the model would calculate a COQ and, hence cost savings/project, that would be much higher than what they should be. Another reason for the discrepancy may be due to a fundamental difference in how much cost savings each model assumes can actually be realized. The macro-model obtains this value from benchmark data. Thus, this value reflects the actual results that were achieved by Black Belts. Consequently, although the process improvement goal may have been to reach 6σ, the actual improvement results may have fallen short of this target. The micro-model, on the other hand, does not take these real-world limitations into account. It automatically assumes that the process can be improved to 6σ which would result in the -model over-estimating the cost savings that can be realized for any given project.

To illustrate this concept, let us assume, for example, that we have a 4σ process. If we use the micro-model that assumes the process can be improved to 6σ, the new, improved process would produce about 1800x defects less than what it had produced previously. Let us say that, in dollar terms, this corresponds to savings of about $569,000. In reality, however, let us assume that a Black Belt can only improve our 4σ process to 5.5σ. In this case, the improved process would only generate 207x fewer defects than what it had produced previously. Consequently, the actual achievable savings would approximately be [207/1800]*$569,000 = $65,435, a value much closer to what is shown for the macro-model in figure 6-9.

At any rate, the results in figure 6-9, at least to a first order approximation, indicate a fairly good correlation between the two models.

7 SIX SIGMA INTEGRATION

7.1 Recommended Integration Framework

Given that, at this stage, one is convinced about the merits of six sigma, how does one go about actually implementing it in one's company? To answer this question, we need to go back to section 5.3.2 which outlines the critical steps for deploying a major six sigma effort at one's company. These steps are:

- **Executive Education and Buy-In:** In general, the effort must have the full support of top management. Otherwise, employees will not take the initiative seriously. Employee motivation can be elicited through direct visible involvement of top management in implementation efforts, and through creation of a sense of "company crisis" Convincing employees that the company is losing ground or money to its competitors due to poor quality can get them to embrace the effort.

Management must also not only "talk the talk, " they must "walk the walk" as well. Employees need to be convinced that six sigma is not just another "flavor of the month" program. Thus, management must familiarize itself with six sigma terminology and principles as well as manufacturing processes and constraints.

- **Training:** The success or failure of one's program will highly depend on the training received by Black Belts. Good training gives Black Belt's the framework and tools as well as the social and technical skills to identify and tackle the "process killers." Bad training results in wasted effort, resources, and money. It is therefore critical to carefully select one's training organization and make sure it is one which is credible and has a good track record of success with other companies.

- **Project/Metric Tracking System:** To sustain the program, metrics must be defined and tracked to ensure that the cost and quality goals are being met and to provide positive reinforcement to sustain the effort.. Some suggested metrics to track includes COQ, TDU, RTY, and Cost Savings/Black Belt. An important part of the tracking system should be project review boards at both the plant and corporate level to make sure that projects receive the required visibility and get completed on time.

- **Rewarding Success:** Once the program strategy, expectations, and metrics have been laid out, it is important that the individuals who execute the strategy successfully and achieve noticeable program specific results get rewarded accordingly. Without a proper reward structure, the effort will ultimately die, especially if people are not being recognized for their Six Sigma achievements. Many companies motivate their people to maintain high enthusiasm and energy level for Six Sigma by actively promoting those who achieve big process improvement results and cost savings. In some companies, for example, becoming a Black Belt is the ticket to getting into the ranks of senior management.

Sometimes, however, it may not be possible to deploy a full-fledged program due to internal company resistance. Top management, for example, may not be accustomed to thinking in terms of "sigma" or "process capability" and thus may be uncomfortable with implementing what, in their minds, they may perceive to be a very "technically complicated" initiative. Another reason one may not get support may simply be due to limited company resources. One's company, for example, may simply be working already on too many initiatives and thus may not be able to spare the resources to implement another major company effort.

In these situations, a more indirect implementation approach may be appropriate. A "pilot" facility, for example, could be selected for carrying out black belt studies for an agreed upon trial period. After the trial period is over, management could evaluate, based on results of the black belt projects, whether it wanted to go ahead with a full scale program. The danger of this approach is that the individuals involved in the pilot, as well as top management, may be less motivated to ensure its success since the stakeholders have much less at stake than they would have if full company resources had been invested in the effort.

7.2 Six Sigma and Lean Manufacturing

As a final note, a brief discussion will be provided concerning Six Sigma and Lean Manufacturing. More often than not, presenting the concepts and benefits of Six Sigma to top management, or to any general manufacturing audience will often illicit the following question:

"Is Six Sigma the same as Lean Manufacturing? If not, which initiative provides more relative benefit to a factory environment?"

To answer this question, a set of informal interviews was conducted with senior managers at companies who had experience with both types of initiatives. The people talked to included consultants (those focused on six sigma and/or lean), and senior managers at Allied Signal, Siebe, and Avery Dennison.

The consensus among all those interviewed was that Six Sigma and Lean Manufacturing were not one and the same thing. Although there were obvious overlaps among the two initiatives (ie. To obtain flow manufacturing, one needs to have a certain amount of process control), the focus and major benefits derived from the two programs were different. In fact, the two initiatives were considered complementary to each other and most agreed that both needed to be implemented to achieve the highest level of manufacturing performance. Figure 7-1 summarizes what the interviewees thought were key areas of focus of Six Sigma and Lean Manufacturing Initiatives.

Six Sigma Focus	**Lean Manufacturing Focus**
• Defects • Variation • "Hidden Factory" • COQ	• Inventory • Floor Space • Production Flow • Cycle Time

Figure 7-1 Perception of Six Sigma And Lean Manufacturing Programs by those Interviewed

Given that the two initiatives are both different and equally beneficial, how does one go about implementing them? The simple illustration shown in figure 7-2 may help us with our decision-making process.

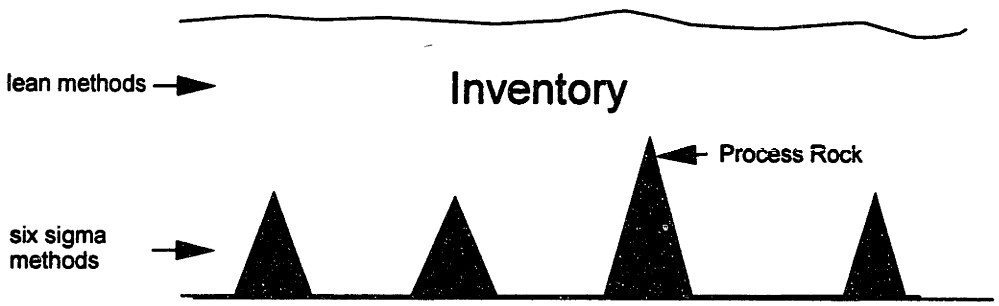

Figure 7-2 Application of Six Sigma and Lean Manufacturing to Manufacturing Process

Figure 7-2 indicates potentially 3 ways we could implement the Six Sigma and Lean Initiatives:

- **Six Sigma -> Lean Manufacturing:** In this approach, Six Sigma is implemented first by eliminating all the "process rocks" in the manufacturing process. Once this has been completed, lean principles can then be applied to lower the "inventory" waters to the point where inventory supply matches demand.
- **Lean Manufacturing -> Six Sigma:** In this approach, Lean principles are applied first thereby lowering the "inventory" waters to the point where the "process rocks" become visible. At this point, Six Sigma is applied to eliminate the rocks.
- **Six Sigma <-> Lean Manufacturing:** Both initiatives are applied simultaneously. Although, theoretically, this approach should result in reaching peak manufacturing performance quicker than the other two approaches,

> there is a high chance that a simultaneous approach will not work. The reason for failure is that manufacturing personnel will tend to prefer one initiative over the other thereby forming internal rivalries and fighting for manufacturing resources. At AlliedSignal, for example, rivalries which formed between those who supported Six Sigma and those who supported lean ended up hampering the efforts of both programs.

Besides the issue of "when to implement," the issue of culture as it relates to Six Sigma and Lean manufacturing also needs to be addressed. Whereas Six Sigma tends to promote hierarchy since power is concentrated in the hands of a few Black Belts, Lean Manufacturing tends to induce the opposite effect since power is pushed down to the lowest levels of the organization. Reconciling the cultural conflicts as these two initiatives are implemented in an organization could potentially be very challenging. Process improvement initiatives, for example, need to somehow be made the responsibility of all employees, not just Black Belts. This objective could potentially be accomplished by emphasizing to workers that process problems that arise out of ordinary operations are still everyone's responsibility and that, in reality, Black Belts, should be only looked at as the resource of last resort.

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Appendix A: Six Sigma Macro-model
Nominal Case - Part Time Black Belts, Full Time Masters
Key Input Values

		Year		
	Cost / Unit	1999	2000	2001
Six SigmaTraining Waves	$ 160,000	0.48	0.48	0
# of active black belts		12	24	24
Six Sigma Leadership Training	$ -	Inc.	Inc.	Inc.
Consultant Travel and expenses	$ 200,000	1	1	0
Plant Manager Training	$ 25,000	5	5	0
Six Sigma Master Black Belts				
Salary	$ 50,000	1	2	2
Benefits	$ 50,000	1	2	2
Relocation	$ 50,000	1	1	0
Travel	$ 50,000	1	2	2
Six Sigma Black Belts - Full Time				
Salary	$ 50,000	0	0	0
Benefits	$ 50,000	0	0	0
Relocation	$ 50,000	0	0	0
Travel	$ 50,000	0	0	0
Six Sigma Program Manager				
Salary	$ 50,000	1	1	1
Benefits	$ 50,000	1	1	1

Notes:

The values that need to be input into the model include Six Sigma personnel costs as well as the year in which they are trained/deployed. The model assumes that full program deployment occurs over a 3-year time span, the average time it took most companies to deploy their own respective programs. In the above illustration, 12 black belts are deployed in year 1 and an additional 12 in year 2. A total of 2 master black belts and 1 program manager are also deployed under this scenario. Note that since, under this scenario, no full-time black belts are used, Black Belt personnel costs (ie. salary, benefits, etc...) are not incurred since the Black Belts are already employees of the organization. Additional capital costs that could potentially be incurred once Six Sigma is deployed were not included in the model since, according to the benchmark study, the companies did not require buying substantial capital. These costs were negligible compared to personnel and training costs.

Appendix A: Six Sigma Macro-model (Cont'd)
Key Outputs

		1999	2000	2001
Six SigmaTraining		$ 76,800	$ 76,800	$ -
Leadership Training		$ 200,000	$ 200,000	$ -
Consultant expenses		$ 125,000	$ 125,000	$ -
Plant Manager Training				
Master Black Belts		$ 50,000	$ 100,000	$ 100,000
Salary		$ 50,000	$ 100,000	$ 100,000
Benefits		$ 50,000	$ 50,000	$ -
Relocation		$ 50,000	$ 100,000	$ 100,000
Travel				
Black Belts - Full Time		$ -	$ -	$ -
Salary		$ -	$ -	$ -
Benefits		$ -	$ -	$ -
Relocation		$ -	$ -	$ -
Travel				
Project Manager		$ 50,000	$ 50,000	$ 50,000
Salary		$ 50,000	$ 50,000	$ 50,000
Benefits		$ 50,000	$ -	$ -
Relocation		$ 50,000	$ 50,000	$ 50,000
Travel				
Total Costs		**$ 801,800**	**$ 901,800**	**$ 450,000**
License Fee Expense	**$ (3,200,000)**	**$ 1,066,667**	**$ 1,066,667**	**$ 1,066,667**
Savings		**$ 2,160,000**	**$ 4,320,000**	**$ 4,320,000**
Savings over Curr. Plan		**$ 160,000**	**$ 2,320,000**	**$ 2,320,000**
Additional Oper. Inc.		**$ (1,708,467)**	**$ 511,533**	**$ 3,283,333**
Additional Cash Flow	**$ (3,200,000)**	**$ 178,264**	**$ 1,332,664**	**$ 2,774,000**
New EBIT		**$ 13,291,533**	**$ 15,511,533**	**$ 18,283,333**
% Increase in EBIT		**-11.4%**	**3.4%**	**21.9%**
NPV @35%	**$ 4,981,804**			
IRR	**0.76**			
Payback(years)	**2.61**			
COQ Results				
New COQ (Beginning)		$ 10,000,000	$ 8,840,000	$ 5,520,000
New COQ (Ending)		$ 7,840,000	$ 4,520,000	$ 1,200,000
COQ (% of revenue)	23.0%	26.1%	15.1%	4.0%

Notes:

Based on model inputs, key outputs including total yearly program costs, additional operating income, cash flow, and EBIT are calculated. How these values are calculated is shown in section 6.1.1. The outputs that help one evaluate the attractiveness of the Six Sigma investment, NPV, IRR, and Payback, respectively are calculated from additional cash flow (shown above) and terminal value (not shown above). How the terminal value is estimated is also covered in section 6.1.1. COQ is calculated as follows:

- COQ (Beginning) –Savings = COQ (Ending) (We assume all savings can be directly applied to COQ)
- COQ (Ending) + Inflation Adjustment = COQ (Beginning)
- COQ (% revenue) = COQ (Ending)/Total Yearly Revenue

Appendix B: Six Sigma Micro-model

Cell08- Muffler Line 313058

Input

Total time (per shift in minutes)	300
Prod. Rate (Pieces/Min)	4
Actual Cycle Time (in minutes)	0.25
Theortical Prod. Rate (Pieces/Min)	5
Theoretical Cycle Time (in minutes)	0.13
Rework Time (per piece in minutes)	0.025

Sales

$ 34,000,000

Labor

	Pay Rate	OT Rate
Operator	11	16.5
Set-up	18	27

Material Cost	**Orig. Equip.**
Muffler Body	21
Sub-Assembly	5

Process Capability Analysis

	Lam. Shell	Shell Lock	Walking Beam	Preflair	BTM Press
First-Pass Yield	0.7	0.7	0.7	0.7	0.7
Scrap	0.1	0.1	0.1	0.1	0.1
Unexpected Downtime	0	0	0	0	0
Rolled-Throughput Yield	0.0011				
TDU	0.3	0.3	0.3	0.3	0.3
Total TDU	5.7				
PPM	300,000.00		Process Sigma	2.1	

Products

5.5X11 and 5X9.25(original equipment)

Yearly Goal	400,000	Daily Goal	1,190
Weekly Goal	8,333	Total Available P	450

Required Material (mufflers)	8812.78	7931.50	7138.35	6424.52	5782.07
Required Material (sub-assembly)	0.00	0.00	0.00	0.00	11564.13
Required Labor (in hours)	37.82	34.04	30.64	27.57	24.81
Theoretical Labor (in hours)	2.58	2.58	2.58	2.58	2.58
Labor Gap (in hours)	35.24	31.46	28.06	24.99	22.24
Rework					
Labor (indirect in hours)	1.10	0.99	0.89	0.80	0.72
Available Time (hours/day)	15	15	15	15	15
Scrap Cost					
Muffler (total)	$ 160,068				
Sub-Assembly (total)	$ 65,983				
Extra Labor Cost					
Within Shift	$ 633	$ 633	$ 633	$ 633	$ 633
Overtime	$ 1,746	$ 1,457	$ 1,196	$ 962	$ 751
Total	$ 2,379	$ 2,090	$ 1,830	$ 1,595	$ 1,384
Totals (Annual)					
Scrap	$ 75,953,218				
Extra Labor	$ 799,444				
Total	$ 76,752,663				
Combined COQ (%Revenues)	226%				

Notes:

The areas that are boxed in the model are those that require input values. Some of the key values that need to be input include actual and theoretical cycle time, revenue generation, wage rate, and material costs. In the process capability section, key process characteristics (ie. First-Pass Yield, Scrap, and Rolled-Throughput Yield) for each process step of the manufacturing line which is being analyzed must also be input into the model. In the above illustration, only 5 out of the 19 process steps of the line being analyzed, in this case, the Cell 08 muffler line, is shown. Some of the key outputs which get calculated once all inputs have been input into the model include, total TDU, PPM, and Sigma of the line as well as total scrap cost (muffler body and sub-assembly units costs), extra labor cost (at each process step and overall), and COQ (% of sales). Details on how all the outputs are calculated are shown in section 6.2.1.

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