Six Sigma Quality For Fuel Manufacturing

MICHAEL D GABBANI*, TOM ONDERWATER**

Fuel Product Engineer*, Six Sigma Quality Leader**

GE CANADA, Fuel Manufacturing Plant
Peterborough, Ontario

Abstract

It is widely recognized that operational performance in product manufacturing is largely determined by understanding and maintaining process capability. By definition, Six Sigma is a statistical unit of measure reflecting process capability that yields less than 6.8 defects per million product produced. Statistically, this translates into obtaining a long term manufacturing process capability of ± 4.5 standard deviations about the mean within specification limits.

The heart of the Six Sigma program developed by the Six Sigma Academy is what we refer to as the Breakthrough Strategy. This rigorous analytical methodology is the driving force in obtaining world class performance of Six Sigma. The methodology applies statistical and practical tools in resolving a problem or improving a product or process.

The application of Six Sigma focuses on attacking process input variables (independent) rather than the output variables. Focusing on these independent variables (temperature, power, force, etc.) and the variation in the end product they create, enables us to get to the root of the problem rather than react to the symptoms of the problem. In this manner we prevent defects from occurring rather than inspecting and monitoring the product.

Why the need for such an ambitious program? It is estimated that the cost of failure (rework, scrap, warranties, etc.) can be as high as 15% of sales for companies typically operating at 3-4 sigma. In achieving Six Sigma, costs of failure are typically less than 5%. The thought of reducing business costs while achieving the recognition of being our customer's premier choice provides enormous incentive to reach such status.

Introduction

The essential elements of customer satisfaction are price, quality and on time delivery. This is becoming more evident as market globalization and deregulation takes place. In today's market companies must find improved ways to do business. Fierce competition now provides customers with more options regarding terms and conditions on the product or service they are rendering. For GE, the undertaking of Six Sigma will open new market opportunities while leading to the development of new and exciting approaches for the improvement of business, engineering and manufacturing, service and administrative performance.

The purpose of this paper will be to present the Six Sigma strategies, tactics and tools as they apply to fuel product manufacturing at GE Canada.

First Six Sigma is defined in statistical and numerical terms. Then the need for Six Sigma is discussed in terms of customer satisfaction, competition advantages, cost savings and business culture. The paper then moves on to elaborate on the heart of the program called " Six Sigma breakthrough strategy". It discusses the statistical tools and leadership skills comprising the breakthrough strategy to attain the level of performance a business should be able to achieve given the investments already made.

The paper ends by discussing what the critical drivers are for the program to remain on track in achieving Six Sigma performance. It talks about how upper management commitment, employee training, employee empowerment and team work play an integral part of Six Sigma success.

What Is Six Sigma ?

Six Sigma is a statistical unit of measurement that reflects process capability. As variation in a process decreases, the sigma rating increases, This translates into improved process capability and a decrease in non-conformances produced.

The sigma scale of measure correlates to such characteristics as defects-per-unit, parts - per-million defective, probability of a failure/error. Figure 1 summarizes how the sigma scale relates to these various measurement indices along with corresponding statistical formulas. All these units of measure focus on characterizing process variation and centering about the specification limits. When we refer to Six Sigma capability it is important to understand that we really mean short term capability and not long term capability. Short term capability is the capability as measured in any instance in time, while long term capability is the performance of a process over extended periods. For example the automotive industry defines short term capability as 300 consecutive parts produced while long term as a week or more of production. The difference between the two, referred to as the sigma shift, reflects how well a process is controlled. Empirically, this shift difference amounts to 1.5σ over time. **Figure 2** illustrates the differences in short and long term capability.

In philosophical terms, Six Sigma can be defined as a program that makes people work smarter, not harder. Six sigma is a problem solving philosophy aimed at identifying and reducing variation in a process. This problem solving approach utilizes a rigorous four phase breakthrough Strategy as depicted below:

Measure → **Analyze** → **Improve** → **Control**

In each of these phases, statistical and practical tools are employed when confronting a process problem to solve. One of the important aspects of this methodology is that each phase is designed such that closure must be obtained before movement to the next phase. Elaboration on the details of these phases is further explained under the sub heading "the heart of Six Sigma".

Six Sigma can also be considered a business strategy in which a competitive advantage is realized. The reason for this is simple - as the sigma rating increases in a process, product quality improves (i.e. less defects, rework, non-conformances) and costs go down.

The Driving Need for Six Sigma Quality

The cost of quality for companies operating at 3-4 sigma is estimated to be 15 % of gross sales. Achieving six sigma means these costs are reduced to less than 5% of sales. This is a huge opportunity for a company to capitalize on in terms of bottomline revenue, excellence in quality and customer satisfaction.

In the world of Six Sigma, the "paradigm shift" is often referred to. This shift corresponds to a change in mind-set away from quality through appraisal. Quality through appraisal means inspection, testing, quality audits and test equipment. In this context, increased quality means higher cost. Six Sigma philosophy changes the mind-set to quality through prevention. Upfront quality planning, process planning, process control and training are utilized such that increased quality reduces cost. This concept is further explained by the charts in Figure 3. The ability of a company to manufacture products under a state of increased quality at reduced costs, certainly reinforces the why of Six Sigma.

Six Sigma is designed to focus on process input variables rather than output variables. In this way, causes rather than effects, problems rather than symptoms, control rather than monitoring are addressed. Employing this kind of business strategy avoids defects in products from ever occurring because the input variables that are responsible are controlled and fixed before product is affected. This means less excursions, rework, and product scrap, another good reason why implementation of six sigma is important.

The Heart of Six Sigma

The heart of Six Sigma is what we refer to as the Breakthrough Strategy - **M**easure, **A**nalyze, **I**mprove, **C**ontrol. This is a rigorous process through which we start with baselining our current level of performance or process capability and then move towards entitlement - the level of performance a business should be able to achieve given the investments already made. The ultimate goal in this process is to achieve benchmark status - world class or Six Sigma performance. The phases that allow us to achieve these ambitious performance standards are explained below:

Measure:

The measure phase of the Breakthrough strategy consists of a series of steps required before the process you are trying to improve can be baselined in terms of performance capability. This phase provides the foundation for the project and sets the stage for the Analyze phase where process capability and performance objectives are defined. The steps involved in this phase typically include:

- Identification of Critical To Quality characteristics (CTQs) for the process under consideration for improvement.
- Identification of Technical requirements/performance Standards
- Process Mapping
- Validation of the Measurement System to ensure variation is measurement system is quantified

Before the capability of the process can be determined, it is important to understand what is critical to quality (i.e. customer technical requirements - internal manufacturing process requirements). For example, in our fuel manufacturing process we are required to coat the inner diameter of the tubes with graphite. The elements of this process that would be considered critical to quality include the thickness of the graphite, adhesion, and graphite coverage. Once these CTQs are identified, the capability of the process can then be determined by sampling and measuring these variables and comparing them to the technical requirements.

If the process being worked on is of a complex nature, we will graphically outline the sequence in the process . This allows us to understand how the steps in the process relate to each other which makes the task of identifying the CTQs much easier. This mapping tool also aids in identifying process bottlenecks, and redundancies.

A very important step in the measure phase is verification of the system used to measure the CTQs. In any Six Sigma project, it is a requirement that the measurement system be validated to ensure that instrument variation is quantified due to such things as human factors, equipment accuracy, and precision, and physical considerations. The measurement system is validated by characterizing the variability in terms of repeatability and reproducibility. The technique employed is a designed experiment.

The measure phase ends when we are in a position to statistically baseline the process capability . This means that we understand what is critical to quality in the process and understand how this relates to the technical requirements as set by our customer.

Analyze

The next phase of Six Sigma involves establishing baseline process capability, benchmarking, and identification and ranking of the sources of variation bridging the gap between baseline process capability and world class process capability of Six Sigma.

The baseline process capability is established using the CTQs of the process that were identified in the measure phase. For example, in our graphite coating operation, the capability of the process would be measured by compliance to thickness of the graphite, adhesion, and graphite coverage of the product in terms of sigma or equivalent capability indices.

In referring to Figure 4, the process of benchmarking positions a company to define the performance objectives required to eliminate the Gap between baseline process capability and Six Sigma status. However, before this gap can be closed, the gap between baseline and entitlement called "Best in Class" must be addressed. Entitlement is the level of performance a business should be able to achieve given the investments already made. Attainment of Six Sigma status requires design for Six Sigma or manufacturability which often involves additional investment to achieve this desired state.

Six Sigma provides a statistical analysis roadmap in achieving "Best in Class" performance. This roadmap identifies and analyzes the major sources of variation that bridge the performance gap. An example of a basic tool employed is a pareto chart which illustrates what key CTQs typically govern process variability. The function of the pareto chart is to help the team involved in the process improvement to focus on the vital few causing the variation and ignore the trivial many.

Once the vital few CTQs have been earmarked as sources where variation constantly surfaces, the stage is set to identify what the variation sources are. A common tool utilized is the Cause & Effect diagram also called a Fishbone diagram. In keeping with our previous example, lets suppose the pareto chart revealed that most of the defects from our graphite coating process were a result of failure to meet graphite thickness on the ID of the sheath. Figure 5 shows how a Fishbone diagram can be utilized to aid in focusing on what the major sources of variation could be causing the thickness problem.

To quantify in statistical terms the major sources of variation, tools such as capability indices, Student t-tests, ANOVA, Regression analysis, hypothesis testing and homogeneity of variance are employed.

The analyze phase is said to be complete once the process is baselined in terms of Six Sigma and the major sources of variation are identified bridging the gap between baseline process capability and entitlement capability.

The first two phases of Six Sigma - Measure and Analyze are referred to as process characterization. These are by far the most important phases, because in the tradition of Six Sigma, if we can't quantify the problem, we cannot understand it.

The last two phases of Six Sigma are what we refer to as the optimization phases. It is these phases that will allow us to move toward achieving entitlement while revealing what is required to achieve world class capability or Six Sigma process capability.

Improve:

The Improve phase is used to diagnose the input variables identified in the analyze phase that cause the major source of product variation. The Statistical tool used to accomplish this task is Design of Experiments. The purpose of this tool is to define the relationship between the input variables (independent) and response or output variables (dependent). Design of experiment allows the experimenter to quantify the effects of the input variables on the response variable. For example, in the case of graphite thickness (response variable), design of experiment will analyze the input variables (graphite viscosity, temperature, time etc.) and any interactions that cause inconsistency in the graphite thickness.

At the completion of the design of experiment phase, the most influential variables that affect center and spread (i.e. temperature change, viscosity) on the response variable are identified and quantified. It is at this point in the improvement process that we are ready to brainstorm solutions that target reducing process variation and centering. In identifying the solutions, testing should be completed for real improvement after a process change is done. Validation of process improvement is done using statistical tools such as T-tests or ANOVA for centering and F-tests for process spread.

The improve phase is complete when the key sources causing variation to the response variables are quantified with a validated process improvement in place, keeping in mind that the improvement made should reflect entitlement capability - the maximum level that the process can perform at without introducing design for Six Sigma capability or manufacturability.

Control

In the final phase of Six Sigma we maintain production within the acceptable ranges and monitor the improved process by utilizing statistical tools such as Statistical Process Control and Capability Indices (Cp and Cpk). The tolerances on the key input variables identified in the improve phase are set. The process capability of the vital variables are determined and further controlled for variation and centering by use of statistical process control. Although additional controls have been added to the process, recall, Six Sigma focuses on prevention rather than appraisal as a means to improve process capability which means a net decrease in cost of quality.

This phase never ends in the sense that we implement these statistical measurements to ensure that the process remains on the Six Sigma track.

What Drives Six Sigma to Work

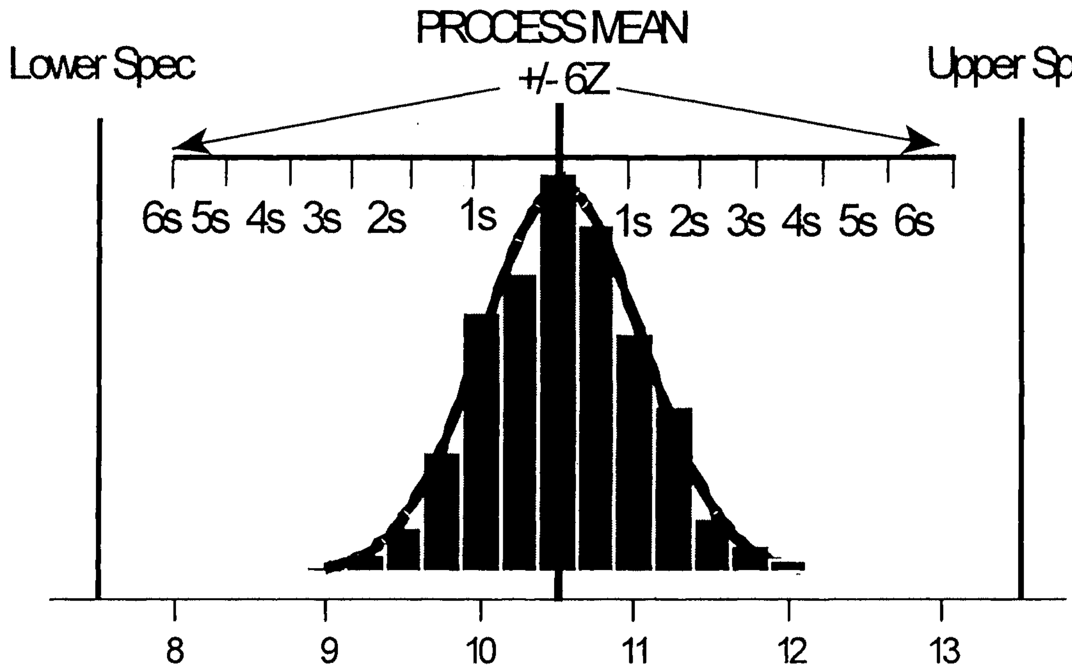
Our Six Sigma program requires three aspects of culture to succeed. To begin, we require a deeply rooted commitment to the program; its philosophy and its resources. Next, we develop a pool of skills through the training of Six Sigma leaders, the general work force and management. As Six Sigma begins to succeed, a new culture of teams empowered to complete challenging projects develops.

The necessary commitment starts at our most senior levels of management. Six Sigma has become part of our long term business plans. A five year goal has been set, with support for Six Sigma staffing, work force training and team resources. GE created a new position of process improvement team leaders. Our team leaders are trained to lead work force teams through the Breakthrough strategy described previously. They are the ones to lead teams through the successful application of, among other tools, problem solving, design of experiments and application of statistical process control. The team leaders are coached by a group of Six Sigma leaders devoted to training, mentoring, project management, coordination and goal setting. We count on our operating management to commit team resources, supply production or testing resources and facilitate project completion where they can. Setting financial and schedule targets for the overall program and individual project completion is shared by our Six Sigma leaders and operating management.

Our crucial training program starts with our Six Sigma leaders and team leaders. A twelve day formal education introduces them to problem solving, team leadership and facilitation tools, statistics, design of experiments, statistical process control and cost saving strategies. We provide the training in installments, one for each phase of the Breakthrough strategy. Each leader takes on his or her first project along with the training. Our management takes an in-depth awareness program sufficient to understand project phases, the tools of Six Sigma and the philosophy of Six Sigma. This prepares them to understand what makes a good Six Sigma project, direct project selection, provide appropriate resources and review progress. General employee awareness training follows. Our work force becomes aware of the role of Six Sigma project leaders and the methodology of our problem solving projects. They come to understand the goal of Six Sigma and the role of statistics, experiments and statistical process control. When they participate on a project team, they learn first hand how to apply the Six Sigma tools, primarily the success that is achievable through team problem solving methods and the proper use of basic statistical tools.

Effective teamwork, empowerment and accountability of the teams to put their recommendations in place is how our Six Sigma program succeeds at the practical level. An effective team will often comprise of operators, technicians and staff as members. The team leaders coach the team through the entire project cycle which goes beyond the study and recommendation phase. We expect them to prove that their recommendations work during the Improve stage of a project. They are given the goal to permanently implement a practicable version of their recommendations and demonstrate that they have made a beneficial impact. Once they have obtained these goals, the team's success is advertised and celebrated.

As Six Sigma succeeds, it fosters a culture of smarter problem solvers and intolerance to second best practices. Eventually every one assists Six Sigma projects by being a team leader or team member, by helping team members acquire information, by helping team members with experiments, or by benefiting from the process improvements in their work area. Through training and rising through the Six Sigma leadership ranks, all of our operating and business leaders will eventually have Six Sigma experience. The use of problem solving methodology, basic statistics, process critique methods then filter down to everyone and become standard practice. This is the key to making a deep rooted change in our company, with long term implications.



Z-Scale Long Term	Short Term	Equivalent Std Deviation	Process Capability	PPM (DPMO)
3	4.5	+/- 3s	1	2700
4.5	6.0	+/- 6s	2	6.8

±Z=[UPPER SPEC- MEAN ; MEAN- LOWER SPEC}
SIGMA (s) SIGMA (s)

Process Capability = Upper Spec- Lower Spec / 6 SIGMA (s)

PPM = DEFECTS / Total Units Produced * 10^6

Figure 1 Relationship Between Sigma - Process Capability - # of Defects

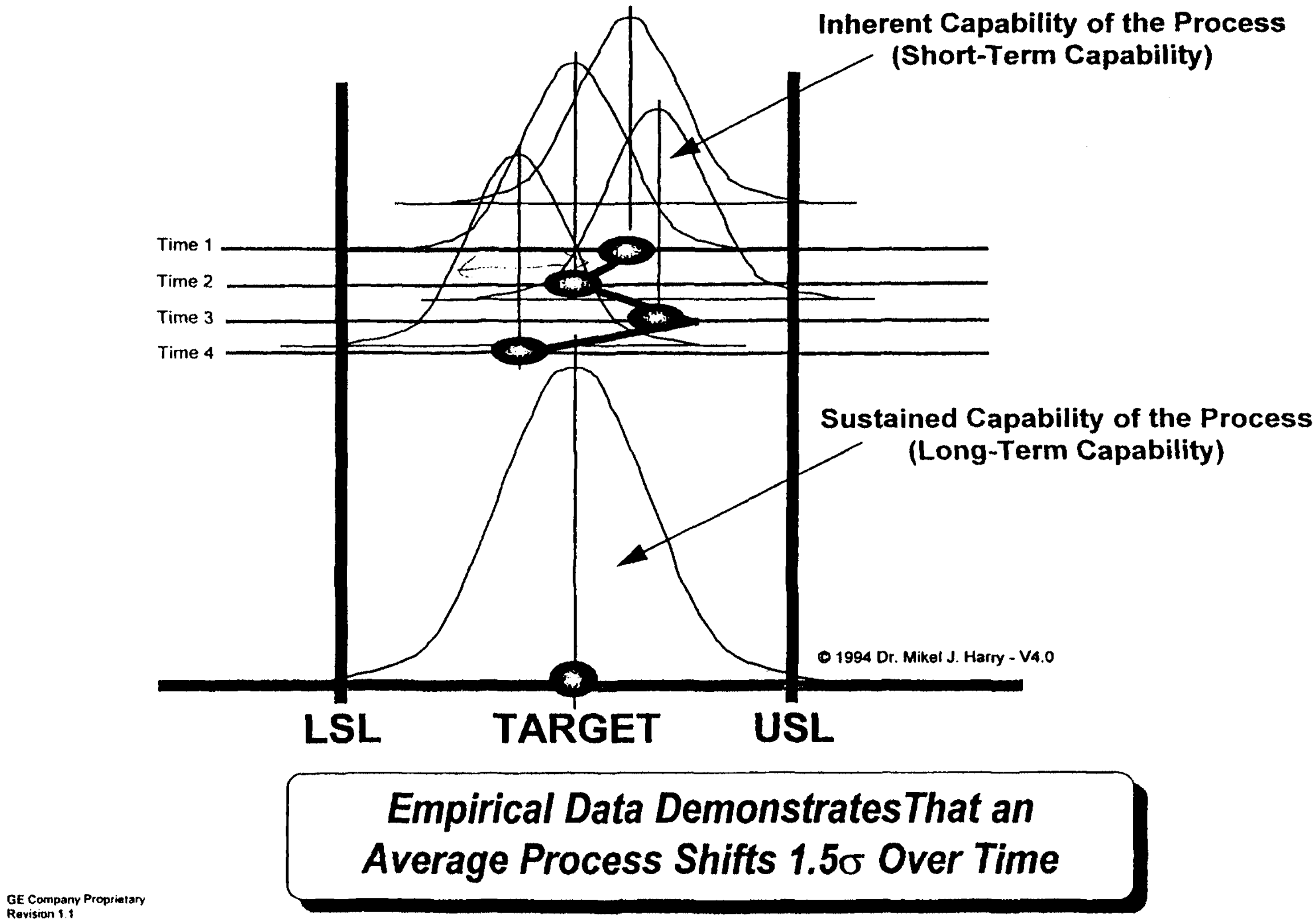


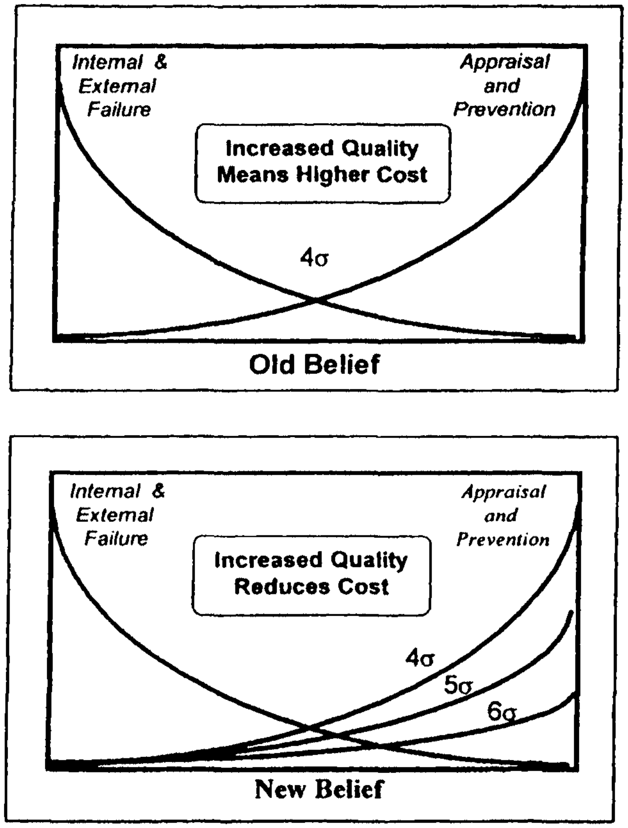
Figure 2. Short Term Process Capability vs Long Term Capability

Internal Failure

- Scrap
- Remake
- Scrap/Rework (Supplier)

External Failure

- Cost to Customer
- Warranty Cost
- Compliant Adjustments
- Returned Material



Appraisal

- Inspection
- Test
- Quality Audits
- Test Equipment

Prevention

- Quality Planning
- Process Planning
- Process Control
- Training

The 6σ Paradigm Shift

Figure 3. Six Sigma Paradigm Shift

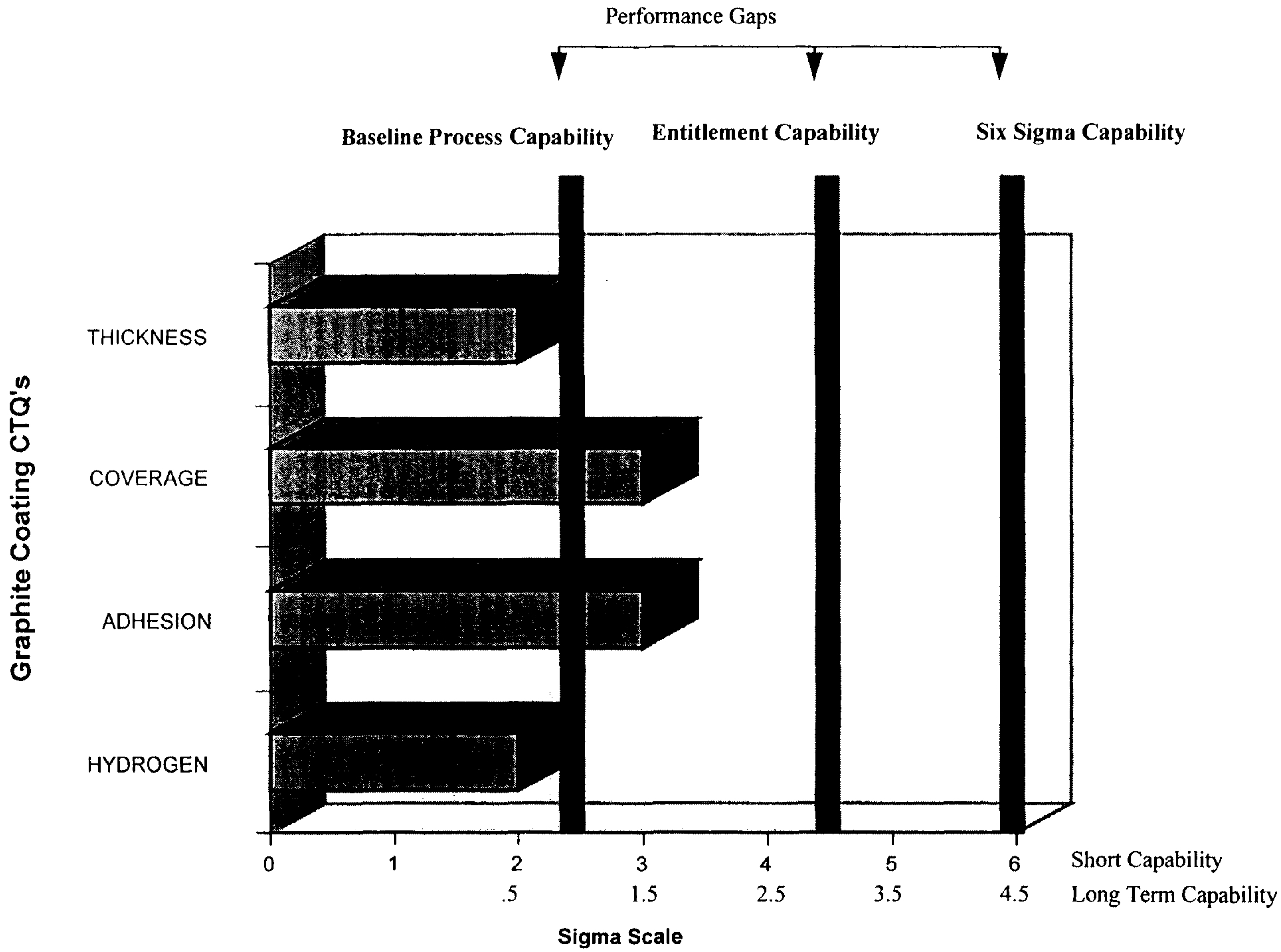


Figure 4. Six Sigma Benchmarking Process

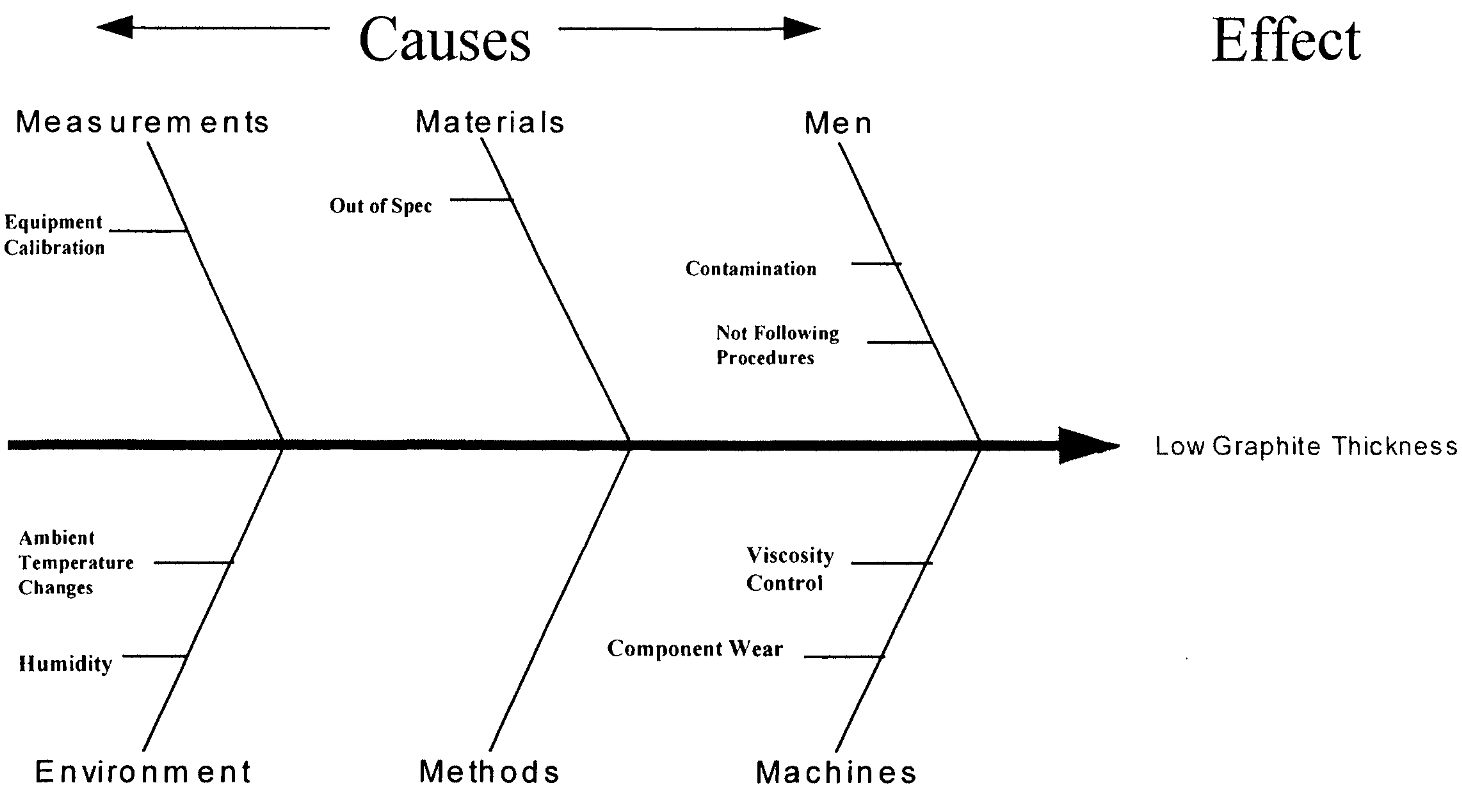


Figure 5. Typical Example of a Fishbone Diagram