Chapter 3
Six Sigma: Continuous Improvement Toward Excellence

Qianmei Feng

Abstract Manufacturing and service organizations attempt to improve their products and processes by decreasing variation, because the competitive global market leaves little room for error. Variation is the biggest enemy of quality that is defined and evaluated by customers. The traditional concept of quality is based on average measures of the process/product and their deviation from the ideal target value. However, customers evaluate the quality of a process/product not only on the basis of the average but also by the variance in each transaction or use of the product. Customers want consistent, reliable, and predictable processes that deliver the best-in-class level of quality.

This is what the Six Sigma approach strives to achieve. Invented by Motorola in the 1980s, Six Sigma has been applied to many manufacturing companies, such as General Electric (GE), DuPont, and Ford. It has proven to be a customer-focused, data-driven, and robust methodology to improve the process and reduce costs. Over the last 20 years, Six Sigma has been successfully implemented in many industries, from large manufacturing to small businesses, from financial services and insurance industry to health-care systems. For example, under the partnership with GE, the Commonwealth Health Corporation launched the Six Sigma initiative in March 1998 and became the Six Sigma pioneer in the health-care industry. Six Sigma has been slowly but successfully implemented by many health-care institutions ever since.

3.1 What is Six Sigma?

As a data-driven and statistics-based approach, Six Sigma aims to deliver near-zero defects (as defined by customers) for the product, process, and transaction within an organization. The objective of using the Six Sigma approach is to reduce process

Assistant Professor, Department of Industrial Engineering University of Houston, Houston, Texas 77004

A.K. Kamrani, E.S. Abouel Nasr (eds.) *Collaborative Engineering: Theory and Practice,*
doi: 10.2007/ 978-0-387-47321-5,

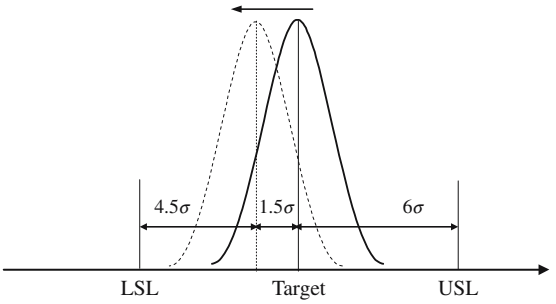

Fig. 3.1 A Six Sigma process with 1.5 σ shift

variation, so that the process results in no more than 3.4 defects per million opportunities (DPMO) in the long term. This defect rate is calculated on the basis of the assumption that many processes are prone to shift 1.50 standard deviations because of unavoidable assignable causes or degradation mechanisms. To achieve this long-term objective, the process capability has to reach the Six Sigma level in the short term, that is, the range between the target value and the specification limit contains six process standard deviations (6σ) on both sides of the target. In this way, the defect rate of a Six Sigma process is only about 0.002 DPMO. However, if the process mean shifts 1.5 process standard deviations over time, as shown in Fig. 3.1, the defect rate will increase from 0.002 DPMO to 3.4 DPMO.

Consequently, for a process that has a lower quality level than Six Sigma, the defect rate will increase significantly when the process shifts. A three-sigma process is used to be regarded as having good quality performance, before the introduction of Six Sigma. However, as shown in Fig. 3.2, the fraction outside of the specifications for the three-sigma process increases dramatically compared to the fraction for a Six Sigma process, which may cause serious quality problems over time. Therefore, three sigma is not good enough for many products or processes that attempt to avoid quality problems in the long run.

A Six Sigma process can also be interpreted in terms of process capability, which is associated with process variation [11]. The typical definition for process capability index, C_{pk}, is,

$$C_{pk} = \min\left\{\frac{\text{USL} - \hat{\mu}}{3\hat{\sigma}}, \frac{\hat{\mu} - LSL}{3\hat{\sigma}}\right\}$$

where USL is the upper specification limit, LSL is the lower specification limit, $\hat{\mu}$ is the point estimator of the mean, and $\hat{\sigma}$ is the point estimator of the standard deviation. If a process is centered at the middle of the specifications, which is also interpreted as the target value, then a Six Sigma process will have a capability of 2, that is, $C_{\text{pk}} = 2$. If a process wants to achieve 3.4 DPMO, it implies that the realized C_{pk} is 1.5 after the process shifts 1.5 standard deviations over time [*6*].

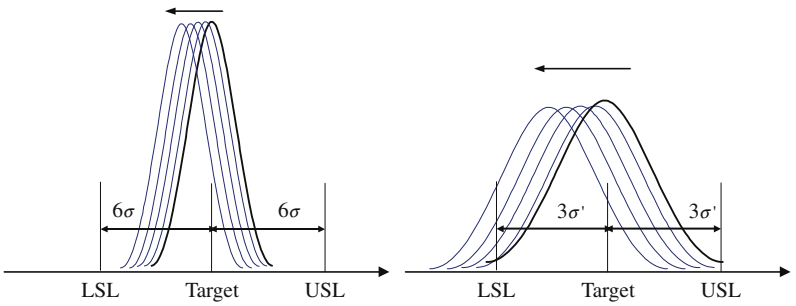

Fig. 3.2 Shifting a Six Sigma process and a three-sigma process

The requirement of 3.4 DPMO or C_{pk} of 1.5 is not the ultimate goal of Six Sigma. The goal is to establish the right business strategy toward organizational excellence. Six Sigma has evolved from a quality metric to an overall business management process that provides tangible business results to the bottom line through continuous process improvement. This is achieved by a dedicated workforce trained in Six Sigma methodology, on the project-by-project team basis, and with intensive support from the top management. As a customer-focused business strategy, Six Sigma puts customer satisfaction as the top priority: projects are driven and selected from the customer perspective, and performance standards are set on the basis of customer requirement. The Six Sigma methodology provides a road map for organizations to achieve the best-in-class business performance benchmarks.

Although the name does not contain the word "quality" or "performance," Six Sigma is a methodology for structured and process-oriented quality or performance improvement. To this end, two different yet similar road maps are available for organizations to choose from: one is the road map for Six Sigma process improvement, and the other is for "Design for Six Sigma" (DFSS). The DMAIC (Define, Measure, Analyze, Improve, and Control) methodology that most people are familiar with is the road map for Six Sigma process improvement, which involves the improvement of existing processes without changing the fundamental structure. DFSS is a Six Sigma approach that involves changing or redesigning the process at the early stages of product/process life cycle [16].

3.2 Why Six Sigma?

By identifying root causes and eliminating variations and defects, Six Sigma positively impacts many Critical-to-Quality (CTQ) features: timeliness/speed, cost, and quality of product/service. As shown in Fig. 3.3, these benefits will ultimately result in enhanced customer satisfaction, increased return-on-investment, and increased market share in the competitive global market.

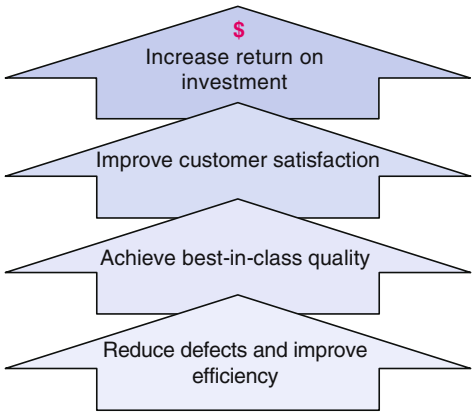

Fig. 3.3 Why Six Sigma? [3]

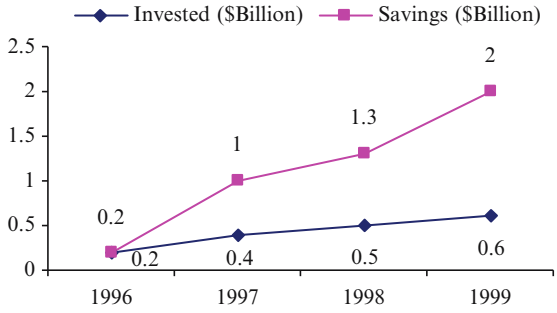

Fig. 3.4 Six Sigma progress at General Electric (GE) [15]

Six Sigma has helped many organizations to gain competitive advantages. For example, General Electric (GE) had more than$2 billion in savings during the first 4 years (1996–1999) of Six Sigma initiative, as shown in Fig. 3.4 [15]. These savings came from reduced rework, less waste, and decreased customer returns. Moreover, 53% of the Fortune 500 companies have deployed Six Sigma to some degree. Between 1987 and 2005, Six Sigma has saved them over $400 billion in total [12]. These convincing numbers speak for themselves regarding why Six Sigma should be implemented.

As the latest name for a comprehensive set of fundamental concepts, philosophies, tools, and methods for process or quality improvement, Six Sigma continues to show its endurance and return-on-investment for more than 20 years. By utilizing statistical tools, the Six Sigma methodology enables practitioners to accurately identify process hindering problems and demonstrate the improvements using objective data. However, Six Sigma is not just a collection of tools. The primary reason for the success of Six Sigma is that it provides a systematic approach for

quality and process improvement. During most quality training in academia, industry, and government, students and professionals usually are taught a number of individual tools such as cause-and-effect diagram, statistical process control (SPC), experimental design, quality function deployment (QFD), and failure mode and effects analysis (FMEA), and leave the course without a mental big picture about how all these tools fit together. While implementing project-by-project, Six Sigma provides an overall process of improvement that clearly shows how to link and sequence individual tools. With Six Sigma, students and professionals know what to do when facing a real problem.

3.3 How is Six Sigma implemented?

As in many other management processes, the Six Sigma initiative may encounter more or less resistance from organizational members and executives. Naturally, members of any organization prefer to stay on the track where they are headed, unless some external force impels them to do otherwise. Many reasons lead people to resist changes, such as feeling "safer" to stick with the expectable status quo, fear of failures or breaking habits, and so on. Many factors must be considered to overcome these resistances. The key to implement Six Sigma successfully includes aligning critical success factors, building up effective deployment teams, and selecting the right projects to pursue.

3.3.1 Critical Success Factors

The expected benefits from implementing Six Sigma are driven by many factors, including organizational consistency of purpose, executive engagement and involvement, communications, and project successes. *Consistency of purpose* for quality and productivity improvement is the key for the principle-centered quality management in the twenty-first century and beyond [6]. Instead of alternating the purpose of quality management according to the trendy quality program, an organization should have the consistency of purpose for the principle-centered quality management.

Executive engagement is one of the most critical factors for Six Sigma to succeed. The consistent support and "buy in" from management are essential elements during the cultural change of implementing Six Sigma. As indicated in the survey of Six Sigma in US health-care organizations [7], lack of commitment from leadership is the major resistance/barrier for the successful implementation of Six Sigma. Executive engagement may include the following:

- Deploying Six Sigma as a core business process;
- Creating accountabilities and rewards system;

- Attending regular meetings to verify progress; and
- Commitment of time, resources, and people.

Effective communications on Six Sigma play an important role in creating the Six Sigma community within an organization. Communications may take the following forms [8]:

- Regular written communications on Six Sigma news and successes;
- Developing and disseminating communication aids to management;
- Advocating and creating a "common language" based on Six Sigma; and
- Communicating pertinent facts about Six Sigma in every company meeting.

One of the major differences between Six Sigma and other quality initiatives is its project-by-project way of implementation. The importance of *project successes* cannot be overemphasized for the Six Sigma implementation, especially at the initial stage. The project successes will bring benefits to business in a short time period (3–6 months), practitioners will feel satisfied for making improvements, and executives will see the benefits and provide full business buy-in. In this sense, selecting the right project can have a tremendous effect on laying the foundation for the success of Six Sigma.

3.3.2 Deployment Roles and Training

The implementation of Six Sigma starts with both the training of a dedicated workforce and the education across the organization. Although Six Sigma is deployed from top down, people in the organization need necessary training to understand the Six Sigma improvement and its potential benefits to the organization and themselves. A well-structured project team is one of the many advantages Six Sigma has over other quality programs. The team members are well-trained and certified at different levels of Six Sigma practice, so that they can work effectively in a team. The typical roles in Six Sigma belts structure include Champions, Master Black Belts (MBB), Black Belts (BB), and Green Belts (GB) [14].

Champion is an important role that bridges the operational level and the strategic level in Six Sigma projects. Champions are responsible to ensure that Six Sigma projects at the operational level are aligned with the strategic level business objectives. They need to provide BB the freedom to focus on the problem by keeping a BB from confrontation with executive managers. In addition to removing roadblocks, Champions should select projects accurately, adjust the speed of the deployment as necessary, and take responsibility for implementation [2].

MBB are typically hired as the leaders of Six Sigma teams who work closely with process owners. They are responsible for training BB and GB, providing technical expertise, and selecting appropriate projects if there are no Champions in the company. MBB are typically trained from BB who have demonstrated capability for solving difficult projects. Additional training is intended to broaden the tool sets and provide MBB with a wider array of skill sets.

At the operational level, BB are the "change agents" who are the heart and soul of the Six Sigma program. As full-time positions, BB help GB and other team members to understand the project and provide appropriate statistical techniques. BB are trained in the basic problem-solving tool and strategy and they are supported by MBB.

GB are employees trained by BB and/or MBB. They typically spend part time completing Six Sigma projects while maintaining their regular full-time work. As the project is completed, GB bring their experience in Six Sigma back to their regular work and begin to include the Six Sigma methodology in their daily activities. Thus, in the long run, GB are the ones who shift the culture of an organization [2].

3.4 Six Sigma Process Improvement—The DMAIC(T) Process

The benefits of Six Sigma process improvement are achieved through the utilization of a systematic approach, the DMAIC process. We extend it to a six-phase process, DMAIC(T), in order to emphasise the importance of technology transfer (T) of successful experiences [5]. Ideas or experiences can be transferred to similar products, processes, or transactions within an organization via an Intranet database of past Six Sigma projects. In this way, the rate of return on the investment from one Six Sigma project can be maximized [10, 11].

Six Sigma projects stay on track by establishing deliverables and reducing the process variation at each phase of the DMAIC(T) process. Each of the six phases answers the targeted question, which improves the effectiveness of the methodology continuously [5].

- **Define**—What is the problem that needs to be solved?
- **Measure**—What is the current process capability?
- **Analyze**—What are the root causes of the process variability?
- **Improve**—How to eliminate defects and improve the process capability?
- **Control**—What should be put in place to sustain the improvement?
- **Technology transfer**—Where else can the experience and/or lessons be applied?

The above questions are answered in each step sequentially as shown in Fig. 3.5. During the DMAIC(T) process, a practice problem identified by process owners, Champions, and/or MBB is translated to a statistical problem, which is solved by BB and/or GB. The statistical solution found is then transformed to a practical solution that can be implemented by the process owners. As shown in Fig. 3.5, the focus of Six Sigma shifts sequentially from monetary measures, to the process output variable (Y), to the process input variables or root causes (X_1, X_2, …, X_n), to the vital few input variables (X_i) that have critical impact on the output variable, and finally to the estimate of savings in money. The six phases are described in the following sections, and the key tools involved in each step are introduced as well.

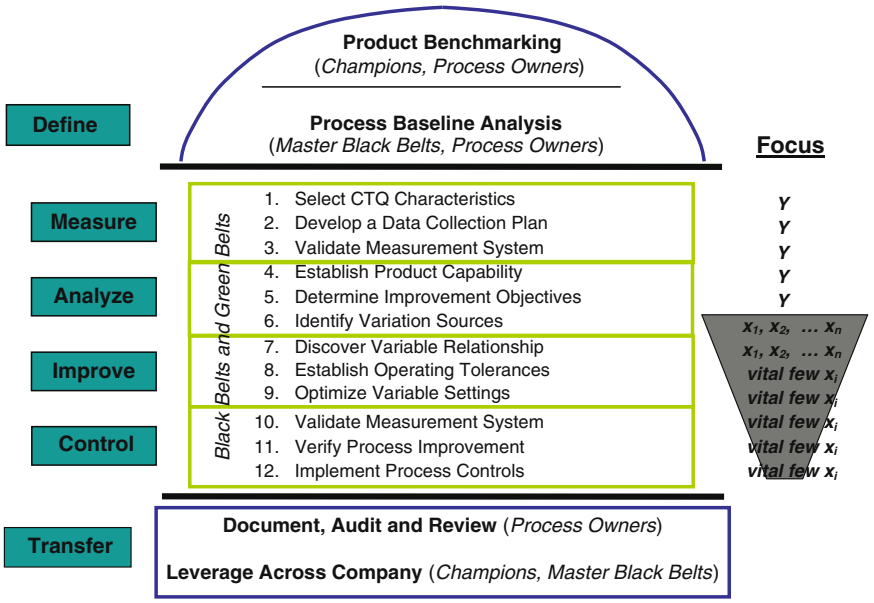

Fig. 3.5 The DMAIC(T) process

3.4.1 The DMAIC(T) Process

3.4.1.1 Phase 0: Define (D)

In the define phase, process owners, Champions, and/or MBB work together to identify the problem, define the project objectives, outline the expected benefits, form the team structure, and schedule the project timeline. Specifically, a project charter needs to be developed, including project scope, expectations, resources, milestones, and the core processes.

Six Sigma projects are customer-oriented as shown in Fig. 3.6. Based on customer requirements, the problem is identified and the project goals and deliverables are defined. Methods such as benchmarking surveys, spider charts, customer needs mapping, and SIPOC (supplier, input, process, output, and customer) **diagram** can be used to ensure that the customer requirements are properly identified. A general SIPOC diagram is given in Fig. 3.6 to illustrate the role of Six Sigma in a process. The critical to quality (CTQ) characteristics are defined from the viewpoint of customers, which are also called external CTQs. In the measure phase, the external CTQs are then translated into internal CTQs that are key process output variables (KPOVs).

3.4.1.2 Phase 1: Measure (M)

Six Sigma is a data-driven approach that requires quantifying the process using actual data. In this phase, the performance of the CTQ characteristics is evaluated

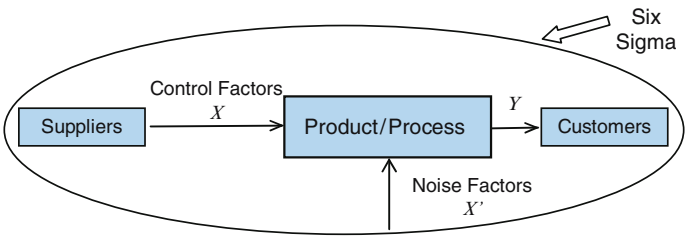

Fig. 3.6 SIPOC Diagram and Six Sigma

and compared to the customer requirements. The shortfalls are identified and the achievable opportunities are assessed.

Step 1.1: Select critical to quality characteristics

This step translates the customer requirements or external CTQs established in the define phase into internal CTQs or KPOVs denoted by *Y*. The performance of the process to be improved is often measured by one or a few KPOVs, which should be at the level the BB can impact. Fishbone chart, cause–effect matrix, QFD, and FMEA can be constructed to help the selection of KPOVs. The deliverables in this step include

- The selected KPOVs or *Y*s
- The identified defect or the undesirable outcome for each *Y*

Step 1.2: Develop a data collection plan

This step develops a data collection plan that gathers historical data over a business cycle, if possible. Six Sigma can then quantify the process using actual data.

Step 1.3: Validate measurement system

The capability of measurement systems needs to be evaluated to capture the variations due to sampling, operator, equipment, and ambient conditions. The repeatability and reproducibility of measurement systems can be assessed using Gage R&R or Analysis of Variance (ANOVA). This evaluation provides the decomposition of the total variability into components, and thus into targeted improvement actions.

3.4.1.3 Phase 2: Analyze (A)

Once the project is understood and the baseline performance is documented, it is time to analyze the process and find the root causes of problems using statistical tools. The objective is to understand the process in sufficient detail so that we are able to formulate options for improvement. To achieve this objective, the focus of the Six Sigma project will shift from the output variables to the process input variables in the analyze phase as shown in Fig. 3.7. The process input variables that

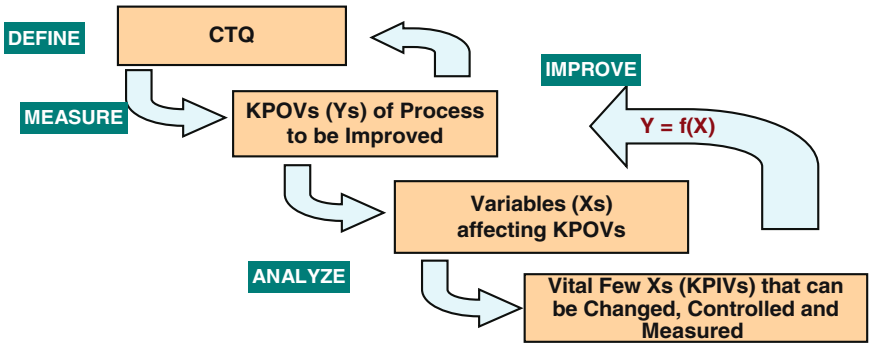

Fig. 3.7 Focus of Six Sigma

will lower the defect rates on KPOVs to achieve the project objectives are identified.

Step 2.1: Establish process capability

This step determines the current product capability, associated confidence levels, and sample size using the process capability analysis. The process capability index is closely related to the Sigma level of a process. For example, a Six Sigma process has the potential process capability of $C_{pk} = 2$ in the short term or when the process has no shift. The assessment of the current process behavior is obtained by analyzing historical data. The references to the current performance will provide an insight into achievable opportunities. The deliverables in this step include the defect rate in DPMO, Sigma level, and the process capability for each KPOV.

Step 2.2: Determine improvement objectives

The "best" Sigma level is defined for the project indicating the attainable process performance. The performance objectives are defined to establish a balance between improving customer satisfaction and available resources. The deliverables in this step include the achievable performance or benchmark for each KPOV.

Step 2.3: Identify variation sources

Starting from this step, the focus of Six Sigma shifts to the process input variables or *X*s, which include the controllable and uncontrollable factors, procedures, and conditions that affect the output variables. Some of these input variables will be used to control the output variables *Y*s, and these are called key process input variables (KPIVs) or vital few *X*s. The deliverables in the step include

- A list of all potential KPIVs that could impact the defect rates of KPOVs
- Identification of vital few *X*s

The key tools to search for the vital few *X*s include both graphical and analytical tools. The graphical tools are histograms, fishbone charts, Pareto charts, scatter plots, box plots, and residual plots. The analytical techniques include hypothesis

testing (*t*-test, *F*-test, etc.), regression analysis, design of experiments (DOE), and SPC control charts.

3.4.1.4 Phase 3: Improve (I)

In the improvement phase, ideas and solutions are identified and implemented to initialize the change in the vital few *X*s. Experiments are designed and analyzed to find the best solution using statistical and optimization approaches.
Step 3.1: Discover variable relationships

This step explores the function relationship between the vital few *X*s and the *Y*s. Sometimes, the relationship is obvious if only one or two *X*s are identified. When many *X*s are present, it may be challenging to understand how these *X*s affect the *Y*s. A system transfer function (STF) can be developed as an empirical model relating *Y*s and the vital few *X*s [3]. The key tool to quantify the relationship is experimental design, which provides better understanding of the process than do the old-fashioned approaches, such as trial and error or changing one factor at a time.

Step 3.2: Establish operating tolerances

With the understanding of the functional relationship between the vital few *X*s and the *Y*s, we need to establish the operating tolerances of *X*s that optimize the performance of *Y*s. Mathematically, a variance transmission equation (VTE) can be developed that transfers variances of the vital few *X*s to variances of *Y*s [3].

Step 3.3: Optimize variable settings

The STF and VTE will be used to determine the key operating parameters and tolerances to achieve the desired performance of the *Y*s. Optimization models are developed to determine the optimum values for both means and variances for these vital *X*s. In this way, the changes in the *X*s are implemented.

3.4.1.5 Phase 4: Control (C)

The key to the overall success of Six Sigma methodology is its sustainability. In the control phase, the process improvement needs to be verified, and performance tracking mechanisms and measurements should be put into place to ensure that the process remains on the new course.
Step 4.1: Validate measurement system

The optimal settings for the vital few *X*s that optimize the output performance have been determined in the improve phase. To ensure that the optimal settings are achieved, the measurement systems need to be validated for the vital few *X*s, as applied in Step 1.3.

Step 4.2: Verify the process improvement

With the changes implemented in the vital few *X*s, the new process output variables need to be evaluated to verify the improvement. It involves the calculation of average, standard deviation, DPMO, Sigma level, and/or process capability for each KPOV. It may be necessary to check if the change in the process average (variance) is statistically significant before/after the improvement. Finally, we need to assess if the performance benchmark defined in Step 2.2 is achieved.
Step 4.3: Implement process controls

Controls need to be implemented to hold the gains, which involves monitoring the performance, developing corrective procedures, training people who run the process, and integrating into the systems. SPC is the major tool used to control the vital few *X*s and the KPOVs. The project is not complete until the changes are documented in the appropriate quality management system, such as QS9000/ISO9000. BB and process owners should work together to establish a turnover plan.

3.4.1.6 Phase ∝: Technology transfer

The infinity sign means that transferring technology is a never-ending phase for achieving Six Sigma quality. Ideas and knowledge developed in one part of the organization can be transferred to other parts of the organization. In addition, the methods and solutions developed for one product or process can be applied to other similar products or processes. The technology transfer can be implemented by creating a database of completed and ongoing Six Sigma projects that can be shared across the organization using the intranet. With the technology transfer, the Six Sigma approach starts to create phenomenal returns.

3.4.2 The Toolbox for the DMAIC(T) Process

Most of existing tools in the Six Sigma methodology are quality management tools and statistical methods, which is quite natural because Six Sigma originated from the statistical concept for quality improvement [1]. Typical quality management tools are process mapping, cause-and-effect diagrams, Pareto charts, QFD, FMEA, and so on. Examples of the statistical methods include the SPC, DOE, ANOVA, hypothesis testing, regression analysis, and so on [9]. These quality management and statistical tools are effective in finding and eliminating causes of defects in business processes by focusing on the inputs, the outputs, and/or the relationship between inputs and outputs. One of the advantages of the Six Sigma methodology over other process improvement programs is that the use of data analysis tools in Six Sigma projects enables practitioners to accurately identify process hindering problems and demonstrate the improvements using objective data. Table 3.1 summarizes the primary tools in the Six Sigma toolbox.

As experience in implementing Six Sigma accumulated, researchers and practitioners observed that Six Sigma has its inherent limitations and cannot be used as a universal solution for any process in any organization [13]. Therefore, additional techniques should be integrated to enhance the effectiveness of Six Sigma. Recent technical development in the field of management science and statistical analysis has provided more effective tools for improving the efficiency and the productivity

Table 3.1 Six Sigma toolbox

Phase	*Steps*	*Primary tools*
Define	Outline project objectives, expected benefits, and project timeline	Project charter Benchmarking surveys Spider charts Flowcharts SIPOC diagrams
	Select CTQ characteristics	QFD FMEA
	Develop a data collection plan	Sampling (data quantity and quality)
Measure	Validate the measurement system	Gage R&R ANOVA
	Establish product capability	Process capability analysis Basic graphical/summary statistics
	Determine improvement objectives	Cost analysis Forecasting Histogram/Pareto chart/Run chart Scatter plot
Analyze		Cause-and-effect diagram
	Identify variation sources	FMEA Hypothesis testing Confidence intervals ANOVA
	Discover variable relationship	ANOVA Linear regression Empirical modeling
Improve	Establish operating tolerances	Robust design ANOVA
	Optimize variable settings	Optimization techniques Sensitivity analysis Simulation
	Validate the measurement system	Gage R&R Process capability analysis
Control	Verify process improvement	Hypothesis testing
	Implement process controls	Statistical process control Control charts QS9000/ISO9000
Technology Transfer	Transfer solutions across the organization	Project management tools Database and intranet

SIPOC supplier, input, process, output, and customer *CTQ* critical to quality, *QFD* quality function deployment, *FMEA* failure mode and effects analysis, *ANOVA* **analysis of variance**

of organizations, such as queuing systems, heuristics, and data envelopment analysis (DEA). Interested readers are referred to Tang et al. [13] and Feng and Antony [4].

3.5 Design for Six Sigma

While Six Sigma's DMAIC approach improves the existing process by removing defects, the fundamental structure of the process remains unchanged. To prevent quality problems from the beginning, the method of DFSS is more proactive, which involves changing or redesigning the process at the early stages of the product/process life cycle. The objective of DFSS is to "design it right at the first time" to avoid the quality defects downstream. Although DFSS takes more effort at the beginning, it will benefit an organization in the long run by designing Six Sigma quality into products/processes.

As shown in Fig. 3.8, the Six Sigma process improvement approach is effective in achieving the benchmark identified for the current process. To reach the future potential and make breakthrough, DFSS comes into play to redesign the existing process, or design a new process or product. DFSS becomes necessary when [16]

- the current process has to be replaced, rather than repaired or just improved,
- the required quality level cannot be achieved by just improving an existing process,
- an opportunity is identified to offer a new process, and
- breakthrough and new disruptive technologies becomes available.

DFSS is a disciplined approach to design a process or product that utilizes statistical tools and engineering methods. There are several methodologies for DFSS, such as DMADV, IDOV, or ICOV. The IDOV (or ICOV) acronym is defined as Identify, Design (Characterize the design), Optimize, and Validate, which is a well-known design methodology, especially in the manufacturing world. The DMADV is a popular methodology since it has the same number of

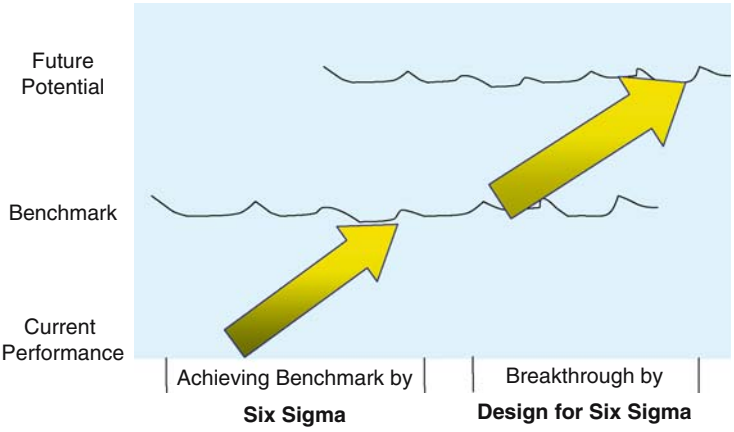

Fig. 3.8 Performance improvement by Six Sigma and DFSS

Table 3.2 Design for Six Sigma toolbox

Phase	Steps	Primary tools
Define	Define project goals and customer (internal and external) requirements	Project charter Benchmarking surveys SIPOC diagrams VOC (voice of customer)
Measure	Measure and determine technical requirements and specifications	QFD FMEA
Analyze	Analyze the process options to meet the customer needs	FMEA Risk assessment Engineering analysis
Design	Design the process to meet the customer needs	Robust design DOE Optimization techniques System engineering Simulation Statistical tolerancing
Verify	Verify and test the design, assess performance and ability to meet customer needs	Reliability testing Accelerated testing FMEA

SIPOC supplier, input, process, output, and customer, *VOC* voice of customer, *QFD* quality function deployment, *FMEA* failure mode and effects analysis, *DOE* design of experiment

letters as the DMAIC acronym. The five phases of DMADV are Define, Measure, Analyze, Design, and Verify. These are described in Table 3.2, as well as the typical tools for each phase.

DFSS integrates many well-known methods, tools, and philosophies for quality and reliability improvement, research, development and design strategies, and management thinking for teamwork from cradle to grave for products and processes in organizations. As pointed out in Welch et al. [15]: "Every new GE product and service in the future will be Designed for Six Sigma. These new offerings will truly take us to a new definition of World Class."

3.6 Case Study

A Six Sigma project implemented to measure physician productivity in a clinical department is given as a case study [4]. The concept of physician productivity is increasingly attracting attention in health-care sectors. As the result and measure of physicians' work, physician productivity can be used as the base of compensation assignment, resource allocation, and work incentive. One of the traditional measures of productivity is the number and types of patient encounters. However, without considering the time and other inputs invested in patient care, this measure does not allow for the measurement of physician efficiency. The application of traditional measures is limited by the complexity which exists in the actual practice.

3.6.1 Define Phase

A project aim statement that specified project objectives, expected benefits, team structure, and project timeline was created. The long-term goal of this study was to provide recommendations to the leadership that would lead to optimized resource planning and enhanced revenue. The project aimed to improve clinical productivity through the measurement of individual faculty productivity relative to the benchmark via persuasive and unique tactics.

3.6.2 Measure Phase

Physicians in the department differ in ages, experiences, and percentage of clinical times. In this study of assessing clinical productivity, three primary types of clinical outputs that capture the major contribution by most clinical physicians were considered: new outpatient visits, consulting, and established outpatient visits, which are the CTQ characteristics. This consideration was validated with the medical director in the department. The data could be collected from *a list of physician workload* (percentage of research, clinical, and teaching*)* and the *outpatient activity report* provided by the department.

3.6.3 Analyze Phase

The team analyzed the number and types of patient encounters using run charts and bar charts to provide illustration for the relative performance of individual physicians. The summary statistics were analyzed including mean, maximum, minimum, and standard deviation.

Furthermore, the following issues needed to be handled effectively:

- Multiple outputs including the numbers of new patients, consulting, and established patients shall be integrated to measure the overall productivity.
- Clinical inputs shall be incorporated into the evaluation to compare the relative efficiency.
- An easy-to-use efficiency measure is required in practice.

A fishbone diagram was constructed to analyze factors that influence physician productivity. Many factors can affect an individual physician's productivity, including patient characteristics, physician characteristics, hospital environment, and third-party reimbursement. It is reasonable to assume that the clinical cost can be estimated by the multiplication of physician's monthly salary and percentage of clinical time. This measure of clinical cost not only captures the budgetary input allocated to each physician but also reflects the clinical efforts produced by each

physician. As the amount of physician's salary is closely related to physician's medical experience, age, and/or specialty, the clinical cost also conveys information about other characteristics of a physician. Therefore, a one-input and three-output clinical production system was in consideration.

3.6.4 Improve Phase

The DEA is an effective method to evaluate the relative efficiency among different organizational units. The DEA was implemented for the inputs and outputs, and the results provided efficiency ranking among physicians. The DEA yields additional information that can be used during the *Improve* phase. This includes the reference set consisting of efficient physicians for each inefficient physician as well as the performance levels that would make a relatively inefficient physician efficient. Beyond the recognition of inefficient physicians, the above-mentioned information can provide a countermeasure to improve physician productivity and optimize resource planning.

3.6.5 Control Phase

Using performance standards set by the DEA model, the relative efficiency for each physician can be monitored monthly. By collecting future data, cost savings can be analyzed to verify the benefits of implementing the DEA in the Six Sigma project. If the performance target is achieved for each physician, the overall efficiency can be improved, which will ultimately enhance organizational revenue with the same amount of inputs.

3.6.6 Technology Transfer Phase

The success of this project will buy-in extensive support from the leadership. The experience can then be transferred to other clinical departments in the organization for evaluating physician productivity and optimizing resource planning.

3.7 Conclusion and Future Trends

Although Six Sigma originated in the manufacturing industry, it has been successfully adopted by many other public or private sectors, from financial services to health-care delivery and management, from information technology to knowledge management. The successful implementation over 20 years supports the hypothesis

that basic thinking and methods that are used in Six Sigma have lasting values, even though they may be marketed by new names in the future. Ideas can be integrated with other productivity improvement methods, for example, the recent focus on Lean Six Sigma. The methodology will continue to show their endurance in the global business environment.

References

1. Allen TT (2006). *Introduction to Engineering Statistics and Six Sigma: Statistical Quality Control and Design of Experiments and Systems*. Springer-Verlag, London.
2. Carnell M, Shank S (2002). The Champion's role in successful Six Sigma deployments. Retrieved August 29, 2007, from http://www.isixsigma.com/library/content/c020422a.asp.
3. Feng Q (2005). *Integrated statistical and optimization strategies for the improvement of Six Sigma methodology*. PhD dissertation, University of Washington, Seattle, WA.
4. Feng Q, Antony J (2007). Integrating data envelopment analysis into Six Sigma methodology for measuring health service efficiency. Submitted to Health Service Research (under review).
5. Feng Q, Kapur KC (2007). Quality control. In: Ravindran AR (ed.), *Operations research and management science handbook*. CRC Press, Boca Raton, FL.
6. Feng Q, Kapur KC (2008). Quality engineering: Control, design and optimization. In: Misra KB (ed.), *Handbook of performability engineering*. Springer-Verlag, London.
7. Feng Q, Manuel CM (2008). Under the knife: A national survey of Six Sigma programs in U.S. healthcare organizations. International Journal of Health Care Quality Assurance 21(6).
8. Hayes BJ (2002). Six Sigma critical success factors. Retrieved August 28, 2007, from http://www.isixsigma.com/library/content/c020415a.asp
9. Henderson GR (2006). *Six Sigma quality improvement with MINITAB*. John Wiley and Sons, New York, NY.
10. Kapur KC, Feng Q (2005). Integrated optimization models and strategies for the improvement of the Six Sigma process. International Journal of Six Sigma and Competitive Advantage 1(2).
11. Kapur KC, Feng Q (2006). Statistical methods for product and process improvement. In: Pham H (ed.), *Springer handbook of engineering statistics*. Springer-Verlag, London.
12. Marx M (2007). Six Sigma saves a fortune. *iSixSigma Magazine*, January 2007.
13. Tang LC, Goh TN, Lam SW, Zhang CW (2007). Fortification of Six Sigma: Expanding the DMAIC toolset. Quality and Reliability Engineering International 23(1): 3-18.
14. Tsung F (2006). Six Sigma. In: Pham H (ed.), *Springer handbook of engineering statistics*. Springer-Verlag, London.
15. Welch JF, Murphy EF, Dammerman DD, Opie JD (1999). Letter to our share owners. Available at: http://www.ge.com/annual98/share/index.htm.
16. Yang K, El-Haik B (2003). *Design for Six Sigma: A roadmap for product development*. McGraw-Hill, New York, NY.