1

Introduction

Six Sigma is a strategic approach that works across all processes, products and industries. (Snee, 2004, p. 8)

Overview

In an overview of Six Sigma, Montgomery and Woodall (2008) state:

> Six Sigma is a disciplined, project-oriented, statistically based approach for reducing variability, removing defects, and eliminating waste from products, processes, and transactions. The Six Sigma initiative is a major force in today's business world for quality and business improvement. Statistical methods and statisticians have a fundamental role to play in this process.

This book is about the understanding and implementation of statistical methods fundamental to the Six Sigma and other approaches to the continuous improvement of products, processes and services. Release 16 of the widely used statistics package Minitab is used throughout. Mindful that in the vast majority of situations those applying statistical methods in quality improvement and Six Sigma are not statisticians, information on the implementation of each method covered will be preceded by some background explanation, typically employing small data sets. The role of each method within the define–measure–analyse–improve–control (DMAIC) framework of Six Sigma will be highlighted.

This chapter deals with quality and quality improvement and in particular with the highly successful Six Sigma approach to quality improvement. It describes the role of statistical methods in quality improvement and Six Sigma and outlines how Minitab can be used to implement these methods.

Six Sigma Quality Improvement with Minitab, Second Edition. G. Robin Henderson.

1.1 Quality and quality improvement

Definitions of quality abound. Wheeler and Chambers (1992, p. xix) define quality as being 'on-target with minimum variance'. They state that operating 'on-target' requires a different way of thinking about processes and that operating with 'minimum variance' can only be achieved when a process is behaving in a reasonably stable and predictable way. Wheeler and Poling (1998, p. 3) state that continual improvement requires a 'methodology for studying processes and systems, and a way of differentiating between the different types of variation present in processes and systems'. They refer to the cycle of activities involved in continual improvement as the plan–do–study–act (PDSA) cycle – see Figure 1.1 (Wheeler and Poling, 1998, p. 5), reproduced by permission of SPC Press, Inc. This cycle of activities is often referred to as the Shewhart–Deming cycle in honour of two key figures in the development of quality improvement methodology, Dr Walter A. Shewhart and Dr W. Edwards Deming.

In 1988 the author had the pleasure, along with some 400 others, of attending a seminar for statisticians by the late Dr Deming at the University of Nottingham. In his presentation handout he described the cycle as follows (Deming, 1988, p. 33):

- *Plan* – Plan a change or test, aimed at improvement.
- *Do* – Carry it out, preferably on a small scale.
- *Study* – Study the results. What did we learn?
- *Act* – Adopt the change or abandon it or run through the cycle again, possibly under different environmental conditions.

In his book *Out of the Crisis*, Deming (1986, p. 23) listed *14 Points for Management*, including the following:

- *Constancy of purpose* – create constancy of purpose for continual improvement of products and service.
- *Improve every process* – improve constantly and forever every process for planning, production and service.
- *Eliminate targets* – substitute aids and helpful supervision; use statistical methods for continual improvement.

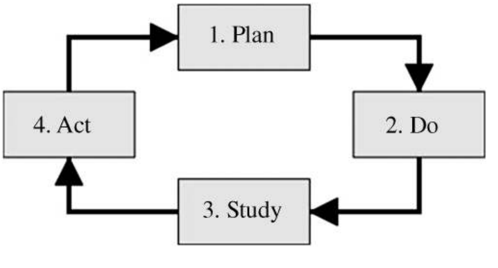

Figure 1.1 The Shewhart–Deming PDSA cycle.

Thus the Deming philosophy of quality improvement advocates never-ending continual improvement of all processes within an organization. The improvement process itself should be structured and employ statistical methods. 'Improvement nearly always means reduction of variation' (Deming, 1988).

1.2 Six Sigma quality improvement

Six Sigma is one of a number of quality improvement strategies based on the Shewhart–Deming PDSA cycle. Truscott devotes a chapter to comparison of Six Sigma with other quality improvement initiatives. He puts Six Sigma in perspective earlier in his book as follows (Truscott, 2003, p. 1):

> Six Sigma focuses on establishing world-class business-performance benchmarks and on providing an organizational structure and road-map by which these can be realized. This is achieved mainly on a project-by-project team basis, using a workforce trained in performance-enhancement methodology, within a receptive company culture and perpetuating infrastructure. Although particularly relevant to the enhancing of value of products and services from a customer perspective, Six Sigma is also directly applicable in improving the efficiency and effectiveness of all processes, tasks and transactions within any organization. Projects are thus chosen and driven on the basis of their relevance to increased customer satisfaction and their effect on business-performance enhancement through gap analysis, namely, prior quantitative measurement of existing performance and comparison with that desired.

Six Sigma originated at Motorola Inc. as a long-term quality improvement initiative entitled 'The Six Sigma Quality Program'. (Six Sigma® is a registered trademark and service mark of Motorola Inc.) It was launched by the company's chief executive officer, Bob Galvin, in January 1987 with a speech that was distributed to everyone in the organization. In the speech Galvin reported on many visits to customers in the previous six months during which desires were expressed for better service from Motorola in terms of delivery, order completeness, accurate transactional records etc. The customers had also indicated that, with better service and an emphasis on total quality, Motorola could expect an increase of between 5% and 20% in future business from them. He therefore challenged employees to respond urgently to make the necessary improvements, emphasized the leadership role of management in the implementation of the programme and announced that Motorola's corporate quality goal had been updated accordingly. The goal included the objective 'Achieve Six Sigma capability by 1992' (Perez-Wilson, 1999, p. 131).

In addition to being a strategy for the continual improvement of quality within organizations, Six Sigma indicates a level of performance equating to 3.4 nonconformities per million opportunities, a level which some regard as being 'world-class performance'. This often leads to confusion. In this book the phrase 'sigma quality level' will be used for this indicator of process performance, as advocated by Breyfogle (2003, p. 3). Thus a sigma quality level of 6 equates to 3.4 nonconformities per million opportunities. The link between sigma quality level and number of nonconformities per million opportunities will be explained in detail in

Table 1.1 Sigma quality levels and nonconformities per million opportunities.

Sigma quality level	Nonconformities per million opportunities
1.5	501 350
2.0	308 770
2.5	158 687
3.0	66 811
3.5	22 750
4.0	6 210
4.5	1 350
5.0	233
5.5	32
6.0	3.4

Chapter 4. Table 1.1 gives some sigma quality levels and corresponding numbers of nonconformities per million opportunities.

The plot in Figure 1.2 (created using Minitab) shows nonconformities per million opportunities plotted against sigma quality level, the vertical scale being logarithmic. Many authors refer to defects rather than nonconformities and state that a sigma quality level of 6 equates to 3.4 defects per million opportunities or 3.4 DPMO.

Imagine a bottling plant where there was concern over the number of bottles of whisky containing contaminant particles. A bottling run of 14 856 bottles had yielded 701 nonconforming bottles in terms of contamination. This corresponds to $(701/14\,856) \times 10^6 =$ 47 186 nonconforming bottles per million. Since 47 254 lies between 22 750 and 66 811, Table 1.1 indicates a sigma quality level between 3.0 and 3.5. The more comprehensive table in

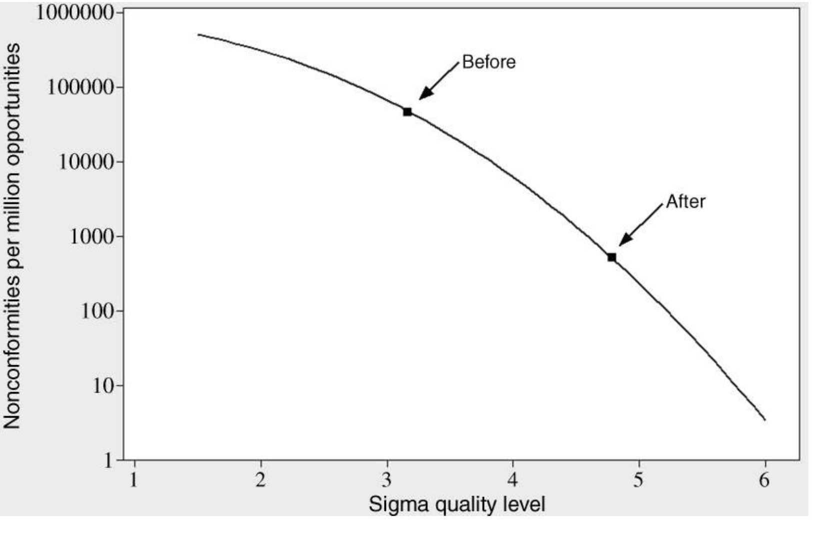

Figure 1.2 Sigma quality levels and nonconformities per million opportunities.

Appendix 1 gives the sigma quality level as 3.17 (47 461 being the entry in the table closest to 47 186).

The main source of contamination was found to be the wax-coated corks used to seal the bottles. Dialogue with the supplier of the corks led to a trial with corks produced using a new method for application of the wax. For the trial there were 8 nonconforming bottles out of 15 841. The reader is invited to verify that this corresponds to 505 nonconforming bottles per million and a sigma quality level of 4.79. Thus the higher the sigma quality level for a process the better is its performance. The points corresponding to the situations before and after the process change are indicated on the curve in Figure 1.2. Montgomery and Woodall (2008) state that 'the 3.4-ppm metric, however, is increasingly recognized as primarily a distraction; it is the focus on reduction of variability about the target and the elimination of waste and defects that is the important feature of Six Sigma'.

Another source of confusion arises from the use of σ, the lower-case Greek letter sigma, as a statistical measure of variation called standard deviation. It will be explained in detail in Chapter 2. Bearing in mind Deming's comment that 'Improvement nearly always means reduction of variation', the consequence is that improvement often implies a reduction in σ. Thus it is frequently the case that improvement corresponds to an increase in sigma quality level on the one hand, and to a decrease in sigma on the other. Therefore it is essential to make a clear distinction between both uses of sigma.

Larry Bossidy, CEO of Allied Signal led the implementation of Six Sigma with his organization (Perez-Wilson, 1999, p. 270). In June1995 Bossidy addressed the Corporate Executive Council of the General Electric Corporation (GE) on Six Sigma quality at 'one of the most important meetings we ever had' (Welch, 2001). The Council was impressed by the cost saving achieved at Allied Signal through Six Sigma and, as an employee survey at GE had indicated that quality was a concern for many GE employees, Welch 'went nuts about Six Sigma and launched it' (Welch, 2001). One of the first steps GE took in working towards implementation of Six Sigma was to invite Mikel Harry, formerly a manager with Motorola and founder of the Six Sigma Academy, to talk to a group of senior employees. In a four-hour presentation 'he jumped excitedly from one easel to another, writing down all kinds of statistical formulas'. The presentation captured the imagination of Welch and his colleagues, the discipline of the approach being of particular appeal to engineers. They concluded that Six Sigma was more than quality control and statistics – 'ultimately it drives leadership to be better by providing tools to think through tough issues' – and rolled out their Six Sigma program in 1996 (Welch, 2001, p. 330). Examples of early Six Sigma success stories at GE, in both manufacturing and non-manufacturing situations, are reported by Welch (2001, pp. 333–334).

Perez-Wilson states that Motorola had looked for a catchy name to shake up the organization when introducing the concept of variation reduction and that in Six Sigma they found it. However, in spite of confusion over the different interpretations of sigma, in his opinion 'It [Six Sigma] reflects a philosophy for pursuing perfection or excellence in everything an organization does. Six Sigma is probably the most successful program ever designed to produce change in an organization' (Perez-Wilson, 1999, p. 195). A Six Sigma process, i.e. a process with a sigma quality level of 6, corresponds to 3.4 nonconformities per million opportunities – 'That's 99.99966 percent of perfection' (Welch, 2001). Harry and Schroeder (2000) refer to a Six Sigma process as the Land of Oz and to the Six Sigma Breakthrough Strategy as the Yellow Brick Road leading there. The Six Sigma 'roadmap' is the subject of Section 1.3.

Antony (2010) and Montgomery and Woodall (2008) refer to the evolution of Six Sigma through three generations of implementations:

- Generation I – focus on elimination of defects and variation reduction, primarily in manufacturing. Spanned the period 1987–1994, with Motorola being a good exemplar.
- Generation II – in addition to the focus in the previous generation there was an emphasis on linking efforts to eliminate defects and reduce variation to efforts to improve product design and reduce costs. Spanned the period 1994–2000, with General Electric a prime exemplar.
- Generation III – since 2000 there has been an additional focus on value creation for both organizations and their stakeholders.

In a keynote presentation at the European Network for Business and Industrial Statistics conference in 2009, Tom Johnstone, CEO of global company SKF, referred to its employment of Six Sigma 'to make it easier and attractive for our customers and suppliers to do business with us'. He referred to four dimensions – 'Standard' Six Sigma, Design for Six Sigma (DFSS), Lean Six Sigma and Six Sigma for Growth. He also referred to the integration of Six Sigma with other improvement initiatives as being a challenge faced by SKF (Johnstone, personal communication, 2010) This concurs with the comment by Montgomery and Woodall (2008) that they 'expect Six Sigma to become somewhat less outwardly visible, while remaining an important initiative within companies'. These comments indicate that Six Sigma is still evolving. In the final section of their paper, on the future of Six Sigma, Montgomery and Woodall (2008) state:

> Six Sigma has become a widely used implementation vehicle for quality and business improvement. It is logical to ask about its future. Some have speculated that 'Six Sigma' is the 'flavour of the month' as management looks for the quick fix to crucial operational problems. However, since Six Sigma is over 20 years old and implementations are growing worldwide, it is difficult to believe that it is simply a management fad. In an ideal implementation, Six Sigma, DMAIC, DFSS and lean tools are used simultaneously in an organization to achieve high levels of process performance and significant business improvement.

Further evidence of the important role of Six Sigma is provided by the current development of two international standards, BS ISO 13053-1/2: *Quantitative methods in process improvement – Six Sigma – Part 1: DMAIC methodology* and *Part 2: Tools and techniques*.

1.3 The Six Sigma roadmap and DMAIC

The ideal roadmap for implementing Six Sigma within an organization is claimed to be as follows (Pande *et al.*, 2000).

1. Identify core processes and key customers.
2. Define customer requirements.

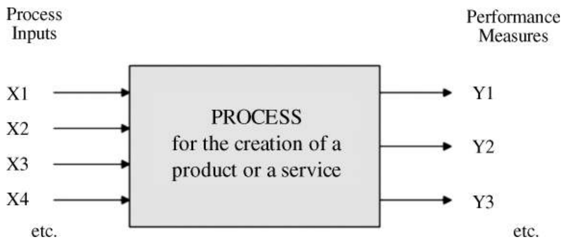

Figure 1.3 Process model.

3. Measure current performance.
4. Prioritize, analyze, and implement improvements.
5. Expand and integrate the Six Sigma system.

A process or system may be represented by the schematic in Figure 1.3, where the *X*s represent inputs and the *Y*s represent performance measures on the process output. For the process of baking biscuits examples of inputs are flour supplier, oven temperature and cooking time. Some inputs are controllable by the baker, such as flour supplier and oven temperature. Others, such as the moisture content of the flour, are not. Examples of performance measures are the proportion of broken biscuits and the height of a stack of 16 biscuits – the number in a standard pack. Problems with the next process of packaging the biscuits may arise because stack height is off target or because there is too much variation in stack height. *X*s are referred to as inputs, independent variables, factors and key process input variables. Uncontrollable inputs are often designated noise factors. *Y*s are referred to as performance measures, dependent variables or responses. Where performance measures are of vital importance to the customer, the phrases key process output variables or critical to quality characteristics are employed.

The process improvement model at the heart of Six Sigma is often referred to as define–measure–analyse–improve–control (DMAIC). The first step is to define the problem or opportunity for improvement that is to be addressed. Writing in *Quality Progress*, a journal of the American Society for Quality (ASQ), Roger Hoerl, who at the time of writing is Manager of the Statistics Lab at General Electric Global Research, described the last four steps as shown in Box 1.1 (Hoerl, 1998). He also Hoerl (2001, p. 403) refers to DMAIC as ‘the glue which holds together the individual tools and facilitates solving real problems effectively’.

Some experts in Six Sigma apply the DMAIC improvement model both to process improvement projects and to process design/redesign projects. Others prefer to think in terms of DFSS and use define–measure–analyse–design–verify (DMADV) in the case of process design/redesign. Montgomery (2009) states that ‘the I in DMAIC may become DFSS’ – in other words, that improvement may only be possible through redesigning a process or creating a new one.

Six Sigma projects are normally selected as having potential in terms of major financial impact through facets of a business such as quality, costs, yield and capacity. Teams working on projects are typically led by employees designated ‘Black Belts’. Black Belts will have

Measure – Based on customer input, select the appropriate responses (the *Y*s) to be improved and ensure that they are quantifiable and can be accurately measured.

Analyze – Analyze the preliminary data to document current performance or baseline process capability. Begin identifying root causes of defects (the *X*s or independent variables) and their impact.

Improve – Determine how to intervene in the process to significantly reduce the defect levels. Several rounds of improvement may be required.

Control – Once the desired improvements have been made, put some type of system into place to ensure the improvements are sustained, even though additional Six Sigma resources may no longer be focused on the problem.

Box 1.1 Description of key phases in applying Six Sigma methodology.

been awarded their titles after several weeks of intensive training, including statistical methods, and on completion of a successful Six Sigma project. A Six Sigma organization will invariably have a Six Sigma 'Champion' on the senior management team and may also have Master Black Belts. 'Green Belts' undergo less extensive training than Black Belts and may lead minor projects but normally assist on Black Belt led projects. Some organizations designate employees who have undergone basic Six Sigma training as 'Yellow Belts'. External consultants are often used to train the first group of Black Belts within an organization. As the organization matures in terms of Six Sigma the Black Belts frequently undertake training of Green Belts and may devote 50–100% of their time to project activities. A discussion of curricula for the training of Black Belts is given by Hoerl (2001). He states that 'the BB [Black Belt] role is intended to be a temporary assignment – typically two years' (Hoerl, 2001, p. 394). Many organizations look to Black Belts to progress to senior roles; for example, at SKF it is envisaged that future company leaders will be former Black Belts (Johnstone, personal communication, 2010). Snee (2004) provides a Six Sigma project case study.

1.4 The role of statistical methods in Six Sigma

Measurement is fundamental to Six Sigma and measurement creates data. Many improvement initiatives lead to 'before' and 'after' data for *Y*s – data collected before and after process changes are implemented. In terms of the process model shown in Figure 1.3 the key to improvement is knowledge of how the *X*s influence the *Y*s, i.e. knowledge of the 'formula' linking the *X*s to the *Y*s, represented symbolically as $\mathbf{Y} = f(\mathbf{X})$. (The use of bold symbols indicates that invariably a process has associated with it a set of *Y*s and a set of *X*s so that $\mathbf{Y}$ represents $Y_1, Y_2, Y_3, \ldots, Y_m$ and $\mathbf{X}$ represents $X_1, X_2, X_3, \ldots, X_n$ in the case of a process with m performance measures and n inputs.) Statistics provides a series of tools to aid the search for such knowledge – tools such as design of experiments and regression.

The author recalls the late John Tukey stating, in a Royal Statistical Society presentation in Edinburgh in 1986, that 'display is an obligation' whenever one is dealing with data. Data display can be highly informative, so the topic will be emphasized. Tools from exploratory data analysis (EDA), on which Tukey's (1977) book *Exploratory Data Analysis* is regarded as a classic, are included.

In many cases, process improvement is clearly evident from data display. In order to formally answer the question 'Has improvement been achieved?' the topics of statistical inference and estimation are crucial for evaluation of evidence from 'before' and 'after' type data and for quantifying the extent of any improvement. Much process improvement experimentation effort is wasted through the use of badly planned experiments, particularly experiments in which the effect of only a single *X* on the *Y*s is considered. The use of properly designed experiments can be of immense benefit, especially when the effects of the *X*s are not independent of one another. Regression and correlation also provide tools for exploring and modelling relationships between *X*s and *Y*s.

Shewhart control charts have a major role to play and many important applications. The example in Figure 1.4 (reproduced by permission of NHS Lothian) displays data from an improvement project at a major hospital. The aim of the project was to reduce delays to assessment at a rapid access transient ischaemic attack and stroke clinic. In the measure and analyse phases of the project, the chart indicated that delay between patient referral and attendance at clinic averaged around 13 days. In early 2007, during the improve phase, a hotline to a consultant was introduced, open 24 hours a day, seven days a week. The consultant on call provided immediate advice and, if appropriate, made an appointment for a clinic visit. The chart indicated a reduction in the average delay from 13 days to around 3 days.

There is a danger that project improvement teams can become involved in measurement without considering the measurement process itself. Statistics provides tools for the evaluation of measurement processes, which 'can and should be continuously improved, just as you would "regular" work processes' (Pande *et al.*, 2000, p. 203).

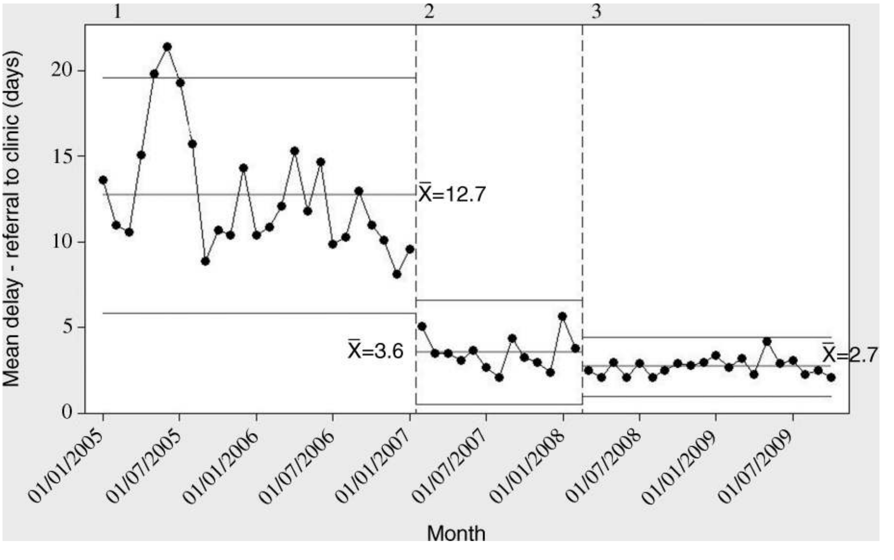

Figure 1.4 A Shewhart control chart demonstrating major improvement.

1.5 Minitab and its role in the implementation of statistical methods

Many involved in Six Sigma projects are busy professional people who welcome rapid and easy access to relevant statistical methods. In a chapter on the history of statistics and quality improvement, Jeroen de Mast (2008, p. 26) refers to thousands of Black Belts and Green Belts worldwide whose applications of statistical methods to quality improvement are 'supported by easy-to-use software'. Minitab is without doubt a statistical software package that is easy to use and its creators claim to be the leading provider of software for statistics education and lean, Six Sigma, and quality improvement projects. Essentially Minitab can provide all the methods referred to in the previous section – and much more.

The author's experience with Six Sigma Black and Green Belt and other trainees has generally been one of their feelings of delight at the ease which statistical methods can be implemented using Minitab. It provides the following capabilities and features:

1. Data and file management
2. Assistant (new in Release 16)
3. Basic statistics
4. Graphics
5. Regression analysis
6. Analysis of variance
7. Design of experiments
8. Statistical process control
9. Measurement systems analysis
10. Reliability and survival analysis
11. Multivariate analysis
12. Time series and forecasting
13. Nonparametrics
14. Tables
15. Power and sample size
16. Simulation and distributions
17. Macros and customizability

A number of quality tools are also provided, e.g. cause-and-effect diagrams. The simulation facilities may be used to illustrate statistical concepts and theory requiring fairly advanced mathematics for a theoretical understanding.

1.6 Exercises and follow-up activities

1. For a familiar process for the creation of a product, list inputs (*X*s) and performance measures (*Y*s). Indicate which inputs you view as being key, and identify those that can be controlled and those that cannot be controlled, or are not controlled, during routine operation, which are noise and which performance measures are critical.

2. Repeat for a process for the creation of a service.

3. Access the Minitab website: http://www.minitab.com/en-GB/theater/default.aspx?video=Minitab16Tour and view the Minitab 16 Statistical Software product tour video. Note the availability of seven other Minitab 16 videos that you might find informative as you progress through the book.