

The word sigma is the eighteenth letter of the Greek alphabet ( $\Sigma$ ,  $\sigma$ ), transliterated as ‘S, s’. These symbols are used to denote a mathematical sum ( $\Sigma$ ) and a standard deviation ( $\sigma$ ); the term standard deviation was introduced to statistics by Karl Pearson (1894), which is a quantity calculated to indicate the extent of deviation for a group of elements as a whole from their expected central tendency. A low standard deviation indicates that the elements tend to be very close to their expected central tendency, whereas high standard deviation indicates that the elements are spread out over a large range from their expected central tendency.

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## 2.1 Setting the Stage: Why Six of These Sigma?

Why six of these “sigma”?

What happened to the first five “sigma”?

What about those “sigma” coming after the sixth “sigma”?

When referring to the Greek letter, as a quantity calculated to indicate the extent of deviation for a group of elements as a whole from their expected central tendency, it is assumed that these elements are homogeneous and spread out in different spatial and temporal places following a regular and stable manner of performance (or occurrence). The stability of occurrence is a very important requirement as it allows the extraction of meaningful measures from these elements. Regardless of their origin and nature, these elements will display variations over time.

We can think of variation as change or slight difference in condition, amount, or level from the expected occurrence, typically within certain limits. Variation has two broad causes that have an impact on data collected from these elements: common (also called random, chance, or unknown) causes and assignable (also called special) causes.

Common causes of variation are inherent and an integral part in the business activities been considered. They can be thought of as the “natural pulse of the business activities” and they are indicated by a stable, repeating pattern of variation.

Assignable causes of variation are those causes that are not intrinsically part of the business activities been considered but arise because of specific circumstances. When they occur, they signal a significant occurrence of change in the business activities and they lead to a statistically significant deviation from the norm. Assignable causes of variation are indicated by a disruption of the stable, repeating pattern of variation. They result in unpredictable performance of the business activities and must therefore be identified and systematically removed before taking any other steps to improve quality of the business activities considered.

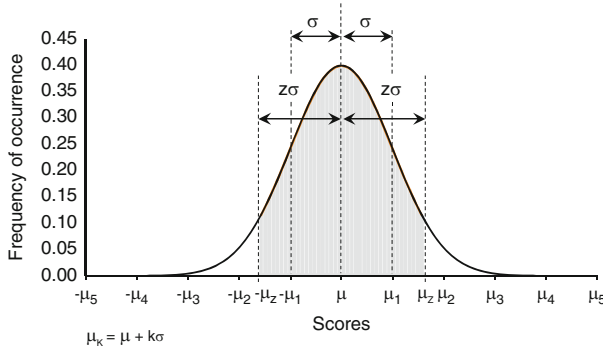
In business applications, the elements considered are measurable features or measurable characteristics of business activities outcomes. Outcomes of business activities can be products, transactions, services delivered, sub-parts or particular features of these entities. In the remaining of this chapter, we will use the term “element” as a generic term to designate a measurable feature or a measurable characteristic of these entities. Here, the concept of outcome of business activities is multi-dimensional as it comprises a core benefit or service for which the customer has a need or want. It has a physical existence which is manifest in its price and quality, its performance, specification, design, reliability and longevity. It has a service that involves such things as its warranty, delivery, after-sales service and promotional support. And even beyond that, it has psychological characteristics such as the outcome image and brand and corporate images which are perceived by existing and potential customers.

Thus, by considering each element of a group as a balanced sum of a large enough number of unobserved random events acting additively and independently, each of which with finite mean and variance, the central limit theorem tells us that the occurrence pattern of the elements of the group will tend to follow a normal distribution in nature.

A normal distribution is a very important statistical data distribution pattern occurring in many natural phenomena, such as height, blood pressure, lengths of objects produced by machines, etc. The frequency of occurrence of certain data, when graphed as a histogram (data scores on the horizontal axis, amount of data or frequency on the vertical axis), creates a bell-shaped curve known as a normal curve, or normal distribution.

As illustrated in Fig. 2.1, normal distributions are symmetrical with a single central peak at the mean ( $\mu$ , average) of the data. The shape of the curve is described as bell-shaped with the graph falling off evenly on either side of the mean. Fifty percent of the distribution lies to the left of the mean and fifty percent lies to the right of the mean. The spread of a normal distribution is controlled by the standard deviation,  $\sigma$ . The smaller the standard deviation, the more concentrated the data around the mean.

This tendency of elements to form a normal distribution is somewhat analogous to the tendency of water to run down a hill—it is simply the easiest and most natural way of going. In order to have water run down a hill, all we need is water and a hill. In order to have numerical values form a normal distribution, all we need is the summation ( $\Sigma$ )—the combined additive result—of a multiplicity of random coincidences. This simple but very important principle, upon which this whole handbook rest on, is embodied on the formal side of probability theory by central limit theorem.



**Fig. 2.1** A plot of a normal distribution (or bell curve)

For occurrence patterns normally distributed, the proportion  $\rho(z)$  of elements falling within  $z$  standard deviations around the central tendency (i.e. the mean) is determined to be:

$$p(z) = \text{erf}\left(z/\sqrt{2}\right)$$

Where erf is the error function.

For various values of  $z$ , the percentages of elements falling within and beyond  $z$  standard deviations of the central tendency are shown in Table 2.1.

During his work on “Economic Control of Quality of Manufactured Product” (Shewhart, *Economic Control of Quality of Manufactured Product*, 1931), Shewhart created the control chart with 3 standard deviations around the central tendency as a performance permissible limit of variations. Shewhart’s use of 3-sigma limits, as opposed to any other multiple of sigma, did not stem from any specific mathematical computation. Rather, the choice of 3-sigma limits was seen to be an acceptable economic value, and it was also justified by “empirical evidence that it works.” No calculations from the normal distribution, or any other distribution, were involved in the choice of the multiplier of 3. Certainly, Shewhart did then check that this multiplier turned out to be reasonable under the artificial conditions of a normal distribution—and plenty of other circumstances as well.

From Table 2.1, we can observe that a business application which operates at a performance permissible limit of variations of 3 standard deviations around its expected central tendency will result in 2.7 elements falling beyond 3 standard deviations from the expected central tendency, out of one thousand occurrences.

Similarly, a business application which operates at a performance permissible limit of variations of 4.5 standard deviations around its expected central tendency will result in 6.8 elements falling beyond 4.5 standard deviations from the expected central tendency, out of one million occurrences.

Furthermore, a business application which operates at a performance permissible limit of variations of 6 standard deviations around its expected central tendency will result in 1.97 elements falling out of 6 standard deviations from the expected central tendency, out of one milliard occurrences.

**Table 2.1** 12 digits Microsoft Excel calculations of  $p(z)$  and  $(1 - p(z))$ 

$z$	% falling within $z\sigma$	% falling beyond $z\sigma$	Amount falling beyond $z\sigma$ out of:		
			One thousand occurrences	One million occurrences	One billion occurrences
1.0	0.682689492137	0.317310507863	317.3	317310.5	317310507.9
1.5	0.866385597462	0.133614402538	133.6	133614.4	133614402.5
2.0	0.954499736104	0.045500263896	45.5	45500.3	45500263.9
2.5	0.987580669348	0.012419330652	12.4	12419.3	12419330.7
3.0	0.997300203937	0.002699796063	2.7	2699.8	2699796.1
3.5	0.999534741842	0.000465258158	0.5	465.3	465258.2
4.0	0.999936657516	0.000063342484	0.1	63.3	63342.5
4.5	0.999993204654	0.000006795346	0.0	6.8	6795.3
5.0	0.999999426697	0.000000573303	0.0	0.6	573.3
5.5	0.999999962021	0.000000037979	0.0	0.0	38.0
6.0	0.999999998027	0.000000001973	0.0	0.0	1.97
6.5	0.999999999920	0.000000000080	0.0	0.0	0.08
7.0	0.999999999997	0.000000000003	0.0	0.0	0.0

While a chosen performance permissible limit of variations around the expected central tendency might work well for certain business applications, it might not operate optimally or cost effectively for applications with a higher performance permissible limit of variations. A pacemaker business application might need higher standards, for example, whereas a direct mail advertising campaign might need lower standards. An automobile car factory business application might need higher standards, for example, whereas a hotel customer service might need lower standards.

In this book, the basis and justification for choosing 6 (as opposed to 3 or 4.5, for example) standard deviations as the permissible limit of variations around the expected central tendency for stable business applications is due to the fact that it results in all produced/occurred elements falling within 6 standard deviations from the expected central tendency, out of one million occurrences, while not more than of two elements are likely to fall beyond 6 standard deviations from the expected central tendency, out of one billion occurrences.<sup>1</sup>

<sup>1</sup> A popularly prearranged definition of a “six sigma” process, in the “six sigma” literature, is one in which there are about 3.4 defects per million opportunities, under a mythological assumption that an unpredictable process will not shift location more than  $\pm 1.5$  sigma. This assumption does not hold true in most high temperatures combustion applications where heat transfer by radiation is predominant. When a high temperature combustion process is operated unpredictably there is no limit on the size of the shifts that can occur.

## 2.2 Standard Deviation, Quality and Cost

In business applications which operate at a performance permissible limit of variations of  $z$  standard deviations around the expected central tendency, every element within those business applications is intended to add value to the enterprise (businesses & customers) as a whole. It has a set of requirements or descriptions of what an element needs to add value to the enterprise. When a particular element meets those requirements, it is said that it has achieved quality, provided that the requirements accurately describe what the businesses and the customers actually need. Those occurred elements falling beyond  $z$  standard deviations of the expected central tendency are often regarded as flaw, unacceptable, or in non conformance quality within the group considered. They will undergo more or less corrective actions: rework, scrapping (of whatever can not be reworked) and conformance use.

Within the enterprise as a whole, we can consider three views for describing the overall quality of an element.

*First is the view of the business producing an element*—the business is primarily concerned with the design, engineering, and activities involved in producing an element. Quality is then measured by the degree of conformance to predetermined specifications and standards, and deviations from these standards can lead to defects also referred to as non conformance quality, unacceptable, or poor quality and low reliability. Hence, efforts for quality improvement are aimed at eliminating defects (components and subsystems of elements that are out of conformance), minimizing the need for scrap and rework, and hence overall reduction in production costs.

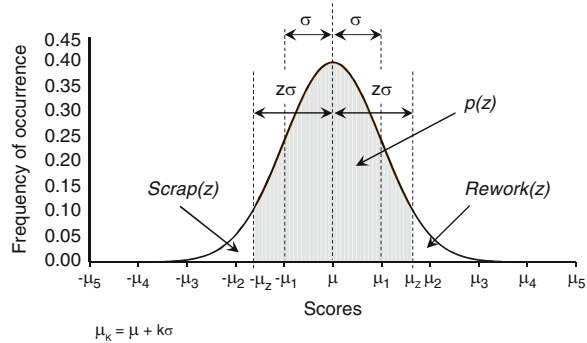
Controlling and improving quality of business activities outcomes has become an important business strategy for many organizations; manufacturers, distributors, transportation companies, financial services organizations; health care providers, and government agencies. Quality is a competitive advantage. A business that can delight customers by improving and controlling quality can dominate its competitors.

*Second is the view of the consumers or users of the produced element*—to consumers, a high-quality element is one that well satisfies their preferences and expectations. This consideration can include a number of characteristics, some of which contribute little or nothing to the functionality of the element but are significant in providing customer satisfaction.

Quality has become one of the most important consumer decision factors in the selection among competing products and services. The phenomenon is widespread, regardless of whether the consumer is an individual, an industrial organization, a retail store, a bank or financial institution, or a military defense program. Consequently, understanding and improving quality are key factors leading to business success, growth, and enhanced competitiveness. There is a substantial return on investment from improved quality and from successfully employing quality as an integral part of overall business strategy.

*A third view relating to quality of an element is to consider the element itself as a system* and to incorporate those characteristics that pertain directly to the value it adds to the enterprise through its usage and functionality. This approach should include overlap of the businesses and customers views.

**Fig. 2.2** A plot of a normal distribution with scrap and rework areas



Thus, keeping to the minimum and almost to none those elements falling beyond  $z$  standard deviations of the expected central tendency is the key concern of businesses as these elements have nominal production costs associated to them and eventually excess costs associated to their corrective actions (rework, scrapping and conformance use).

For a given element, we can think of its associated excess cost as the cost incurred as a result of deviation of the element from the expected central tendency of the group as a whole. The excess cost, which is equal to the sum of an excess cost of production plus and excess cost of conformance use, is equal to zero at the expected central tendency for a group of elements as a whole.

We can also think of the cost of scrap as the cost of the raw materials plus the cost of all processing done to the element, including the cost of inspection and the cost of disposal of the element as well. In business practices, scrapping an element is done only when it is cheaper to scrap it than to use or keep it within the group. The expected cost of reworking an element is less than or equal to the cost of scrapping the element. In business applications which operate at a performance permissible limit of variations of  $z$  standard deviations, Fig. 2.2 shows the data score intervals of those elements in non conformance quality.

The total cost of corrective actions (rework, scrapping and conformance use) is known as the Cost of Quality (CoQ). It is a measure of the costs specifically associated with achievement or non achievement of an element quality—including all elements requirements established by the business and its contracts with its customers. Requirements include marketing specifications, end-product and process specifications, purchase orders, engineering drawings, company procedures, work instructions, professional or industry standards, governmental regulations, and any other documents or customer needs that can affect the definition of an element.

### 2.3 Quality Related Costs Elements

Over the last several decades, quality costs have been divided into several categories (Campanella, 1999). By increasing magnitude, these are: prevention, appraisal, and failure costs.

### **2.3.1 Prevention Costs**

Prevention costs are the costs of all activities specifically designed to prevent poor quality in element. These costs can be divided into two categories: costs related to non-conforming elements and costs incurred because the business activities to produce them are themselves less than adequate.

There are those costs that may be regarded as an essential part of business activities, for example field testing, design proving, failure modes and effect analysis. These are really costs associated with performing good business practice; they would be incurred regardless of the failure and appraisal costs and are not to be considered in this definition of prevention costs.

Costs that are considered in the definition of prevention costs are those that must be incurred if the current cost of failure and appraisal is to be reduced. These represent an investment in the “Continuous Improvement” initiative and, if effective, should result in a significant reduction of the overall costs. Obviously, these costs are likely to be small otherwise the failures would not occur and relevant appraisal cost would not be necessary.

### **2.3.2 Appraisal Costs**

These are costs associated with measuring, evaluating or auditing elements to assure conformance to quality standards and performance requirements. These costs can be divided into two categories: costs related to non-conforming elements and costs incurred because the business activities to produce them are themselves less than adequate.

There are those costs that must be incurred regardless of the likelihood of occurrence of the associated adverse risk event, because the consequences of such an event are severe and potentially life threatening. Such is the case for many of the controls and procedures at power stations. This form costs are not to be considered in this definition of appraisal costs. Because they will always be incurred regardless of the likelihood of occurrence of a threatening risk event.

Costs that are considered in the definition of appraisal costs are those that are related directly to the likelihood of occurrence of error or failure. In this case, the amount of appraisal costs increases as the likelihood of occurrence of error increases more or less in direct proportion and vice-versa. Business activities which are included embrace all the costs of: incoming and source inspection/test of purchased material; in-process and final inspection/test; product, process or service audits; calibration of measuring and test equipment; and associated supplies and materials; which are carried out for no other reason than that the related failure or non achievement of an element quality occurred.

### 2.3.3 Failure Costs

These are costs resulting from elements not conforming to requirements or customer/user needs. Failure costs are divided into internal and external failure categories.

#### 2.3.3.1 Internal Failure Costs

These are failure costs occurring prior to delivery or shipment of an element to the customer. Internal failure costs can be many and varied. They include all costs and losses due to performing again what has already been done, or repairing or modifying the result of an activity, the cost of post mortems and all other consequential costs together with the waste of resources performing the business activities that need to be redone.

The consequential costs will include the effect on the balance sheet of excessive inventory and work-in-process (WIP) resulting from quality related deficiencies. In service industries, the equivalent problems do not show in inventory, but are hidden in direct costs. Most inventory and work-in-process, other than work actually being processed, can be regarded as Quality-Related costs. These include:

1. Reworking, redoing or repeating activities already performed because of inadequate performance at the first attempt. Costs of modification resulting from previous undetected design or planning weaknesses. These costs include the associated design or planning business activities, changes to tools and cost of retraining if procedures and methods are changed.
2. Retro design of a business activity element with a known design fault and all of the associated new features, fixtures and tools. Extra space in stores to accommodate replacement parts with different issue numbers. Revisions to parts lists, instruction manuals and the increased complexity of related service activities.
3. Increases to inventory and work-in-process due to disruptions to the smooth flow of work.
4. Modifications due to poor quality design.
5. Storage space

#### 2.3.3.2 External Failure Costs

These are failure costs occurring after delivery or shipment of the product—and during or after furnishing of a service—to the customer. These costs can be further subdivided into residual and random categories.

The residual non conformances of produced elements to requirements or customer/user needs include the underlying costs of warranty calls, servicing, complaints, etc. . .

Some of the more spectacular costs may be found in the random category which, if they occur, can produce catastrophic results. These will include product recall or product withdrawal. Enterprise businesses often spend fortunes on advertising how good their products or services are; then suddenly they are plunged without warning into huge expenditure telling the public that they have put their lives at risk. In many cases, this negative publicity is overwhelmed by media attention, which places the very survival of the enterprise business at stake.



Other external costs which can also be included in the records include:

1. Failed product (resp. service) launches which are due to deficiencies in the product (resp. service) and identified and exposed by its first customers. These costs are invariably incurred when an enterprise business is overzealous in its attempt to obtain prior franchise with an innovative new product (or service) and is a common problem. In these cases of failed product (resp. service) launches, the enterprise business tries to take shortcuts and fails to test and prove the product (or service) performance characteristics prior to launch. This results in the customer unwittingly being the first inspector of the product (or service).
2. Failure to meet either the emotional or specified needs of the customer: this is usually caused by poor voice of the customer capturing, poor market research and poor competitor-related information, inadequate and misdirected promotion, wrong launch time, short shelf-life in the case of chemical, food and pharmaceutical products, contamination, poor packaging and consequent adverse publicity.
3. Customer complaints and the recording and analysis of customer complaints, and the cost of running a customer service department (i.e. a euphemism for customer complaints department).
4. Excessive after-delivery, service or maintenance support. Excessive costs including storage, delivery and all related administration, particularly those that infer, conceal from or mislead the public.

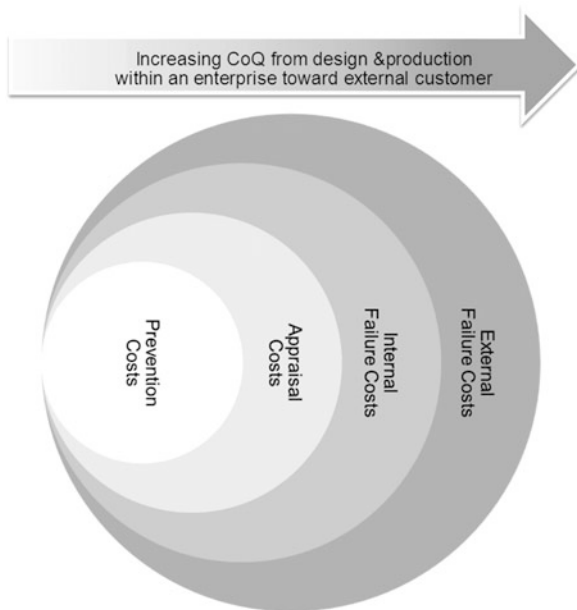
The failure costs go far beyond the internal and external costs indicated above. They include the devastatingly demotivating impact on employees within an enterprise. Employees want to feel good about the quality of their work. But regrettably, some enterprise businesses make decisions, and design systems, that deprive employees of their right to pride in workmanship, a prerogative that Edwards Deming considered one of the keys to motivation in the workplace (Deming, *The New Economics: For Industry, Government, Education*, 1994; Deming, 1982).

### 2.3.4 The Cost of Quality

The Cost of Quality is the total of the costs of the above costs. As indicated already, it is a measure of the costs specifically associated with achievement or non achievement of an element quality—including all elements requirements established by the business and its contracts with its customers. It is not the cost of creating a quality element; it is the cost of NOT creating a quality element. It represents the difference between the actual cost of an element and what the reduced cost would be if it did not deviate from the central tendency within the group as a whole. It is the total of the costs incurred by:

1. Investing in the prevention of nonconformance to requirements.
2. Appraising an element for conformance to requirements.
3. Failing to meet requirements.

**Fig. 2.3** Quality costs categories and their relative magnitude



For a given element, the Cost of Quality increases as the element moves toward the consumer, as shown in Fig. 2.3.

We have mentioned in the previous section that a low standard deviation indicates that the occurred elements tend to be very close to their expected central tendency. When this happens, there will be few excess costs associated with the use of those occurred elements. Also, a high standard deviation indicates that the occurred elements are spread out over a large range from their expected central tendency. As an occurred element falls further and further away from the expected central tendency, the costs of keeping it within the group and using it will increase. Moreover, these costs are often extremely high and they increase up to the point where it will be cheaper to scrap or rework the unacceptable element than it will be to try to keep it within the group and use it further.

For business applications operating at 6 standard deviations as the permissible limit of variations, all occurred elements will certainly fall within 6 standard deviations from the expected central tendency, out of one million occurrences, while not more than of two elements are likely to fall beyond 6 standard deviations from the expected central tendency, out of one billion occurrences. Thus, fewer revenues are spent on rework and scrapping of elements in non conformance quality.

From this, it becomes self evident that focusing on minimizing (standard) deviations in key business applications or “making zero-defect products, profitably,” hence minimizing excess costs and controlling quality in those applications, is the

true goal behind the adoption of “Six standard deviations as the permissible limit of variations from the expected central tendency” (i.e. six-sigma) in enterprises.

## 2.4 Why Lean?

We have indicated in a previous section that, in business applications, the elements considered are measurable features or measurable characteristics of business activities outcomes. Furthermore, the concept of outcome of business activities is multi-dimensional:

1. It comprises a core benefit or service for which the customer has a need or want.
2. It has a physical existence which is manifest in its price and quality, its performance, specification, design, reliability and longevity.
3. It has a warranty, a delivery, an after-sales service and promotional support.
4. It has psychological characteristics such as the outcome image and brand and corporate images which are perceived by existing and potential customers.

An enterprise business needs activities that are worthy and can handle today's values and complexities accurately and efficiently; activities that are positioned for the future and therefore can move ahead with the business and not struggle along behind.

In this book, we shall think of a “Lean” business activity, which is often known simply as “Lean” or “Flexible,” as a business activity that considers the expenditure of resources for any goal other than the creation of value in the element considered for the end customer to be wasteful. Eliminating waste is invariably the first and simplest way of improving the way things are done, in much the same manner as removing assignable causes of variation. We shall say that:

*“A ‘Lean’ business activity is a business activity that is:*

1. *Effective—Producing the desired outcome correctly the first time;*
2. *Efficient—Minimizing the resources used to produce the desired outcome in the shortest time;*
3. *Flexible or Adaptable—Being able to adapt to changing customers and to the circumstances surrounding the business and its market needs.”*

The term “Lean” in the production context was first coined by John Krafcik in his 1988 article, “Triumph of the Lean Production System,” based on his master's thesis at the MIT Sloan School of Management (Krafcik, 1988).

Toyota production line is the most often cited exemplar of “Lean” business activity where the insight is to continually improve both the efficiency and the effectiveness of work by eliminating unnecessary actions and activities (Koichi & Takahiro, 2009; Shingo & Dillon, 1989; Womack, Jones, & Roos, 2007; Ohno, 1988; Monden, 2011; Wang, 2010; Dennis, 2007). This insight descends from Taylor's ‘scientific management’ and much of the subsequent ‘human relations’ work that was focused on how to bring management and labor together in productive partnership from which both should gain (Taylor, 1911; Fayol, 1949).

### 2.4.1 Early Production Developments

Preceding ‘scientific management,’ the nineteenth-century factory production system was characterized by ad hoc organization, decentralized management, production organized on a craft basis with informal relations between employers and employees, and casually defined jobs and job assignments. Work was performed by highly skilled craftsmen who often prepared their basic raw materials, carried the product through each of the stages of manufacture, and ended with the finished product. These skilled craftsmen used with unsystematic workshop methods based on customary practice—the “rules of thumb” wielded by skilled craftsmen—as well as the “arbitrariness, greed, and lack of control.”

Typically, the craftsman spent several years at apprenticeship learning each aspect of his trade; often he designed and made his own tools. He was identified with his product and his craft, enjoyed a close association with his customers, and had a clear understanding of his contribution and his position in society. While his product may be of extremely high quality, the uniqueness can be detrimental as seen in the case of early automobiles: No two products were exactly identical, and in many cases each product was intentionally made different from others. In craft production, all or most aspects of the work process are determined by the worker in accordance with the empirical lore that makes up craft principles.

By the end of the nineteenth century, however, increased competition, novel technologies, pressures from government and labor, and a growing consciousness of the potential of the factory had inspired a wide-ranging effort to improve organization and management.

### 2.4.2 Scientific Management and Mass Production Developments

The central figure in the movement to improve organization and management by the end of the nineteenth century was the American engineer, inventor, and management theorist Frederick W. Taylor. The events of Taylor’s early years played a large and important part in these activities. Daniel Nelson, in “A Mental Revolution: Scientific Management since Taylor,” chronicles the following (Nelson, 1992):

*Born in 1856 into an aristocratic Philadelphia family, Taylor had the benefit of tutors and exclusive schools, extended travel, and associations with the Philadelphia elite. After attending Phillips Exeter Academy, he rejected a university education in favor of a traditional apprenticeship and an industrial career, which began in the machine shop of the Midvale Steel Company in 1878. ... Taylor left in 1893 to become a self-employed consultant.*

*By that time he had taken important steps toward a new role. He had a substantial reputation as an inventor of industrial machinery and broad experience as an industrial manager. He had also undertaken several experiments that forced him to think more explicitly about organizations and people. One of these, an effort to compute operating times for machine tools with a stopwatch, would evolve into time and motion study, his signature contribution to industrial management.*

Taylor's groundwork was time and motion study which involved the detailed study of work and the assessment of what a normal competent worker would achieve working at normal speed for a given time.

In Taylor's view, the task of factory management was to determine the best way for the worker to perform the work, to provide the proper tools and training, and to provide incentives for good performance. After carefully studying the smallest parts of simple tasks, such as the shoveling of dry materials, Taylor was able to design methods and tools that permitted workers to produce significantly more with less physical effort. He broke each task down into its individual motions, analyzed these to determine which were essential. Later, by making detailed stopwatch measurements of the time required to perform each step of manufacture, Taylor brought a quantitative approach to the organization of production functions. With unnecessary motion eliminated, the worker, following a machinelike routine, became far more productive.

At the same time, Frank B. Gilbreth and his wife, Lillian M. Gilbreth, U.S. industrial engineers, began their pioneering studies of the movements by which people carry out tasks (Merrill, 1970). Using the then new technology of motion pictures, the Gilbreths analyzed the design of motion patterns and work areas with a view to achieving maximum economy of effort. The "time-and-motion" studies of Taylor and the Gilbreths provided important tools for the design of contemporary manufacturing systems.

Daniel Nelson further records that:

*... Taylor had become associated with two enterprises that were reshaping the industrial environment. The first was the rapidly maturing engineering profession, whose advocates sought an identity based on rigorous formal education, frequent contact, mutually accepted standards of behavior, and social responsibility. In factories, mines, and railroad yards, they rejected the empiricism of the practitioner for scientific experimentation and analysis. They acknowledged the primacy of the profit motive, but they insisted that reason and truth were essential to continued financial success.*

*The second, closely related development was the systematic management movement, an effort among engineers and sympathizers to substitute administrative systems for the informal methods of industrial management that had evolved with the factory system. Systematic management was a rebellion against tradition, empiricism, and the assumption that common sense, personal relationships, and craft knowledge were sufficient to run a small factory. In the large, capital intensive, technologically advanced operations of the late nineteenth century, 'rule-of thumb' methods resulted in confusion and waste. The revisionists' answer was to replace traditional managers with engineers and to substitute managerial systems for guesswork and ad hoc evaluations.*

*By the time Taylor began his career as an engineer and manager, cost accounting systems, methods for planning and scheduling production and organizing materials, and incentive wage plans were staples of engineering publications and trade journals. Their objective was an unimpeded flow of materials and information. In human terms, proponents of systematic management sought to transfer power from the first-line supervisor to the plant manager and to force all employees to pay greater attention to the manager's goals. Most threatening, perhaps, they advocated decisions based on performance rather than on personal qualities and associations.*

*... By 1901 Taylor had fashioned scientific management from systematic management. As the events of Taylor's career make clear, the two approaches were intimately related. ... His first report on his work, 'Shop Management' (1903), portrayed an integrated complex of systematic management methods, supplemented by refinements and additions like time*

*study. Between 1907 and 1909, with the aid of one of his shrewdest associates, Morris L. Cooke, he wrote a sequel to 'Shop Management' that ultimately became The Principles of Scientific Management (1911). Rather than discuss the specific methods he introduced in factories and shops, Taylor used colorful stories and language to illuminate 'principles' of management. To suggest the integrated character and broad applicability of scientific management, he equated it with a 'complete mental revolution'.*

Though Taylor used the words “a complete mental revolution” to describe his contributions to factory or “shop” management, Morris L. Cooke, a friend and professional associate, and Louis Brandeis, a prominent attorney, deliberately chose the words “scientific management” to promote their contention that Taylor’s methods were an alternative to railroad price increases in a rate case they were preparing for the Interstate Commerce Commission.

Taylor’s ‘scientific management’ and much of the subsequent ‘human relations’ work clearly accommodated some subjective judgment. This was the basis of many and various incentive payment systems which were applied across much of manufacturing industry and which became the symbolic focus of industrial disputes through the first half of the twentieth century.

Taylor’s ‘scientific management’ was concerned first and foremost with how a business could survive. Its aims were twofold. Firstly, to improve both the efficiency and the effectiveness of work by eliminating unnecessary actions and activities, improving methods and building in suitable relaxation breaks. Secondly, to share the resulting benefit between employer and employee and so remove the distrust between workers and management which had resulted in ‘soldiering’, a phenomenon of workers purposely operating well below their capacity, or slow working and restricting output intended by the workers to safeguard employments.

Much of the credit for bringing these early concepts of time and motion, and ‘human relations’ studies together in a coherent form, and creating the modern, integrated, mass production operation, belongs to the U.S. industrialist Henry Ford and his colleagues at the Ford Motor Company, where in 1913 a moving-belt conveyor was used in the assembly of flywheel magnetos. With it assembly time was cut from 18 min per magneto to 5 min. The approach was then applied to automobile body and motor assembly. The design of these production lines was highly analytical and sought the optimum division of tasks among work stations, optimum line speed, optimum work height, and careful synchronization of simultaneous operations.

The success of Ford’s operation led to the adoption of mass production principles by industry in the United States and Europe. The methods made major contributions to the large growth in manufacturing productivity that has characterized the twentieth century and produced phenomenal increases in material wealth and improvements in living standards in the industrialized countries.

### **2.4.3 Principles of Mass Production**

The efficiencies of mass production result from the careful, systematic application of the ‘scientific management’ ideas and concepts. The following summary lists the four basic principles of mass production:

1. *Division of Labor*—The careful division of the total production operation into specialized tasks comprising relatively simple, highly repetitive motion patterns and minimal handling or positioning of the work-piece. This permits the development of human motion patterns that are easily learned and rapidly performed with a minimum of unnecessary motion or mental readjustment.
2. *Standardization of tasks*—The simplification and standardization of component parts to permit large production runs of parts that are readily fitted to other parts without adjustment. The imposition of other standards (e.g., dimensional tolerances, parts location, material types, stock thickness, common fasteners, packaging material) on all parts of the product further increases the economies that can be achieved.
3. *Use of machinery and automation of work*—The development and use of specialized machines, materials, and processes. The selection of materials and development of tools and machines for each operation minimizes the amount of human effort required, maximizes the output per unit of capital investment, reduces the number of off-standard units produced, and reduces raw material costs.
4. *Systematic planning of work*—The systematic engineering and planning of the total production process permit the best balance between human effort and machinery, the most effective division of labor and specialization of skills, and the total integration of the production system to optimize productivity and minimize costs.

To achieve the maximum benefits that application of these principles can provide, careful, skilled industrial engineering and management are required. In a mass production factory, planning begins with the original design of the product; raw materials and component parts must be adaptable to production and handling by mass techniques. The entire production process is planned in detail, including the flows of materials and information throughout the process. Production volume must be carefully estimated because the selection of techniques depends upon the volume to be produced and anticipated short-term changes in demand. It must be large enough, first, to permit the task to be divided into its sub-elements and assigned to different individuals; second, to justify the substantial capital investment often required for specialized machines and processes; and third, to permit large production runs so that human effort and capital are efficiently employed.

The need for detailed advance planning extends beyond the production system itself. The large, continuous flow of product from the factory requires equally well-planned distribution and marketing operations to bring the product to the consumer. Advertising, market research, transportation problems, licensing, and tariffs must all be considered in establishing a mass production operation. Thus, mass production planning implies a complete system plan from raw material to consumer.

In addition to lowering cost, the application of the principles of mass production have led to major improvements in uniformity and quality. The large volume, standardized design, and standardized materials and processes facilitate statistical control and inspection techniques to monitor production and control quality. This leads to assurance that quality levels are achieved without incurring the large costs that would be necessary for detailed inspection of all products.

#### 2.4.4 “Lean” or “Flexible” Production Method

A major problem of mass production based on continuous or assembly line processes is that the resulting system is inherently inflexible. Since maximum efficiency is desired, tools, machines, and work positions are often quite precisely adapted to details of the parts produced but not necessarily to the workers involved in the process. Changes in product design may render expensive tooling and machinery obsolete and make it difficult to reorganize the tasks of workers. One answer has been to design machinery with built-in flexibility; for relatively little extra cost, tooling can be changed to adapt the machine to accommodate design changes.

Similarly, a production line is usually designed to operate most efficiently at a specified rate. If the required production levels fall below that rate, operators and machines are being inefficiently used; and if the rate goes too high, operators must work overtime, machine maintenance cannot keep up, breakdowns occur, and the costs of production rise. Thus, it is extremely important to anticipate production demands accurately. Planning, an important function of management and engineering design, can alleviate the problems of increased demand by incorporating excess capacity in the facilities that would require the longest time to procure and install. Then, if production loads increase, it is easier to bring the entire system up to the new level. Similarly, if large fluctuations in demand cannot be avoided, flexibility to accommodate these changes economically must be planned into the system.

The ideas of Taylor’s ‘scientific management’ and Henry Ford’s operation spread wider than its origins in the study of work, from the “efficiency movement” of the 1920s, through the depression-era “rationalization” and wartime mobilization, up to postwar “productivity” drives and quality-control campaigns. Imported to Japan, these ideas were embraced—and ultimately transformed—in Japan’s industrial workshops. Adaptation of Taylor’s ‘scientific management’ and Henry Ford’s operation to improve production as a response to specific demands of postwar Japanese automobile gave rise to innovation as Japanese managers sought a “revised” model that combined mechanistic efficiency with respect for the humanity of labor.

The Toyota production line paradigm evolved from the shops of Toyota Motor Company in the thirty years after World War II. The model pioneered by Toyota is an integrated system characterized by a flow of processing information backward from final assembly, “flexible” and multipurpose or multifunctional machinery and workers to make a wide range of product (i.e. automobile) components, tightly rationalized simplified and standardized tasks, low lead and setup times, and small-lots operations for manufacturing, in-house conveyance, and deliveries from subcontractors (Tsutsui, 2001; Cusumano, 1985). It remains, however, noticeably consistent with Taylor’s ‘scientific management’ in general approach and adapting to customer demands. It constitutes a more rigorous and stringent application of Taylor’s ‘scientific management’ principles than the standards that were applied at Henry Ford’s factories.



Nowadays, “lean” production or Toyota production line is the envy of the world for its efficient and humane management practices. ‘Humane’, as Toyota understands it, means:

*to eliminate from the work force worthless, unproductive persons who should not be there and to awaken in all the awareness that they can improve the work place through their own efforts and to foster a feeling of belongingness. . .*

“Lean” production appears “human centered” only to the extent that tapping the skills and defining duties of individual workers would allow for further ascent of labor productivity. It has the objective of diluting individual worker skills. Despite the currently widespread preconception that the Toyota Production System is uniquely humane, flexible, and participative, the ‘scientific management’ ideals of control, discipline, and expertise are paramount in the “lean” approach to workplace labor relations. Rigid obedience, rather than nurturing inclusion, seems to define Toyota’s shop-floor strategy. Supervisors must drill into the minds of workers that they must strictly abide by standard operations.

As Taiichi Ohno in an interview conducted by Koichi Shimokawa and Takahiro Fujimoto has indicated (Koichi & Takahiro, 2009):

*The Toyota Production System is one and the same with Total Quality Control (TQC) and with its principle of zero defects. They are simply different names for the same basic approach.*

It rests on two pillars. The first pillar is Sakichi Toyoda’s Jidoka, the essence of which states that: “Turning out defective work is not what we are here for.” The second pillar is Kiichiro Toyoda’s just in time, the essence of which states that: “Just make what is needed in time, but don’t make too much. . .”

The Toyota production line paradigm may have revolutionary implications, yet, to a large degree, the changes that Toyota made were “evolutionary” adaptations to the circumstances surrounding the company and its domestic market needs. Faced with a complex landscape of restrictions and opportunities—rapid growth in demand, low production volumes, highly diversified product lines, competitive pressure to reduce costs and improve quality, limited capital, and increasingly scarce labor—William Tsutsui (2001) has shown that the creators of the Toyota production line system finely modified Taylor’s ‘scientific management’ methods and mind-sets to address urgent needs. It is an ingenious and practical rearrangement of the Taylor building blocks of the Ford approach, resulting in a new model—and seemingly non Ford model—of industrial production. The critical environment factor in this evolution was the lack of: sustained labor opposition, powerful craft unions and hostile workers.

Taken as a whole, the Toyota Production system—or “lean” production—can be seen as an innovative model of mass production achieved by mobilizing the ‘scientific management’ approaches and adapting them to the specific demands of postwar Japanese automobile manufacturing.

## 2.5 Conclusion

The precise and narrowly defined concept of “6 standard deviations as the permissible limit of variations around the expected central tendency” coupled with the insight of “Lean” business activities have grown over time and in media to represent a framework for quality improvement and control, the goal of which is to facilitate quality improvement efforts that will lead to operating cost reduction opportunities (Harry & Schroeder, 2006; Eckes, 2002; Pyzdek & Keller, 2009; Bertels & Strong, 2003; Pande, Neuman, & Cavanagh, 2000, 2001; Breyfogle, 2003; Webb & Gorman, 2006; Truscott, 2003; Summers, 2007; Perez-Wilson, 1999; Sodhi & Sodhi, 2008; Breyfogle, Cupello, & Meadows, 2001; Gupta, 2004; Przekop, 2005). This framework covers four perspectives—philosophy, economics, marketing, and operations management. Philosophy is focusing on definitional issues; economics is focusing on profit maximization and market equilibrium; marketing is focusing on the determinants of buying behavior and customer satisfaction; and operations management is focusing on engineering practices and manufacturing control.

To keep the balance of economic activity between services and manufacturing operations, we shall say that:

*A ‘Lean’ Six Sigma business activity is a business activity operating at a performance permissible limit of variations of 6 standard deviations around its expected central tendency and that is:*

1. *Effective—Producing the desired outcome correctly the first time;*
2. *Efficient—Minimizing the resources used to produce the desired outcome in the shortest time;*
3. *Flexible or Adaptable—Being able to adapt to changing customers and to the circumstances surrounding the business and its market needs.*

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