Chapter 8
Dimensional Metrology for Manufacturing Quality Control

This chapter presents the current quality control techniques used for dimensional measurement data used in small to medium sized and global manufacturing industries. Quality is defined as strict and consistent adherence to measureable and verifiable standards to achieve uniformity of output that satisfies specific customer or user requirements. It is exactly this striving for quality within manufacturing today that separates one business from the other with respect to production costs, product reliability, and brand reputation. There are many approaches to establishing a quality program and many tools to choose from. This chapter describes these approaches and tools in order to provide a backdrop for the types of information that are central to quality analysis and data reporting. Information modeling for different manufacturing industries is discussed for different types of quality control at the end of this chapter.

8.1 Six Sigma and Dimensional Metrology

The goal and process of achieving less than 3.4 defects/million opportunities in production is commonly known as a six sigma program. Since its advent within Motorola in 1981, the six sigma approach to defect reduction is used by more than two thirds of the Fortune 500 companies [1]. This discipline is viewed by many as a business process management strategy that draws extensively on quality improvement techniques such as statistical quality control (SQC) and total quality management (TQM).

The Six Sigma philosophy holds that the first priority of a manufacturing quality improvement program is to achieve process stability through continuous improvements that are intended to reduce variation, thereby resulting in predictable behavior. Through identification of characteristics that can be measured, analyzed and controlled, quality improvements can be sustained throughout the manufacturing enterprise.

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The primary project methodology in a six sigma program employs a phased approach derived from the Deming plan-do-check-act (PDCA) cycle for continuous process improvement. It is a 5 phase cycle whose acronym is DMAIC. The DMAIC cycle is described as:

- Define the problem with emphasis on stakeholder consideration, and the project goals.
- Measure key aspects of the current process and collect relevant data.
- Analyze the data to investigate and verify cause-and-effect relationships. Determine what the relationships are, and attempt to ensure that all factors have been considered. Seek out root causes of defects.
- Improve or optimize the current process based upon data analysis using techniques such as design of experiments, poka-yoke or mistake proofing, and standard work to create a new, future state process. Set up pilot runs to establish process capability.
- Control the future state process to ensure that any deviations from target are corrected before they result in defects. Implement control systems such as statistical process control, production boards, and visual workplaces, and continuously monitor the process.

Within the DMAIC cycle a Six Sigma initiative will rely on many quality management techniques such as:

- Process Capability Studies
- ANOVA (Analysis of Variance)
- Gage R&R (Repeatability and Reproducibility)
- Control Charts (XbarR, XbarS, EWMA, etc.)
- Correlation Studies
- Histograms
- Pareto Analysis
- Root Cause Analysis
- Design of Experiments

From a dimensional metrology perspective it is clear that the Six Sigma method can be applied to quality problems associated with deviations of manufactured items from design intent. The purpose of inspection and measurement in manufacturing is to provide data that can be used both for validation of conformance to specification and for providing data for process analysis when deviation from design nominal dimensions is found.

Six Sigma identifies several key roles for its successful implementation [2].

- Executive Leadership includes the CEO and other members of top management. They are responsible for setting up a vision for Six Sigma implementation. They also empower the other role holders with the freedom and resources to explore new ideas for breakthrough improvements.

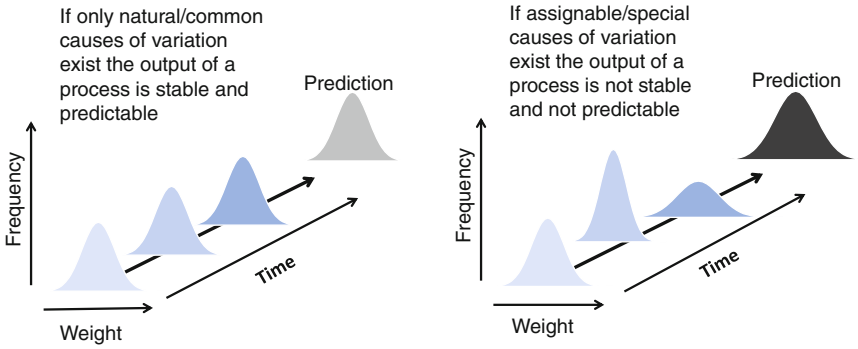


Fig. 8.1 Natural versus Assignable causes of variation through time

- Champions take responsibility for Six Sigma implementation across the organization in an integrated manner. The Executive Leadership draws them from upper management. Champions also act as mentors to Black Belts.
- Master Black Belts, identified by champions, act as in-house coaches on Six Sigma. They devote 100% of their time to Six Sigma. They assist champions and guide Black Belts and Green Belts. Apart from statistical tasks, they spend their time on ensuring consistent application of Six Sigma across various functions and departments.
- Black Belts operate under Master Black Belts to apply Six Sigma methodology to specific projects. They devote 100% of their time to Six Sigma. They primarily focus on Six Sigma project execution, whereas Champions and Master Black Belts focus on identifying projects/functions for Six Sigma.
- Green Belts are the employees who take up Six Sigma implementation along with their other job responsibilities, operating under the guidance of Black Belts.

8.2 Quality Control for Manufacturing Industry

In the complexity of applying production operations against raw materials to make finished goods it is impossible to avoid variation of actual dimensions from design dimensions. There are many sources of variation that contribute to the need for quality control.

8.2.1 Process Variation

Variation can be both natural and special. Natural variation can be considered as stemming from background noise in the manufacturing system. These causes of variation are inherent to the system and lack significance when encountering low or high values (Fig. 8.1). The distribution of dimensional values from a system

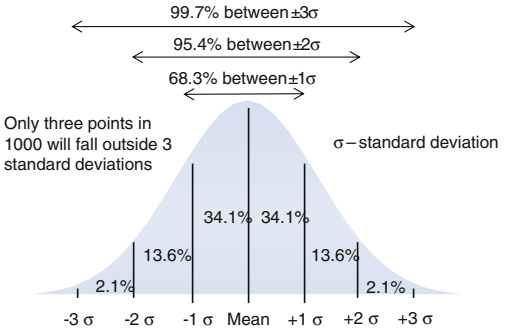


Fig. 8.2 *Bell shaped curve* with standard deviation spread

that is subject to natural variation only will be represented by a Gaussian curve (as shown in Fig. 8.2), thus reflecting the random dispersion from a process mean or central tendency. Examples of these Natural or ‘‘common” fluctuations include:

- Lack of consistency of raw materials
- Vibration in industrial processes
- Ambient temperature and humidity
- Normal wear and tear
- Variability in settings
- Computer response time

Special or ‘‘Assignable” causes of variation are described as those that exist outside of natural variation. In many cases they are seen as identifiable events or signals from the system that may be reflective of new, emergent or previously neglected phenomena. Examples of these special causes of variation include:

- Poor adjustment of equipment
- Operator error
- Broken tools
- Faulty controllers
- Machine malfunction
- Computer crashes
- Poor batch of raw material
- Power surges

In any quality control program the first task is to identify the functional characteristics along with their nominal values and tolerances that are necessary from a design perspective for form and function of the manufactured part. Once this is accomplished, a quality control plan can be formulated in which an inspection program can be identified. It is in this process that a dimensional measurement plan and the associated dimensional metrology equipment are specified.

A quality control plan will typically incorporate the tools of the statistical process control method in which variable and attribute data for product conformance characteristics are measured.

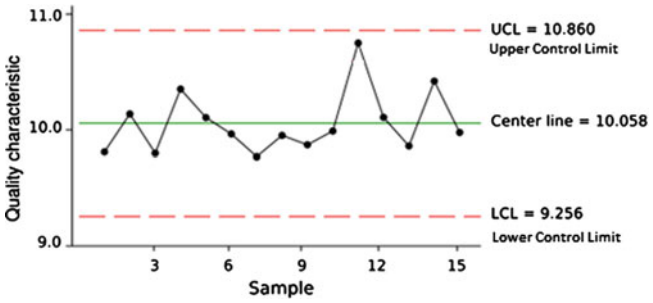


Fig. 8.3 Natural variation about nominal through time on SPC control chart

8.2.2 Control Chart Theory

Since quality inspection is not considered a value-added process by most businesses the cost of quality has been driven down by the use of statistical methods.

This began when Dr. Walter A. Shewhart wrote Economic Control of Quality of Manufactured Product in 1931 [3]. As a physicist, engineer and mathematician working for the Western Electric Company's Hawthorne Works plant, he had recognized the only source of quality control was limited to inspecting finished products and removing defective items. This is sometimes known as acceptance sampling. Others refer to this quality control technique as ''inspecting quality into the product". Shewhart recognized the natural variation in the manufacturing process and derived a basis for developing sampling plans for quality control based on the well-established mathematical principles of probability and statistics. By understanding the extrapolated relationship between the characteristics of a specific sample group within a larger population (e.g. production lot), he conceived the control chart as a time ordered line chart displaying the average and range of production samples. In addition to plotting these points against the process mean or ''central tendency", Shewhart also incorporated the concept of control limits based on standard deviation calculations of the entire sample population. Figure. 8.3 is an example. Example SPC chart showing random variation about a nominal value.

8.2.3 Data Tests

As part of the control chart theory Western Electric also worked to identify pattern recognition on the Shewhart control charts [4]. These behaviors included:

- Cycles
- Trends
- Freaks
- Mixtures

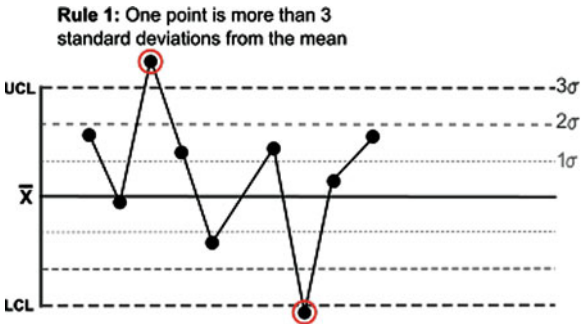


Fig. 8.4 Extreme point test on control chart

- Grouping or "bunching" of measurements
- Gradual change in level
- Sudden shift in level
- Instability (abnormally large fluctuations)
- Stratification (abnormally small fluctuations)
- Interactions (two or more variables acting together)
- Systematic variation
- Tendency of one chart to follow another

In 1981 Dr. Lloyd S. Nelson, expanded the Western Electric Rule definition to form the Nelson Rules. Any failure of these rules would indicate the presence of assignable causes of variation [5].

- Extreme Points Test (Rule 1)
  This test watches for extreme subgroups beyond the control limits. This test applies to both Xbar and R control charts. The rule is as follows: The existence of a single point beyond a control limit signals the presence of an out-of -control condition. An example of data flagged by this Rule 1 is shown in Fig. 8.4.
- Run Above or Below the Centerline Test (Rule 2)
  This test watches for 7, 8 or 9 consecutive subgroups above or below the centerline and applies to both the control charts. This test is defined by a number of successive points that fall above or below the centerline. The presence of such a run is strong evidence that the process mean or variability has shifted from the centerline. An example of data that Rule 2 will flag is shown in Fig. 8.5.
- Linear Trend Test (Rule 3)
  This test watches for six subgroups in a row steadily increasing or decreasing. This test applies to control charts and fails when there is a systematic increase or decrease trend in the process. Neither the zones nor the centerline come into play in this test. An example of data that Rule 3 will flag is shown in Fig. 8.6.
- Oscillatory Trend Test (Rule 4)
  This test watches for fourteen subgroups in a row alternating up or down and applies to control charts. When 14 successive points oscillate up and down a systematic trend in the process is signaled. Again, neither the chart centerline

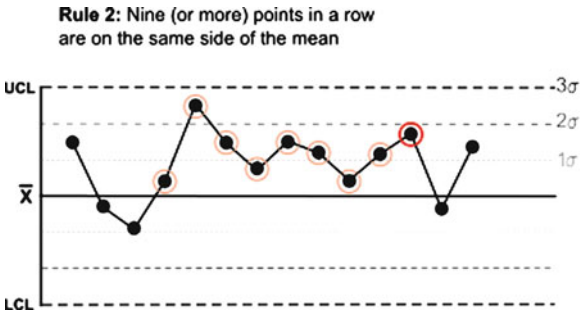


Fig. 8.5 Run test on control chart

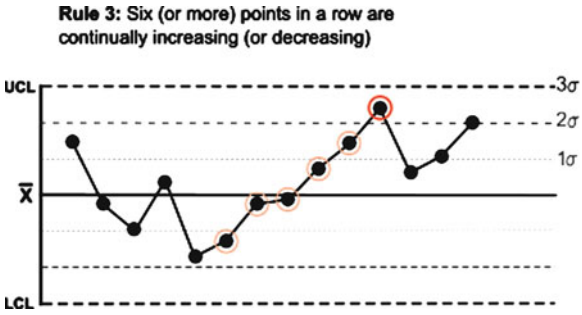


Fig. 8.6 Linear trend test on control chart

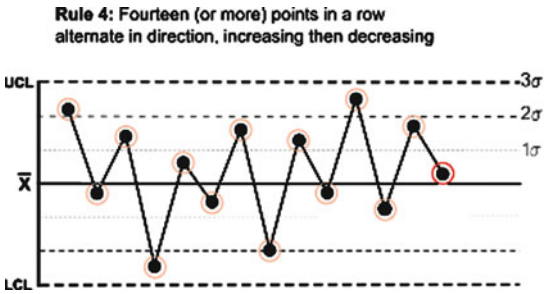


Fig. 8.7 Oscillatory test on control chart

nor the zones come into play for this test. An example of data that Rule 4 will flag is shown in Fig. 8.7.

- Two Sigma Test (Rule 5)
  This test watches for two out of three subgroups in a row in outside of two standard deviations. It is based on the specific control chart zones and therefore only applies to the Xbar chart. The rule is this: The existence of two of any three successive points outside of two standard deviations signals the presence of an out-of-control condition. An example of data that Rule 5 will flag is shown in Fig. 8.8.
- One Sigma Test (Rule 6)
  This test watches for four out of five subgroups in a row outside of one standard deviation. It is based on the specific control chart zones and therefore only applies to the Xbar chart. The rule is this: The existence of four of any five successive

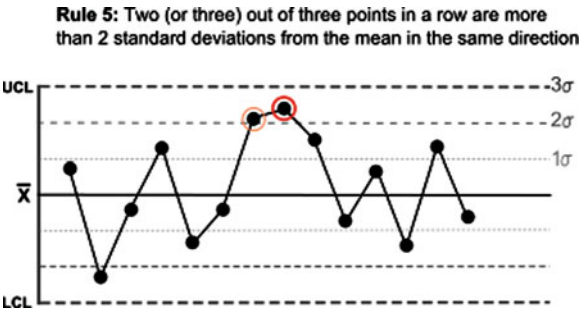


Fig. 8.8 Two sigma test on control chart

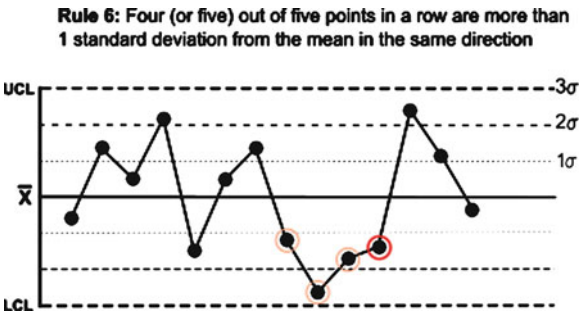


Fig. 8.9 One sigma test on control chart

points outside of one standard deviation signals the presence of an out-of-control condition. An example of data that Rule 6 will flag is shown in Fig. 8.9.

- Stratification Test (Rule 7)
  Also known as the Reduced Variability Test. This test watches for 15 subgroups in a row in within one standard deviation, above and below the centerline. When 15 successive points on the Xbar chart fall within one standard deviation only, to either side of the centerline, an out-of-control condition is signaled. This can arise from improper sampling techniques or a change (decrease) in process variability that has not been properly accounted for in the X-bar chart control limits. An example of data that Rule 7 will flag is shown in Fig. 8.10.
- Mixing/Overcontrol Test (Rule 8)
  This test watches for eight subgroups in a row on both sides of the centerline outside of one standard deviation. The rule is: Eight successive points on either side of the centerline outside of one standard deviation signals an out-of-control condition. This test failure could mean more than one process being plotted on a single chart (mixing) or perhaps overcontrol (hyper-adjustment) of the process. An example of data that Rule 8 will flag is shown in Fig. 8.11.

8.2.4 Taguchi Method

In the early 1990s Genichi Taguchi developed an approach to quality control that began with a focus on the costs of poor quality. He understood that quality losses result mainly from product failure after sale and that product ‘‘robustness” was

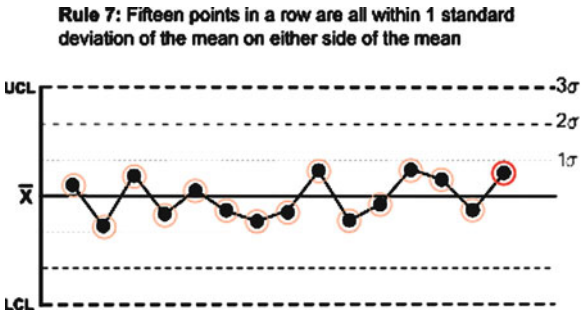


Fig. 8.10 Stratification test on control chart

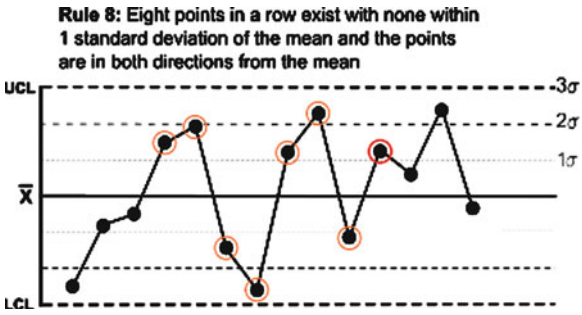


Fig. 8.11 Overcontrol test on control chart

more of a function of product design than online control, however stringent a manufacturing process [6, 7].

The approach to robust design recognizes that a work-in-progress may be subject to wide variations in manufacturing processes and that products when used are subject to wide conditional variations.

By recognizing the tolerance stack-up of components in any assembled product and the reduction in perceived quality of parts that behave in less than a perfect manner, Taguchi rejected the commonly held quality philosophy of zero defects, especially the pass/fail, in-spec/out-of-spec style of thinking. Robustness derives from consistency.

In the Taguchi approach to quality, variations must be driven from the system and a design target must be achieved. This begged the question of which design target was appropriate and led to the development of Designed Experiments in which an orthogonal array of system input parameters are varied and several trials are conducted in order to maximize a given output.

For example, when the Ford Motor company set about designing the anti-lock braking system, they employed the Taguchi method and set up an experiment designed to minimize braking distance. Several component characteristics were varied in combinatorial permutations. Various spring tensions, fluid viscosities and pad materials were used in the experiment. What resulted was the identification of the appropriate combination that minimized braking distance. A happy coincidence also resulted in a system that weighed less and reduced the overall cost.

Take these ideas back to the factory and it is easy to see how maximizing the ''signal-to-noise" ratio in a manufacturing process can be accomplished by a design to manufacture strategy in which the designer seeks to eliminate variation generated by the complex interaction of shop-floor quality factors such as operators, operating methods, equipment and material

8.3 Comparing Quality Control in Small and Medium Manufacturing to Large Global Industry

Significant differences exist in the necessity, approach, toolsets and resources between large and small manufacturing quality control programs. This section describes these environments, the differences and similarities and the tools used as provided from one sector to another.

8.3.1 Small to Medium Manufacturing Industry Quality Control

Every company must satisfy customers, stakeholders and employees to survive. Day-to-day details often divert attention from what is good for the company. Conflicts in priorities and contention for resources combine to form a huge barrier to organizational excellence. Smaller businesses also have a narrow buffer to shelter customers from error and waste. In a small business, quality planning and business planning are synonymous. The best time to start a quality program is during the initial planning for the business when designing quality into product and service delivery is essential.

A review of the relative strengths and weaknesses of small firms reveals that the TQM principles such as employee participation and flexibility could be more successfully applied in small firms than in large ones [8]. For example, small businesses tend to encourage innovation and can supply products at lower cost due to low overhead. On the other hand, researchers argue that small firms lack clout with suppliers and lack sufficient capital. They also lack professional managerial expertise, which accounts for about 90 percent of small business failures [9]. These are critical aspects for implementing TQM. For example, lack of clout with suppliers could impact a firm's ability to dictate the quality of incoming material. Also, lack of capital may limit a small firm from investing in high quality processes. Furthermore, knowledgeable and committed management is essential for successfully implementing TQM. Human resource management priorities and the practices of small firms also differ from those of large firms [10]. Small business owners and managers tend to view human resource management strategies as being less important than finance, marketing, and planning [11]. Small business managers do not perceive incentives to be critical to improving productivity. These

findings may lead one to believe that the experiences of small firms with TQM implementation may differ widely from large firms. Thus, the size of an organization does, indeed, influence the effectiveness of various quality management practices.

Large original equipment manufacturers (OEMs) are increasingly pushing production up the supply chain. Along with these production mandates, the tier 1 and tier 2 suppliers to the large manufacturers are also required to carry the quality directives as provided by their customers. Quality information flows through the supply chain. From the smallest component in an assembly to the finished good, quality is a necessary component of a manufacturing operation in order to assure fit and function.

In the mid-market business environment, companies are faced with the need to be responsive to customer demands. Family owned job-shops provide goods to downstream consumers that have a wide array of needs. This results in multiple quality control measures. Some may employ traditional quality lab environments in which samples are brought to the inspector for measurement. The inspector is responsible for maintaining the lab's equipment procedures and ultimately evidence of conformance to specification. Quite often the smallest of shops have only a single individual responsible for quality inspection. Although quality control theory may well be understood, these companies typically have few resources to create robust quality control initiatives; therefore, they tend to find efficiencies in data acquisition and reporting. The movement from mechanical gauging to digital data collection has continued for the last several decades as metrology equipment providers design better tools for taking measurements. Micrometers, Calipers, indicators are now produced with output and even wireless communication to desktop computers that host inexpensive quality management software.

The small manufacturers tend to focus on production and establish sufficient quality programs to gain contracts and ensure adequate quality for customer acceptance and contract renewal. They tend not to have continuous improvement programs but rather rely on standard technique. Some, however, do have visionary programs that recognize the competitive advantage of improving quality, especially as it relates to fostering a healthy reputation among clients.

Many small manufacturing companies, as component suppliers, are pressured by their customers to improve their quality assurance. Component suppliers may also be subcontractors themselves and in turn need the same assurance from their suppliers. This pressure through the supply chain has led many suppliers to rethink their processes [12].

Successful implementation of TQM has been seen to hinge upon a human resource policy that is based on effective communications, teamwork, empowering of employees and the reinforcement of commitment [13]. This means creating trust between employees and management and also in internal and external customer–supplier relations. Meeting customer needs depends upon understanding what these are, and many TQM programs express internal relationships in terms of everyone having a customer who relies upon your part of the product or service delivery. Thus, successful external customer relationships hinge upon the

effectiveness of internal relationships, which are facilitated by teamwork and communications. It is easy to recognize the need for horizontal integration in large functionally organized companies, where communications across functional boundaries are often physically and culturally inhibited. People feel strong loyalties to their particular area and 'turf wars' are not uncommon between functional heads. Vertical integration can be problematic too, as is often the case. In particular, management-employee relations in manufacturing have traditionally been adversarial [14].

Part of the strategy involves the development of selective partnerships to drive down costs and open the door to increased quality and value. Change also arises from the development of supply chain relationships between original equipment manufacturers and their suppliers, involving closer, ongoing relationships with a smaller number of suppliers. This has, for instance, led to greater involvement by first-tier suppliers in particular in the design of the component that they will be providing. In this way, design features can be identified which, if modified, would avoid quality problems later in manufacture [15].

The need to adopt a longer-term perspective is particularly problematic in smaller companies, where human and financial resources are often stretched seemingly to the limit, particularly in the tight profit margin environment of most component suppliers. Integration across functions is harder in large firms than smaller ones, as in small firms the authority and influence of top management are more immediate. In manufacturing, owner managing directors who have developed the company from inception usually have in-depth process knowledge or technical skills that are keys to the company's operations [13].

Over the years, several programs have forced the hand of small and medium sized manufacturers to standardize and institute better quality programs. For example, AIAG originally established as a consortium of the Big Three American car companies (GM, Ford, Chrysler), created a set of quality guidelines for use by suppliers. A standard guide for SPC sampling and charting allowed the market to standardize on calculation and data visualization methods. A specification for Measurement Systems analysis (MSA) provides a consistent and systematic approach to determining the variation inherent in measurement systems such as gage repeatability, appraiser reproducibility, gage linearity, bias and stability. The Part Production Approval Process established a set of guidelines on the quality analysis requirements for validating new or changing existing manufacturing processes.

Indeed, the AIAG raised the bar for industry with its release of the QS-9000 program in which manufacturers were required to establish quality procedures and prove them out through a detailed audit process whose ultimate goal was certification.

8.3.2 AS9100

In the Aerospace industry, Boeing has similarly established a specification for quality control and first article inspection (FAI). The AS9100, Aerospace Basic Quality System Standard, was developed by a group of US aerospace prime contractors, including Allied-Signal, Allison Engine Company, Boeing, General Electric Aircraft Engines, Lockheed Martin, McDonnell Douglas, Northrop–Grumman, Pratt and Whitney, Rockwell Collins, Sikorsky Aircraft, and Hamilton Sundstrand. AS9100 was developed and issued under the auspices of the Society of Automotive Engineers.

The intent and concept behind AS9100 are similar to Boeing's D1-9000. The standard is based in ISO 9000, with 27 additional requirements unique to the aerospace industry. The intent is to standardize and streamline many of the other aerospace quality management standards.

Representing the first international effort to formulate a quality management system standard for the aerospace industry, the two-year-old AS9100 is beginning to show its long-term value as an updated specification for quality control practices. The standard supplements ISO 9001 by addressing the additional expectations of the aerospace industry. Already, reports along this complicated manufacturing chain attest to among other benefits AS9100s contribution to more consistent verification methods and fewer verification audits. Initially released in October 1999 by the Society of Automotive Engineers in the Americas and the European Association of Aerospace Industries in Europe, and shortly thereafter by standards organizations in Japan and Asia, AS9100 was a cooperative effort of the International Aerospace Quality Group. As such, it combines and harmonizes requirements outlined in the SAE's AS9100 and Europe's prEN9000-1 standards. Recently, AS9100 was revised to align with ISO 9001:2000 [16].

AS9100 defines additional areas within an aerospace quality management system that must be addressed when implementing an ISO 9001:2000-based quality system. Typically, these requirements are included within robust aerospace quality systems. The industry experts who wrote the standard and the representatives who approved it all agree that these additions are essential to ensure product, process and service safety and quality. The AS9100 standard provides guidance for managing variation when a "key characteristic" is identified. Keys are features of a material, process or part in which the variation has a significant influence on product fit, performance, service life or manufacturability. AS9100 requires that an organization establish and document a configuration management process.

Planning product realization is essential for effective and efficient processes. The standard emphasizes planning for in-process verification when a product cannot be verified at a later point. Tooling design must also be considered when process control methodology is used to ensure that process data will be captured. The AS9100 standard includes extensive supplementation in design-and-development functions. This is not surprising given the complexity of aerospace

products and customers' expectations for reliable performance during a protracted period of time. The European prEN9000-1 standard provided many of these additions. Both standards cover planning for design-and-development activities and ensuring interim control points during the design process. Design outputs are supplemented to provide identification of key characteristics, and the data essential for the product that will be identified, manufactured, inspected, used and maintained is detailed. Notes are included for both design-and-development verification and validation highlighting traditional areas of emphasis. Additionally, AS9100 provides information on areas of verification documentation and validating testing and results [17].

Managing suppliers throughout the aerospace supply chain remains a major challenge for the industry. The chain is very long, and within the supply base, there are sources that serve multiple industries. Because the industry is so dependent upon this supply chain, it isn't surprising that AS9100 includes a number of additional expectations for identifying and maintaining suppliers. Supplier approval is just one step in the process of managing suppliers. The industry typically relies upon one of three methods for product acceptance. An organization might conduct a receiving inspection, perform the inspection at the supplier's facility or formally delegate product acceptance to the supplier. Procedures for determining the method of supplier control are required, as are the processes used when employing these methods. However, no element of supplier control is more important than understanding that a supplier is responsible for managing its suppliers and sub tier suppliers. This includes performing special processes that are frequently subcontracted to processing houses. The supplier must use customer-approved sources; however, ensuring that the processing is properly performed is the supplier's responsibility.

Manufacturing a product as sophisticated as an airplane or space vehicle requires special attention during the production processes. It's important, for example, to ensure that the correct revision of the engineering documentation is being used and documented within the work instructions, and that work performance is recorded. This frequently requires a specific reference to the person performing the work. Controlling production processes is essential to demonstrate that operations have been correctly performed. This is especially important when conducting special processes that don't lend themselves to after-the-fact inspection techniques [17].

The industry frequently relies upon tooling and other production equipment, including computer-controlled machines, to fabricate and assemble products. This equipment often forms the basis for product acceptance. In these cases, it's essential to demonstrate the integrity of these tools and machines and to develop a process that will ensure adequate oversight of the entire process. Aircraft are designed to perform for 50 years or more, and properly maintaining the aircraft is essential for continued safe operation. Thus, servicing requirements are an important part of the total quality system. These include maintenance and repair manuals as well as the actual servicing work. Again, record-keeping is important in documenting the work performed, the equipment used and the people doing the

work. Some products require traceability of part or all of their components. This requirement may be imposed by contract, regulatory agency or internal need. In any case, AS9100 provides the essentials of an effective traceability program. Using measuring devices of known accuracy (and this may include computer-assisted measuring and test equipment) is essential in the verification process. Maintaining a calibration history of this equipment and documented proof that it's reviewed and verified periodically underlies the entire metrology system.

Diagnosing the quality management system's health and using this information to guide improvement activity is important for efficiency and effectiveness. Internal audits performed by competent personnel are a vital input into this health measurement system. AS9100 provides some additional expectations regarding internal quality audits. Detailed first-article inspections are frequently performed to demonstrate product conformance to engineering requirements. Documenting the actual inspection and test results is an established method of demonstrating initial item acceptance [16, 17].

When things don't go as planned, AS9100 gives directions for controlling and disposing nonconforming material. This includes specific requirements for contacting the customer for authorization when using or repairing a product that doesn't conform to engineering requirements. Organizations within the industry differ in their compliance to AS9100 verification requirements. Some use their own external auditors to verify suppliers' quality management systems. Others share the results of their quality system audits with suppliers in the industry. Most provide suppliers with copies of external audits. Most permit suppliers to share the audit results with other customers, too.

Increasingly, the industry is using the results of third-party registrars as a means of demonstrating a quality management system's compliance to AS9100. The Americas Aerospace Quality Group (AAQG), working with the Registrar Accreditation Board, has established a process and requirements for auditors performing audits to AS9100 and registrars granting supplemental registrations. The process includes additional training and practical experience and ensures that auditors are competent and that registrars are experienced in the industry. The AAQG has created a Registrar Management Committee to oversee this important function. Its methodology is defined in SAE AIR5359. Europe and Asia are developing equivalent methods.

The United States Federal Aviation Administration has determined that AS9100 is ''a comprehensive quality standard containing the basic quality control/assurance elements required by the current Code of Federal Regulations (CFR), Title 14, Part 21." Both the US Department of Defense and NASA have reviewed the standard and have published guidance material on using the standard for contractual requirements. As AS9100 becomes established within the industry, the standard's benefits become apparent. Two obvious ones are a reduction in multiple expectations and a consistency in verification methodology. Both prime manufacturers and their suppliers are pleased with the results. Suppliers report a reduction in verification audits and an increased consistency in expectations. As a direct result, suppliers' customers are seeing a reduction in oversight costs and an improvement in supplier performance [18].

As indicated, larger OEMs are extremely concerned with the performance of their suppliers in that their performance is crucial to the overall quality of their output.

In all cases the following is recognized as the distinctive approach expected in common:

- It is important to control the process and not the product.
- Controlling the human process is as vital, if not more so, as controlling the technical process.
- Quality is the responsibility of top management.
- Management must foster the participation of the workforce to develop a quality culture.
- Education and training are needed for changing attitudes and enhancing competence.
- Emphasize prevention of defects, not inspection after the event.
- Quality improvement is a process built up over time and not an instant cure.
- Functional integration is an important ingredient of TQM.
- Quality is a company-wide activity.

8.3.3 Global Manufacturing Industry Quality Control

In today's postmodern factories the systems approach embeds the physical process of making things to create business value. The Deming Cycle and kaizen are institutionalized practices. SQC techniques build quality and productivity into the manufacturing process. Numerically controlled machines and robots rapidly change tools, fixtures, molds as automated equipment reduces non-producing time by highly repeatable processes that are designed to ''get it right the first time''. Changeover times have been dramatically decreased in today's agile manufacturing environments.

The cooperative efforts have further been enhanced through organizations such as CAM-I group where automation producers, multi-national manufacturers and accountants have developed new cost accounting procedures that focus on resource consumption, capacity and throughput [19].

When Henry Ford famously stated that ''The customer can have any color as long as it's black'', he understood that flexibility costs time and money. Standardization enables the low cost model. In the early 1920s, when the model T was in its full glory, Ford decided to control the entire process of making and moving all supplies and parts needed by his new plant, the gigantic River Rouge. He built his own steel mill and glass plant. He founded rubber plantations in Brazil. He brought the railroad in to carry the finished cars across the country after rolling off the assembly line. This created a monstrous conglomerate that was expensive, unmanageable and horrendously unprofitable. When the Japanese introduced just-in-time concepts for supply chain inventory control the factory

logistics model required an end-to-end overhaul starting from the end backwards and managed as an integrated flow.

In either case, manufacturing needed to concern itself with the responsibility of integrating people, materials, machines and time. Whether parts are outsourced or processed internally, quality procedures and conformance practices were keys to survival. Today's larger manufacturers employ several tools beyond the simple SQC control charts of the Shewhart era.

TQM is a principle as established by Deming, The basis of TQM is to reduce the errors produced during the manufacturing or service process, increase customer satisfaction, streamline supply chain management, aim for modernization of equipment and ensure workers have the highest level of training.

The Plan Do Check Act cycle introduced the concept of quality circles. A quality circle is a volunteer group composed of workers usually under the leadership of their supervisor. These individuals are trained to identify, analyze and solve work-related problems and present their solutions to management in order to improve the performance of the organization, and motivate and enrich the work of employees. They bring back the concept of craftsmanship, which when operated on an individual basis is uneconomic, but when used in group form (as is the case with quality circles) it can be devastatingly powerful and enables the enrichment of the lives of the workers and creates harmony and high performance in the workplace. Typical topics are improving occupational safety and health, improving product design, and improvement in the workplace and manufacturing processes.

Quality circles are formal groups that spring up from large quality conscious manufacturers. Members are typically cross-functional by design. They meet at least once a week on company time and are trained by competent persons (usually designated as facilitators) who may be personnel and industrial relations specialists trained in human factors and the basic skills of problem identification, information gathering and analysis, basic statistics, and solution generation [20].

The toolset is often referred to as the seven basic tools of quality. These are a fixed set of graphical analyses that are identified as being the most useful for quality control. They are called basic because they are suitable for people with little formal training in statistics and because they can be used to solve the vast majority of quality-related issues [21, 22].

The tools are:

- The cause-and-effect or Ishikawa diagram
- The check sheet
- The control chart
- The histogram
- The Pareto chart
- The scatter diagram
- Stratification (alternately flow chart or run chart)

We have discussed the control chart in great depth earlier in this chapter.

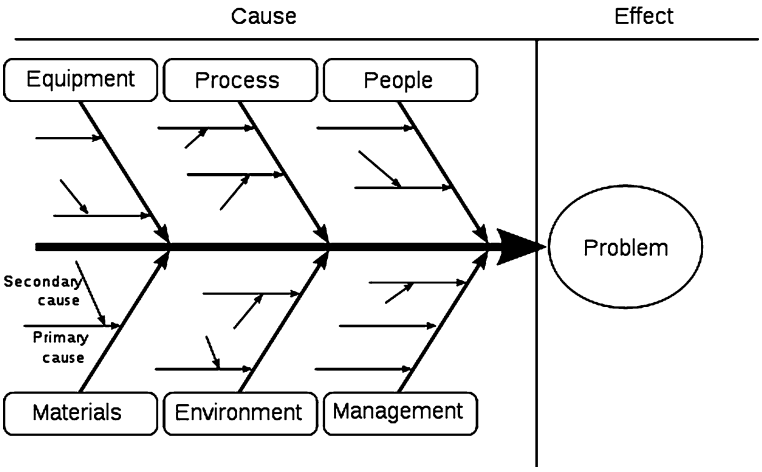


Fig. 8.12 Ishikawa fishbone cause/effect diagram

The check sheet is a simple document that is used for collecting data in real-time and at the location where the data is generated. The document is typically a blank form that is designed for the quick, easy, and efficient recording of the desired information, which can be either quantitative or qualitative. When the information is quantitative, the check sheet is sometimes called a tally sheet.

A defining characteristic of a check sheet is that data is recorded by making marks (‘‘checks”) on it. A typical check sheet is divided into regions, and marks made in different regions have different significance. Data is read by observing the location and number of marks on the sheet. There are five basic types of Check Sheets:

- Classification: a trait such as a defect or failure mode must be classified into a category.
- Location: the physical location of a trait is indicated on a picture of a part or item being evaluated.
- Frequency: the presence or absence of a trait or combination of traits is indicated. Also number of occurrences of a trait on a part can be indicated.
- Measurement Scale: a measurement scale is divided into intervals, and measurements are indicated by checking an appropriate interval.
- Check List: the items to be performed for a task are listed so that, as each is accomplished, it can be indicated as having been completed.

Ishikawa diagrams (also called fishbone diagrams or cause-and-effect diagrams) are diagrams that show the causes of a certain event. An example is shown in Fig. 8.12. Common uses of the Ishikawa diagram are product design and quality defect prevention, to identify potential factors causing an overall effect. Each cause or reason for imperfection is a source of variation. Causes are usually

grouped into major categories to identify these sources of variation. The categories typically include:

- People: anyone involved with the process.
- Methods: how the process is performed and the specific requirements for doing it, such as policies, procedures, rules, regulations and laws.
- Machines: any equipment, computers, tools etc. required to accomplish the job.
- Materials: raw materials, parts, pens, paper, etc. used to produce the final product.
- Measurements: data generated from the process that are used to evaluate its quality.
- Environment: the conditions, such as location, time, temperature, and culture in which the process operates.

Causes in the diagram are often categorized, such as to the 6 M's, described below. Cause-and-effect diagrams can reveal key relationships among various variables, and the possible causes provide additional insight into process behavior.

Causes can be derived from brainstorming sessions. These groups can then be labeled as categories of the fishbone. They will typically be one of the traditional categories mentioned above but may be something unique to the application in a specific case. Causes can be traced back to root causes with the 5 Whys technique.

Typical categories are:

- The 8 Ms (used in manufacturing)
  - Machine (technology)
  - Method (process)
  - Material (includes raw material, consumables and information)
  - Man Power (physical work)/Mind Power (brain work): Kaizens, Suggestions
  - Measurement (inspection)
  - Milieu/Mother Nature (environment)
  - Management/Money Power
  - Maintenance
- The 8 Ps (used in service industry)
  - Product = Service
  - Price
  - Place
  - Promotion
  - People
  - Process
  - Physical Evidence
  - Productivity and Quality

A Pareto chart is a type of chart that contains both bars and a line graph, where individual values are represented in descending order by bars, and the cumulative total is represented by the line.

The left vertical axis is the frequency of occurrence, but it can alternatively represent cost or another important unit of measure. The right vertical axis is the cumulative percentage of the total number of occurrences, total cost, or total of the particular unit of measure. Because the reasons are in decreasing order, the cumulative function is a concave function.

The purpose of the Pareto chart is to highlight the most important among a (typically large) set of factors. In quality control, it often represents the most common sources of defects, the highest occurring type of defect, or the most frequent reasons for customer complaints, and so on.

The Pareto principle (also known as the 80–20 rule, the law of the vital few, and the principle of factor scarcity) states that, for many events, roughly 80% of the effects come from 20% of the causes. Business management thinker Joseph M. Juran suggested the principle and named it after Italian economist Vilfredo Pareto, who observed in 1906 that 80% of the land in Italy was owned by 20% of the population; he developed the principle by observing that 20% of the pea pods in his garden contained 80% of the peas [3]. It is a common rule of thumb in business; e.g., ''80% of your sales come from 20% of your clients.'' Mathematically, where something is shared among a sufficiently large set of participants, there must be a number k between 50 and 100 such that ''k% is taken by (100−k)% of the participants''. The number k may vary from 50 (in the case of equal distribution, i.e., 100% of the population have equal shares) to nearly 100 (when a tiny number of participants account for almost all of the resource). There is nothing special about the number 80% mathematically, but many real systems have k somewhere around this region of intermediate imbalance in distribution.

8.3.4 ISO/TS 16949

The ISO/TS16949 is an international standard aiming to the development of a quality management system that provides for continual improvement, emphasizing defect prevention and the reduction of variation and waste in the supply chain. TS16949 applies to the design/development, production and, when relevant, installation and servicing of automotive-related products. It is based on ISO9001 and supersedes the QS9000 certifications. The requirements are intended to be applied throughout the supply chain. Most automotive manufacturing vehicle assembly plants are encouraged to seek ISO/TS16949 certification.

8.4 Information Modeling for Manufacturing Quality Control

Software is increasingly determining the nature of the experiences customers, employees, partners and investors have with a company, its products and services and its operations. Positive software mediated transactions are critical for retaining customers, motivating employees, and collaborating effectively with partners [6].

Many companies have accumulated an unwieldy number of incompatible, customized software systems to handle the same applications. The CIO at General Motors has estimated the organization has installed more than 7800 distinct software systems worldwide. When these systems are not compatible, transferring data, information and knowledge become nearly impossible. It is quite often the case that many of these installed applications and databases were built for individual business lines and simply do not talk to each other. In today's market, competitive advantage depends on the nature and sophistication of a company's information infrastructure. Businesses run not only through effective use of property, machines and people, they rely heavily on its data sources, databases and operating systems.

Managerial decisions depend on the availability of high quality information supplied by application software. Consider a company's primary supplier relationships and the software that mediates these interfaces. More and more information is being exchanged and each party increasingly relies on the other's information systems. It is precisely these interfaces that need sufficient structure in order to ensure low information loss.

Incoming raw material may be validated for conformance to specifications upstream in the supply chain. In the past the quality control information was typically provided in a paper report. Today, it is more often the case that the information is supplied electronically. Many formats are available including spreadsheets, text files, and other documents that serve to haul the data downstream from creator to consumer. Lack of standardization makes persistent analysis difficult at best. Unless a common format is established and agreed upon, a manufacturer can end up with many different forms of the same type of information. Integration with internal systems becomes a challenge.

Inside the factory things can be just as bad. Historically IT organizations were set up to manage an information infrastructure designed around a centralized mainframe. However, over the last 20 years these same organizations have seen a mass proliferation of decentralized and distributed computing systems, including client server architectures that have interfaces with intranets and the Internet. Although some packaged applications such as enterprise resource planning (ERP) have alleviated some standardization pressures that require information modeling exercises to design cross platform compatibility, these systems may not be robust in certain lines of business applications including engineering specialties such as computer aided design, manufacture and quality control.

8.4.1 Statistical Process Control Data Model

Statistical process control (SPC) relies on graphical presentation of inspection data through the use of control charts. SPC is the application of statistical methods to the monitoring and control of a process to ensure that it operates at its full potential to produce conforming product. Under SPC, a process behaves predictably to

produce as much conforming product as possible with the least possible waste. While SPC has been applied most frequently to controlling manufacturing lines, it applies equally well to any process with a measurable output. Key tools in SPC are control charts, a focus on continuous improvement and designed experiments.

Much of the power of SPC lies in the ability to examine a process and the sources of variation in that process using tools that give weight to objective analysis over subjective opinions and that allow the strength of each source to be determined numerically. Variations in the process that may affect the quality of the end product or service can be detected and corrected, thus reducing waste as well as the likelihood that problems will be passed on to the customer. With its emphasis on early detection and prevention of problems, SPC has a distinct advantage over other quality methods, such as inspection, that apply resources to detecting and correcting problems after they have occurred.

In addition to reducing waste, SPC can lead to a reduction in the time required to produce the product or service from end to end. This is partially due to a diminished likelihood that the final product will have to be reworked, but it may also result from using SPC data to identify bottlenecks, wait times, and other sources of delays within the process. Process cycle time reductions coupled with improvements in yield have made SPC a valuable tool from both a cost reduction and a customer satisfaction standpoint.

8.4.1.1 SPC Quality Indices

Quality statistics give the machine operator or quality engineer a current reading of relevant numerical information.

The following items are examples of traditional quality statistics:

- Subgroup number (k).
- Subgroup size (n).
- ObsCnt = Observation Count = number of individual observations made.
- XDBar = $\overline{\overline{X}}$= *X*-double bar = the mean of the subgroup averages.
- Rbar = average of the subgroup ranges.
- s (all) = $\sqrt{\frac{\sum (X-\overline{\overline{X}})^2}{n-1}}$ = standard deviation of measurement population
- RBar/d2 = estimated standard deviation
- Min = minimum observation value
- Max = maximum observation value
- Mean ± 3,4,6s = control limits for XBar chart
- Defect Ratio = percentage of measurements outside of tolerance
- PPM = parts per million outside of tolerance
- Cp = potential process capability index = (UTL-LTL)/6 s, where s = standard deviation = RBar/d2, (UTL = Upper Tolerance Limit, LTL = Lower Tolerance Limit)

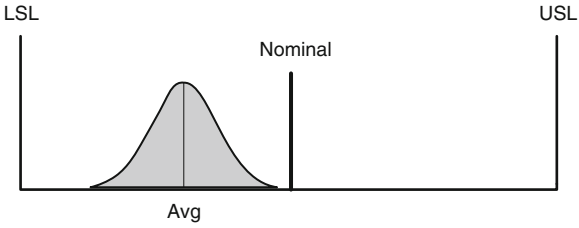


Fig. 8.13 Case 1

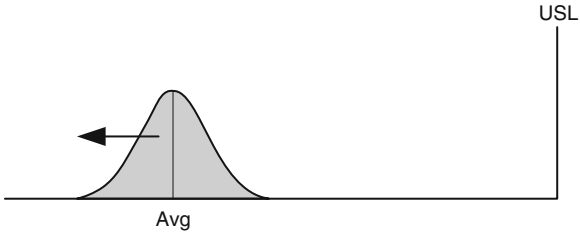


Fig. 8.14 Case 2

- Cpk = potential process performance index = Zmin/3, where Zmin = min {(UTL $-\overline{\overline{X}}$)/s, ($\overline{\overline{X}}$−LTL)/s}, where s = RBar/d2,
- CR = capability ratio = 1/Cp
- CPL = ($\overline{\overline{X}}$−LTL)/3s, where s = RBar/d2
- CPU = (UTL−$\overline{\overline{X}}$)/3s
- Pp = actual process capability index = (UTL−LTL)/σs, where $\sigma = \sqrt{\frac{\sum (X-\overline{\overline{X}})^2}{n-1}}$
- Ppk = actual process performance index = Zmin/3, where Zmin = min {(UTL−$\overline{\overline{X}}$)/s, ($\overline{\overline{X}}$−LTL)/s}.

8.4.1.2 Special Cases for Process Capability Calculations

Given: Engineering Specifications = 60 ± 5; USL = UTL = 65, LSL = LTL = 55, $\sigma \approx$s = 2.3232 (USL = Upper Specification Limit, LSL = Lower Specification Limit). Since Cp depends on the unknown value of σ, we will use an estimate of σ (which is s), to estimate Cp.

- Step 1: Calculate the engineering Tolerance.

  Engineering tolerance is 65−55 = 10.

- Step 2: Estimate capability.

  Process capability = 6 $\sigma \approx$ 6 s = 6 × 2.3232 = 13.9392.

- Step 3: Estimate Cp.

Fig. 8.15 Case 3

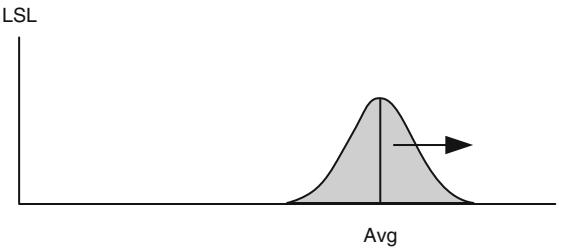
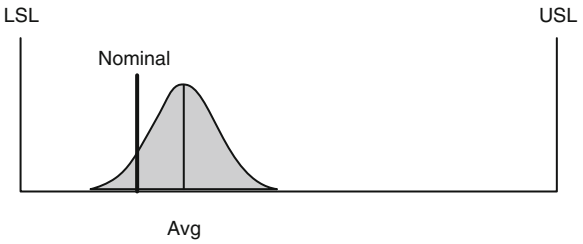


Fig. 8.16 Case 4



$$\text{Cp} \approx \frac{10}{13.9392} = 0.72$$

- Step 4: Estimate Cpk.

$$\text{Cpk} = \text{Smaller of } \left[\frac{USL - Avg}{3\sigma}, \frac{Avg - LSL}{3\sigma}\right]$$

Given engineering specifications = 60 ± 5, USL = 65, LSL = 55. Avg = 60.15, $\sigma \approx$s = 2.3232.

$$\text{Cpu} = \frac{USL - Avg}{3\sigma} \approx \frac{65 - 60.15}{3 \times 203232} = \frac{4.85}{6.9696} = 0.70 \leftarrow \text{Smaller of the two}$$

$$\text{Cpl} = \frac{Avg - LSL}{3\sigma} \approx \frac{60.15 - 55}{3 \times 2.3232} = \frac{5.15}{6.9696} = 0.74$$

Calculating Cpk for Specific Cases:

- *Case 1* (Fig. 8.13): Upper and lower specifications are provided and engineering nominal (or target) is centered between the specification limits.

$$\text{Cpk} = \text{Smaller of} \left[\frac{USL - Avg}{3\sigma}, \frac{Avg - LSL}{3\sigma}\right]$$

Fig. 8.17 Case 5

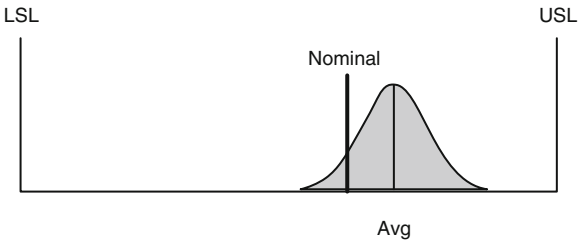
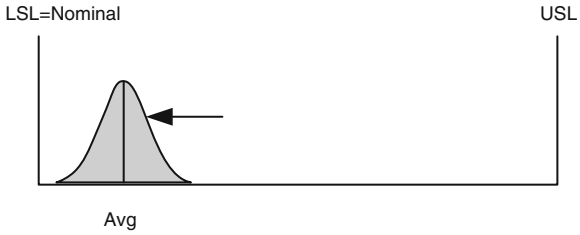


Fig. 8.18 Case 6



- *Case 2* (Fig. 8.14): A lower physical bound is used as the lower specification limit, or no lower specification exists. It is assumed that smaller feature measurements are always superior to larger values.

$$\text{Cpk} = \text{Cpu} = \frac{USL - Avg}{3\sigma}$$

- *Case 3* (Fig. 8.15): An upper physical bound is used as the upper specification limit, or no upper specification exists. It is assumed that larger feature measurements are always superior to smaller values.

$$\text{Cpk} = \text{Cpl} = \frac{Avg - LSL}{3\sigma}$$

- *Case 4* (Fig. 8.16): Upper, lower, and engineering nominal (or target) specifications are given, but nominal is closer to the lower specification than the upper specification. Cpk is maximized when the process average equals the nominal specification. Cpk is positive when the process average lies between the upper and lower specification limits, and is 0.0 when the process average equals either LSL or USL. When nominal is not centered between the upper and lower specification limit, a higher Cp is required to meet a Cpk of 1.33 than if the nominal had been centered.

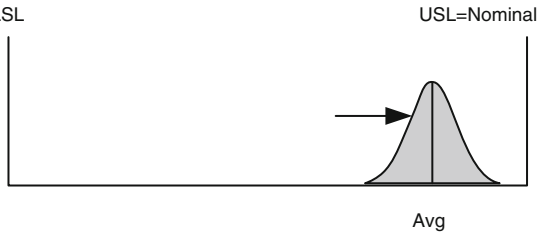


Fig. 8.19 Case 7

$$\text{Cpk} = \text{Smaller of}\left[\frac{Avg - LSL}{3\sigma}, \left(\frac{USL - Avg}{3\sigma}\right)\left(\frac{Nom - LSL}{USL - Nom}\right)\right]$$

- *Case 5* (Fig. 8.17): Upper, lower, and engineering nominal (or target) specifications are given, but nominal is closer to the upper specification than the lower specification. Cpk is maximized when the process average equals the nominal specification. Cpk is positive when the process average lies between the upper and lower specification limits, and is 0.0 when the process average equals either LSL or USL. When nominal is not centered between the upper and lower specification limit, a higher Cp is required to meet a Cpk of 1.33 than if the nominal had been centered.

$$\text{Cpk} = \text{Smaller of}\left[\left(\frac{Avg - LSL}{3\sigma}\right)\left(\frac{USL - Nom}{Nom - LSL}\right), \frac{USL - Avg}{3\sigma}\right]$$

- *Case 6* (Fig. 8.18): Upper, lower, and engineering nominal (or target) specifications are given, but the nominal is equal to the lower specification limit and there are no physical bounds limiting measurements from going below nominal.

$$\text{Cpk} = \frac{Avg - LSL}{3\sigma}$$

For this case and the following case only, a large Cpk is not desirable. The optimal Cpk is 1.33, and Cp should be maximized instead of Cpk.

- *Case 7* (Fig. 8.19): Upper, lower, and engineering nominal (or target) specifications are given, but the nominal is equal to the upper specification limit and there are no physical bounds limiting measurements from going above nominal.

$$\text{Cpk} = \frac{USL - Avg}{3\sigma}$$

For this case and the preceding case only, a large Cpk is not desirable. For most operations optimal Cpk is 1.33, and Cp should be maximized instead of Cpk.

When no nominal is given, a manufacturing target should be established—generally halfway between the upper and lower specifications. In such instances, use case 1, 4, 5, 6, or 7, as appropriate.

Cases 4, 5, 6, and 7 are encountered in manufacturing on a daily basis. Engineers give design guidance to manufacturers when nominal is intended to be off-centered and is so desired to achieve optimum product performance in the market-place. Likewise, operators machining features to maximum material condition (MMC) may help to minimize scrap and add serviceable life to many high-cost parts. Therefore, it becomes advantageous for manufacturing to know and understand where to center a process on what optimum target value, and when to aggressively strive for improving Cp while holding Cpk to a relatively lower, constant index. The value of a capable measurement system cannot be overstated, especially for these cases. Gage variation studies should be performed to add confidence in accepting and rejecting process output targets close to specification limits. There are, of course, cost considerations and tradeoffs, but setting the proper capability goals can help the producer (as well as the customer) achieve superior quality and performance. Data and information feedback to Engineering and manufacturing will enhance current and future products. Along with other information, the use of statistical control charts and capability data are vital pieces of the communication process [18].

8.4.2 Advanced Product Quality Plan Data Model

Advanced product quality planning (APQP) [23] is a framework of procedures and techniques used to develop products in industry, particularly the automotive industry. It is quite similar to the concept of design for six sigma (DFSS). It is a defined process for a product development system for General Motors, Ford, Chrysler and their suppliers. According to AIAG, the purpose of APQP is ‘‘to produce a product quality plan which will support development of a product or service that will satisfy the customer.”

APQP is a process developed in the late 1980 s by a commission of experts gathered from the ‘Big Three’ US automobile manufacturers: Ford, GM and Chrysler. This commission invested five years to analyze the then-current automotive development and production status in the US, Europe and especially in Japan. At the time, the success of the Japanese automotive companies was starting to be remarkable in the US market. APQP is utilized today by these three companies and some affiliates. Tier I suppliers are typically required to

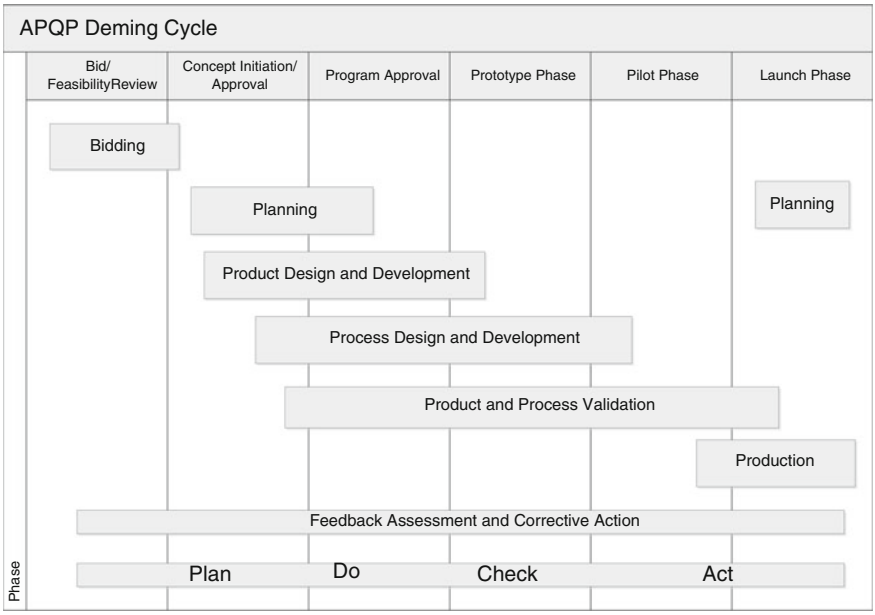


Fig. 8.20 APQP Deming cycle

follow APQP procedures and techniques and are also typically required to be audited and registered to ISO/TS 16949.

The APQP process is defined in the AIAG's APQP Manual, which is part of a series of interrelated documents that the AIAG controls and publishes. The basis for the make-up of a process control plan is included in the APQP Manual. The APQP provides a five stage process (as shown in Fig. 8.20) for establishing a product quality program.

- Phase 1—Plan and Define Program
  Determine customer needs, requirements and expectations using tools, such as quality function deployment (QFD), to review the entire quality planning process in order to enable the implementation of how to define and set the inputs and the outputs of a quality program.
- Phase 2—Product Design and Development
  Review the inputs and execute the outputs, which include failure mode effect analysis (FMEA), design for manufacture and assembly (DFMA), design verification, design reviews, material and engineering specifications.
- Phase 3—Process Design and Development
  Address features for developing manufacturing systems and related control plans. These tasks depend on the successful completion of phases 1 and 2 with executed outputs.

- Phase 4—Product and Process Validation
  Validate the manufacturing process and its control mechanisms through production setup while evaluating process conditions and production requirements through the analysis of pilot phase outputs.
- Phase 5—Launch, Feedback, Assessment and Corrective Action
  Focus on reducing variation and continuously improving outputs and links to customer expectations.

Control plan methodology is a key concept in the APQP specification. It describes the use of control plans and relevant data required to construct and determine control plan parameters and stresses the importance of the control plan in the continuous improvement cycle.

APQP defines the following control plan element descriptions:

- Control Plan Type—Prototype, Pre-Launch, Production
- Control Plan Number—for tracking purposes
- Part Number Latest Change Level
- Part Name and Description
- Supplier and Plant
- Supplier Code
- Key Contact and Phone Number
- Core Team
- Supplier Plant Approval Date
- Date of Original Plan
- Date of Current Revision
- Customer Engineering Approval and Date
- Process Name, Operation and Description
- Machine, Device, Jig, Tools for Manufacturing
- Product Characteristics
- Process Characteristics
- Special Characteristic Classification—e.g. Critical, Key, Safety, etc.
- Product and Process Specification and Tolerances
- Evaluation and Measurement Techniques
- Sample Size and Frequency
- Control Method
- Reaction Plan

8.4.3 OAGi Engineering to Business Data Model

The open applications group (OAGi), the organization that oversees the OAGIS, was formed in November 1994 in an effort to dramatically ease everywhere-to-everywhere integration (inside and outside of the enterprise, as well as across the supply chain). OAGi has done this by crafting standards where necessary and by recommending standards where they already exist.

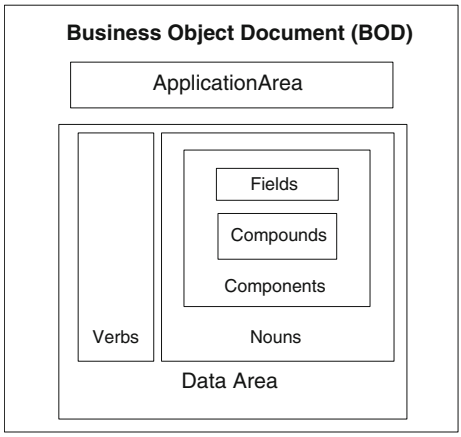


Fig. 8.21 BOD structure

The first release of OAGIS was developed in 1995 to address the need for a common business language that would enable business applications to communicate. OAGIS provides the definition of business messages in the form of business object documents (BODs) (as shown in Fig. 8.21) and example business scenarios that provide example usages of the BODs. The business scenarios identify the business applications and components being integrated and the BODs that are used. OAGIS is currently at release 9.5 and supports more than 400 business messages.

OAGi also partners with other standards bodies to provide a true canonical business language. OAGi recognizes that no one organization can be all things to all people. However, by partnering with industry vertical groups OAGIS provides the means to plug in the additional requirements and constraints that meet the specific needs of each vertical industry. Because of this long history of delivering quality usable integration standards, OAGIS has support from application vendors and implementation providers, and has been implemented by various customers in over 40 countries worldwide.

OAGIS is built as a horizontal business language, enabling it to be used in many industries worldwide. The scope of OAGIS extends the enterprise's reach across the organization, from application to application, down into the organization for enterprise application to execution systems, and outside the organization for B2B functions. The scope of OAGIS is targeted for the following types of transactions.

- eCommerce
  - e-Catalog
  - Price Lists
  - RFQ and Quote
- Order Management

  - Purchasing
  - Invoice
  - Payments
- Manufacturing
  - MES
  - Shop Floor
  - Plant Data Collection
  - Engineering
  - Warehouse Management
  - Enterprise Asset Management
- Logistics
  - Orders
  - Shipments
  - Routings
- CRM
  - Opportunities
  - Sales Leads
  - Customer
  - Sales Force Automation
- ERP
  - Financials
  - Human Resources
  - Manufacturing
  - Credit Management
  - Sarbanes/Oxley and Control

The OAGIS model is said not to compete with standard electronic data interchange (EDI) business models such as ANSI X12 which was developed in 1979. However, like X12, OAGIS does target multiple business domains and does not yet have a robust quality definition although there has been significant work done for discrete manufacturing dealing with cross platform data exchange between enterprise resource planning and manufacturing execution systems.

8.5 Summary

Variation is the enemy of quality. Many types of quality improvement techniques target the reduction of variation as a key process. Quality control programs have a number of tools available including SPC, Six-Sigma, Fishbone diagrams and Pareto analysis.

Total Quality Management is concerned with improving quality across the enterprise, both small and large. Larger enterprises can afford dedicated resources and training efforts in the quality discipline but may not be agile enough to indoctrinate them. Smaller enterprises can be lean enough to adopt Quality practices but may not have sufficient resources for the effort.

Many large OEMs (including those in Automotive and Aerospace) have provided guidelines for their component suppliers. For example the QS9000 (now ISO/16949) and AS9100 standards offer manufacturers standardized approaches to quality. Data models do exist for quality as derived from the APQP and SPC guidelines from the automotive industry action group.

Some effort has been made to standardize quality models for discrete manufacturing (e.g. open applications group); however the enterprise has not fully engaged quality engineering and the shop floor.

References

1. Feo JAD, Barnard W (2004) Juran Institute's six sigma breakthrough and beyond: quality performance breakthrough methods. McGraw-Hill Professional, New York
2. Harry MJ, Schroeder R (2000) Six Sigma. Random House, UK
3. Shewhart WA (1931) Economic control of quality of manufactured product. D. Van Nostrand, New York
4. NIST (2006) Engineering statistics handbook. NIST/SEMATECH e-Handbook of statistical methods
5. Nelson LS (1984) Shewhart control chart—tests for special causes. J Qual Technol 16(4):237–239
6. Prahalad CK, Krishnan MS (1999) The new meaning of quality in the information age. Harv Bus Rev 77(5):109–118 184
7. Genichi T, Clausing D (1990) Robust quality. Harv Bus Rev January–February:65–75
8. Manoochehri GH (1988) JIT for small manufacturers. J Small Bus Manag 26(4):22–30
9. Siropolis NC (1994) Small business management: a guide to entrepreneurship. Houghton Mifflin Co, USA
10. Golhar DY, Deshpande SP (1997) HRM practices of large and small Canadian manufacturing firms. J Small Bus Manag 35(3):30–38
11. McEvoy GM (1984) Small business personnel practices. J Small Bus Manag 22(4):1–8
12. Lee GL, Oakes IK (1995) The 'pros' and 'cons' of TQM for smaller firms in manufacturing: some experiences down the supply chain. Total Qual Manag 6(4):431–444
13. Blackburn R, Rosen B (1993) Total quality and human resource management: lessons learned from baldrige award-winning companies. Acad Manag Executive 7(3):49–66
14. Lee GL (1991) The challenge of CAD/CAM: some experience of British and Canadian engineering companies. New Technol, Work Employ 1(2):100–112
15. Dawson P (1994) Total quality management. In: Storey J (ed) New wave manufacturing strategies: organizational and human resource management dimensions. P. Chapman, London
16. Bizmanualz (2006) AS 9100 Aerospace policies procedures and forms. Bizmanualz, USA
17. Barker EM (2002) Aerospace's AS9100 QMS standard, quality digest. August
18. Boeing. Advanced quality systems tools AQS D1-9000-*1*. 1998 [cited 2011 January 21]; Available from: http://www.boeingsuppliers.com/supplier/d1-9000-1.pdf
19. Drucker PF (1990) The emerging theory of manufacturing. Harv Bus Rev 68(3):94–102
20. Hutchins DC (1985) Quality circles handbook. Nichols, New York

21. Ishikawa K (1985) What is total quality control? The Japanese way. Prentice-Hall, USA
22. Tague NR (2005) The quality toolbox. ASQ Quality Press, Milwaukee
23. AIAG (1995) Advanced product quality planning and control plan (APQP) [cited 2011 January 21]; Available from: http://www.aiag.org/staticcontent/education/trainingindex.cfm?classcode=APQP