# Quality Management

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Whether a systems engineer delivers a product, a service, or an enterprise, the deliverable should meet the needs of the customer and be fit for use. Such a deliverable is said to be of high quality. The process to assure high quality is called quality management.

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# Overview

Over the past 80 years, a *quality movement* has emerged to enable organizations to produce high quality deliverables. This movement has gone through four stages:

1. **Acceptance Sampling** was developed to apply statistical tests to assist in the decision of whether or not to accept a lot of material based on a random sample of its content.
2. **Statistical Process Control** (SPC) was developed to determine if production processes were stable. Instead of necessarily measuring products, processes are measured instead. Processes that departed from a state of statistical control were far more likely to develop low quality deliverables.
3. **Design for Quality** focused on designing processes that were robust against causes of variation, reducing the likelihood that a process would go out of control, and accordingly reducing the monitoring requirements.
4. **Six sigma** methods are applied the tools and power of statistical thinking to improve other aspects of the organization.

# Definitions

The American Society for Quality provides the following definitions:

- Acceptance Sampling involves the inspection of a sample to decide whether to accept the entire lot. There are two types of sampling:
  - In attributes sampling, the presence or absence of a characteristic is noted in each of the units inspected.
  - In variables sampling, the numerical magnitude of a characteristic is measured and recorded for each inspected unit. This involves reference to a continuous scale of some kind.
- SPC is the application of statistical techniques to control a process. It is often used interchangeably with the term “statistical quality control.”
- Quality is a subjective term for which each person or sector has its own definition. In technical usage,

quality can have two meanings:
    - The characteristics of a product or service that bear on its ability to satisfy stated or implied needs.
    - A product or service free of deficiencies. According to Joseph Juran, quality means “fitness for use.” According to Philip Crosby, it means "conformance to requirements."
- Six Sigma is a method that provides organizations with tools to improve the capability of their business processes. This increase in performance and decrease in process variation leads to defect reduction and improvement in profits, employee morale, and quality of products or services. Six Sigma quality is a term generally used to indicate a process is well controlled (±6 s from the centerline in a control chart).

# Quality Attributes

Quality attributes, also known as quality factors, quality characteristics, or non-functional requirements, are a set of system functional and non-functional requirements that are used to evaluate the system performance. There are a large number of system quality attributes identified in the literature (e.g. MSDN 2010, Barbacci et al. 1995). Depending on the type of the system being considered, some of these attributes are more prominent than others. Ideally, a system would be optimized for all the quality attributes that are important to the stakeholders, but this is an impossible task. Therefore, it is important to conduct a trade-off analysis to identify the relationship between the attributes and establish whether a change in one attribute would positively or negatively affect any other attributes. An example of such trade-off is shown in Table 1 below. (See SEBoK discussion on specialty engineering for additional information on quality attributes.)

**Table 1. Attribute Trade Off.** (SEBoK Original)

| | Flexibility | Maintainability | Reliability |
|---|---|---|---|
| **Flexibility** | | + | - |
| **Maintainability** | + | | + |
| **Reliability** | - | + | |

Finding the right set of quality attributes is the first step in quality control and management. In order to achieve high quality, quality must be measured, monitored, managed, and improved on. Therefore, in order to increase the overall system quality, it is necessary to:

- identify and prioritize the quality attributes
- identify the metrics that can be used for these attributes
- measure and monitor the attributes
- validate the measurements
- analyze the result of those measurements
- establish processes and procedures that result in improved system quality, based on the analysis.

## Quality Attributes for Products

Quality attributes for a product focus on the conformance to the specifications for the product; frequently these are manufacturing specifications. Examples include physical characteristics (length, weight, finish, capacity, etc.) being inside a given tolerance range. The physical characteristics can be related to the function of the product or to aesthetic qualities.

A single product may have a vector of quality attributes of high dimension as well as an associated region in which the vector is expected to be. Often the quality is summarized by saying the item is "in compliance" (if the vector is in the acceptable region) or "defective" (if the vector is outside the acceptable region).

## Quality Attributes for Services

Quality of services plays a major role in customer satisfaction, which is the measurement of the overall system quality. Services can be divided into two major categories: primary and secondary. The city public transportation system, the U.S. postal service, or the medical services provided by a hospital are all examples of primary services. Services that provide help to a customer are secondary services, which are typically referred to as a *customer service*. Identifying the appropriate quality attributes is critical in the quality management of services. Some examples of service quality attributes include: affordability, availability, dependability, efficiency, predictability, reliability, responsiveness, safety, security, usability, etc. Again, depending on the type of the service, some of these attributes are more prominent than the others.

For example, in the case of services that are provided by the hospital, one may potentially be more interested in the availability, reliability, and responsiveness than the security (typically hospitals are assumed to be safe) and the affordability (typically insurance covers the majority of the cost). Of course, if the patient does not have a good insurance coverage, then the importance of affordability will increase (de Knoning, 2006).

## Quality Attributes for Enterprises

An enterprise typically refers to a large, complex set of interconnected entities that includes people, technologies, processes, financial, and physical elements. Clearly, a typical enterprise has a number of internal and external stakeholders, and as a result there are a large number of quality attributes that will define its quality. Identifying the right set of attributes is typically more challenging in such a complex system. An example of an enterprise is the air traffic management system that is mainly responsible for the safe and efficient operation of the civil aviation within a country or collection of countries. There are many stakeholders that are concerned about the overall quality of the system, some example of these stakeholders and some of the primary quality attributes that they are concerned with are identified in Table 2.

**Table 2. Enterprise Stakeholders and their Quality Attributes.** (SEBoK Original)

| Stakeholders | Primary Quality Attributes |
|---|---|
| Passengers | Safety, affordability, and reliability |
| Airlines | Adaptability, efficiency, and profitability |
| Air Traffic Controller | Safety, reliability, and usability |
| Hardware & Software Developers | Reliability, fault tolerance, and maintainability |
| Government/Regulatory Agency | Safety, reliability, affordability, etc. |

## Measuring Quality Attributes

Quality cannot be achieved if it cannot be measured. The Measurement System Analysis (MSA) (Wheeler and Lynday 1989) is a set of measuring instruments that provide an adequate capability for a team to conduct appropriate measurements in order to monitor and control quality. The MSA is a collection of:

- **Tools** - measuring instruments, calibration, etc.
- **Processes** - testing and measuring methods, set of specifications, etc.
- **Procedures** - policies and procedures and methodologies that are defined by the company and/or regulatory agency
- **People** - personnel (managers, testers, analysis, etc.) who are involved in the measurement activities
- **Environment** - both environmental setting and physical setting that best simulate the operational environment and/or the best setting to get the most accurate measurements

Once the quality attributes are identified and prioritized, then the MSA supports the monitor and control of overall system quality.

Additional details about measurement are presented in the measurement article.

# Quality Management Strategies

## Acceptance Sampling

In acceptance sampling many examples of a product are presented for delivery. The consumer samples from the lot and each member of the sample is then categorized as either *acceptable* or *unacceptable* based on an attribute (attribute sampling) or measured against one or more metrics (variable sampling). Based on the measurements, an inference is made as to whether the lot meets the customer requirements.

There are four possible outcomes of the sampling of a lot, as shown in Table 3.

**Table 3. Truth Table - Outcomes of Acceptance Sampling.** (SEBoK Original)

| | **Lot Meets Requirement** | **Lot Fails Requirement** |
|---|---|---|
| **Sample Passes Test** | No error | Consumer risk |
| **Sample Fails Test** | Producer risk | No error |

A sample acceptance plan balances the risk of error between the producer and consumer. Detailed ANSI/ISO/ASQ standards describe how this allocation is performed (ANSI/ISO/ASQ A3534-2-1993: *Statistics—Vocabulary and Symbols—Statistical Quality Control*).

## Statistical Process Control

SPC is a method that was invented by Walter A. Shewhart (1931) that adopts statistical thinking to monitor and control the behaviors and performances of a process. It involves using statistical analysis techniques as tools in appropriate ways, such as providing an estimate of the variation in the performance of a process, investigating the causes of this variation, and offering the engineer the means to recognize when the process is not performing as it should based on the data. (Mary et al. 2006, 441). In this context, *performance* is measured by how well the process is performed.

The theory of quality management emphasizes managing processes by fact and maintaining systematic improvement. All product developments are a series of interconnected processes that have variation in their results. Understanding variation with SPC technology can help the process executors understand the facts of their processes and find the improvement opportunities from a systematic view.

Control charts are common tools in SPC. The control chart is also called the Shewhart 3-sigma chart. It consists of 3 limit lines: the center line, which is the mean of statistical samples, and the upper and lower control limit lines, which are calculated using the mean and standard deviation of statistical samples. The observed data points or their statistical values are drawn in the chart with time or other sequence orders. Upper and lower control limits indicate the thresholds at which the process output will be considered as *unlikely*. There are two sources of process variation. One is common cause variation, which is due to inherent interaction among process components. Another is assignable cause, which is due to events that are not part of the normal process. SPC stresses bringing a process into a state of statistical control, where only common cause variation exists, and keeping it in control. A control chart is used to distinguish between variation in a process resulting from common causes and assignable causes.

If the process is in control, and if standard assumptions are met, points will demonstrate a normal distribution around the control limit. Any points outside either of the limits, or in systematic patterns, imply a new source of variation would be introduced. A new variation means increased quality cost. Additional types of control charts exist, including: cumulative sum charts that detect small, persistent step change model departures and moving average charts, which use different possible weighting schemes to detect persistent changes (Hawkins and Olwell 1996).

## Design for Quality

Variation in the inputs to a process usually results in variation in the outputs. Processes can be designed, however, to be robust against variation in the inputs. Response surface experimental design and analysis is the statistical technique that is used to assist in determining the sensitivity of the process to variations in the input. Such an approach was pioneered by Taguchi.

## Six Sigma

Six sigma methodology (Pyzdek and Keller, 2009) is a set of tools to improve the quality of business processes; in particular, to improve performance and reduce variation. Six sigma methods were pioneered by Motorola and came into wide acceptance after they were championed by General Electric.

Problems resulting in variation are addressed by six sigma projects, which follow a five-stage process:

1. **Define** the problem, the stakeholders, and the goals.
2. **Measure** key aspects and collect relevant data.
3. **Analyze** the data to determine cause-effect relationships.
4. **Improve** the current process or **design** a new process.
5. **Control** the future state or **verify** the design.

These steps are known as **DMAIC** for existing processes and **DMADV** for new processes. A variant of six sigma is called lean six sigma wherein the emphasis is on improving or maintaining quality while driving out waste.

### Standards

Primary standards for quality management are maintained by ISO, principally the IS0 9000 series. The ISO standards provide requirements for the quality management systems of a wide range of enterprises, without specifying how the standards are to be met. The key requirement is that the system must be audited. ISO standards have world-wide acceptance.

In the United States, the Malcolm Baldridge National Quality Award presents up to three awards in six categories: manufacturing, service company, small business, education, health care, and nonprofit. The Baldridge Criteria have become de facto standards for assessing the quality performance of organizations.

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