Source: Archie Miles.

Chapter 17

Quality planning and control

Introduction

Quality is the only one of the five 'operations performance criteria' to have its own dedicated chapter in this book (or two chapters if you include total quality management which is covered in Chapter 20). There are two reasons for this. First, in some organizations a separate function is devoted exclusively to the management of quality. Second, quality is a key concern of almost all organizations. High-quality goods and services can give an organization a considerable competitive edge. Good quality reduces the costs of rework, waste, complaints and returns and, most importantly, generates satisfied customers. Some operations managers believe that, in the long run, quality is the most important single factor affecting an organization's performance relative to its competitors.

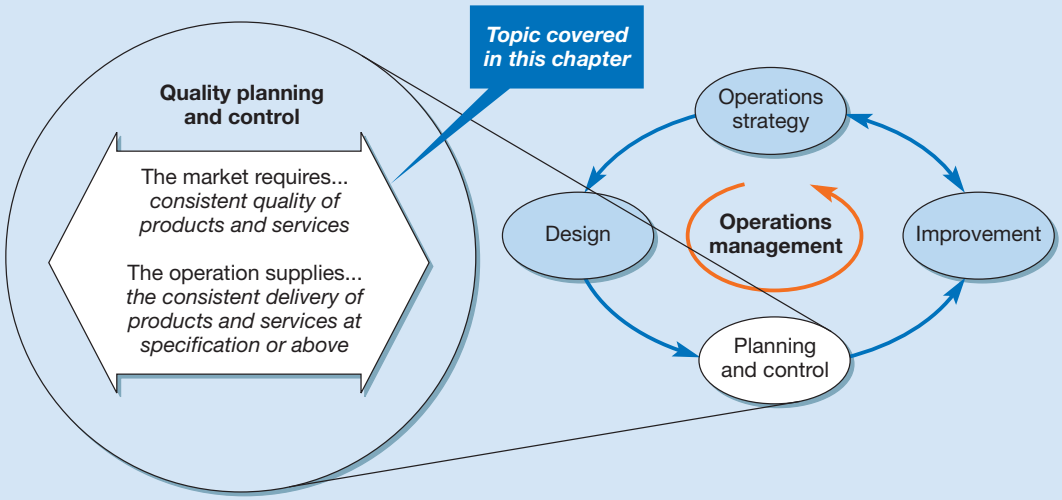

Figure 17.1 **This chapter covers quality planning and control**

Key questions ???

- How can quality be defined?
- How can quality problems be diagnosed?
- What steps lead towards conformance to specification?
- How can statistical process control help quality planning and control?
- How can acceptance sampling help quality planning and control?

Operations in practice

Quality at the Four Seasons Canary Wharf[1]

The first Four Seasons Hotel opened over 40 years ago. Since then the company has grown to a chain of over 60 properties in 25 countries. Famed for its quality of service, the hotel group has won countless awards including the prestigious Zagat survey ranking as 'top hotel chain' internationally. From its inception the group has had the same guiding principle, '*to make the quality of our service our competitive advantage*'. The company has what it calls its Golden Rule: '*Do to others (guests and staff) as you would wish others to do to you.*'

'*It may be a simple rule, but it guides the whole organization's approach to quality,*' says Karen Earp, General Manager of the Four Seasons London Canary Wharf Hotel, who was recently voted Hotelier of the Year by one of the most popular trade journals. '*Quality of service is our distinguishing edge. The golden rule means treating your guests with courtesy and intelligence. It also means that treating your employees with humanity and respect encourages them to be equally sensitive to the needs and expectations of guests. When guests come to a Four Seasons Hotel they need to have our assurance that they are going to get exceptional food, great service, anything they need from our 24-hour concierge service and a great night's sleep. We are not trading in service quality gimmicks. We focus on giving what we call 'the exceptional basics'. So we listen very carefully to our guests, give a lot of thought to their needs and provide what they really need. For example, more than anything else, guests value a good night's sleep. We have invested time and research into obtaining the very best beds (they are made especially for us) and we have very strict linen requirements using the very finest cotton sheets. We have even developed a special fold at the end of the bed linen that means very tall people cannot push their feet out of the bottom of the bed. We also spend an extraordinary amount of time on developing and maintaining our*

Source: Four Seasons Hotels, Photographer Robert Miller.

blackout curtains so that no unwanted light comes into the bedroom to interrupt your sleep. It's this attention to detail that counts in helping a good night's sleep.

'*There is nothing more important than our staff in achieving such high quality of service. They respond to the culture of the organization that encourages three things – creativity, initiative and attitude. The most important of these is attitude. You can teach people the technical skills of the job but it is the attitude of our staff that sets us apart from any other hotel chain. We try to hire people with an attitude that takes great pride in delivering exceptional service. It really is rewarding to see a guest take pleasure in the fact that we have remembered something from the last time they visited us. And attitude leads on to innovation and creativity. For example, we had a well-known person who was staying with us and speaking to a large gathering in the hotel in the evening. He was dressed casually and wearing bright green trainers. One of our staff escorted him to his room and carried his tuxedo for the evening's event. On arriving at*

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the room the guest let out a sigh when he realized that he had forgotten to bring his formal shoes. Seeing that the guest's feet seemed to be around the same size as his own, our member of staff gave him his own shoes to wear. Not only was that guest delighted, he stood up at the event and told 200 very important people of his delight.'

Like all Four Seasons hotels, a 'guest history system' is used to track guests' preferences. If a guest likes particular types of flowers or fruit in their room, or if they like a particular type of wine, it is recorded and these items can be made available on the guest's next visit. Within the limits of privacy, all staff are empowered to make a record on the guest history file of anything that could improve the guest's stay next time. '*Many of our guests are senior managers of high-quality businesses themselves, so they know about quality and their standards are very high,' says Karen. 'Our objective is to exceed their expectations. And although* ***our*** *expectation is that we will achieve zero defects, you cannot always do that. Obviously we design our systems to try to prevent errors occurring, but it is impossible to prevent all mistakes. We very rarely get formal complaints, but when we do I will always personally see to them myself by talking to the guest or answering any letters. The key is service recovery; this is why empowerment is so important. You have to make sure that all staff know they can turn around any negative experiences into positive ones before the guest leaves. It really is worth the effort. Giving exceptional service pays off in the long run because we get tremendous loyalty from our guests.*'

What is quality and why is it so important?

GO TO WEB! 17B

It is worth revisiting some of the arguments which were presented in Chapter 2 regarding the benefits of high quality. This will explain why most operations see quality as being so important. Figure 17.2 illustrates the various ways in which quality improvements can affect other aspects of operations performance. Revenues can be increased by better sales and enhanced prices in the market. At the same time, costs can be brought down by improved efficiencies, productivity and the use of capital. A key task of the operations function must be to ensure that it provides quality goods and services to its internal and external customers. This is not necessarily straightforward. For example, there is no clear or agreed definition of what 'quality' means.

Professor David Garvin[2] has categorized many of the various definitions into 'five approaches' to quality: *the transcendent approach, the manufacturing-based approach, the user-based approach, the product-based approach and the value-based approach.*

- **The transcendent approach** – views quality as synonymous with *innate excellence.* A 'quality' car is a Rolls-Royce. A 'quality' flight is one provided by Singapore Airlines. A 'quality' watch is a Rolex. Using this approach, quality is being defined as the absolute – the best possible, in terms of the product's or service's specification.
- **The manufacturing-based approach** – is concerned with making products or providing services that are *free of errors* and that conform precisely to their design specification. A car which is less expensive than a Rolls-Royce, or a Swatch watch or an economy flight, although not necessarily the 'best' available, is defined as a 'quality' product provided it has been built or delivered precisely to its design specification.
- **The user-based approach** – is concerned with making sure that the product or service is *fit for its purpose.* This definition demonstrates concern not only for its adherence to specification but also for the appropriateness of that specification for the customer. A watch that is manufactured precisely to its design specification yet falls to pieces after two days is clearly not 'fit for its purpose'. The cabin service on a night-time flight from Sydney to Stockholm may be designed to provide passengers with drinks every 15 minutes, meals every four hours and frequent announcements about the position of the plane. This quality specification may not be appropriate, however, for the customer whose main need is a good sleep.

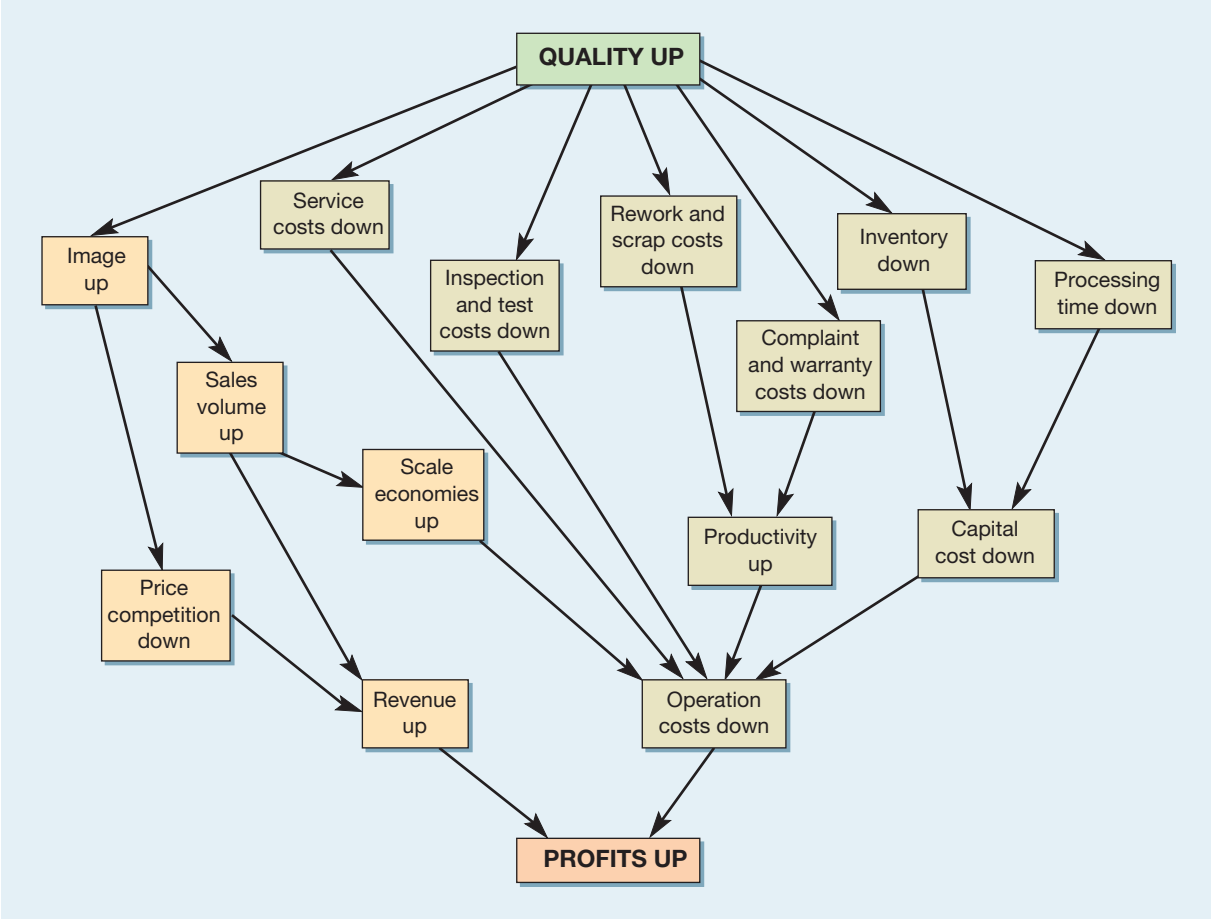

Figure 17.2 Higher quality has a beneficial effect on both revenues and costs
Source: Based on Gummesson, E.[3]

- **The product-based approach** – views quality as a precise (and measurable) set of the characteristics which will satisfy customers. A watch, for example, may be designed to run, without the need for servicing, for at least five years while keeping time correct to within five seconds.
- **The value-based approach** – takes the manufacturing definition a stage further and defines quality in terms of *cost and price*. This approach contends that quality should be perceived in relation to price. A customer may well be willing to accept something of a lower specification quality, if the price is low. A simple and inexpensive watch may give good value by performing quite satisfactorily for a reasonable period of time. A passenger may be willing to fly from Singapore to Amsterdam with a four-hour wait in Bangkok and endure cramped seating and mediocre meals in order to save hundreds of guilders on the cost of a direct flight.

Quality – the operation's view

Quality
Quality is consistent conformance to customers' expectations.

Here we try to reconcile some of these different views in our definition of **quality**:

Quality is consistent conformance to customers' expectations.

The use of the word 'conformance' implies that there is a need to meet a clear specification (the manufacturing approach); ensuring a product or service conforms to specification is a key operations task. 'Consistent' implies that conformance to specification is not an *ad hoc*

event but that the materials, facilities and processes have been designed and then controlled to ensure that the product or service meets the specification using a set of measurable product or service characteristics (the product-based approach). The use of 'customers' expectations' attempts to combine the user- and value-based approaches.[4] It recognizes that the product or service must meet the expectations of customers, which may indeed be influenced by price.

The use of the word 'expectations' in this definition, rather than needs or wants, is important. 'Wants' would imply that anything the customer desires should be provided by the organization. 'Needs' implies only the meeting of a basic requirement. Take the example of a car. Our *need* might be for a mobile box that gets us from A to B. We might *want* a car that has the looks and acceleration of a sports car, with the carrying capacity of an estate, the ruggedness of a cross-country vehicle, and which comes to us at no cost. Our *expectation*, however, is that which we believe to be likely. We know that it is difficult to get sports performance with a large carrying capacity, and certainly not at zero cost.

Quality – the customer's view

One problem with basing our definition of quality on customer expectations is that an individual customer's expectations may be different. Past experiences, individual knowledge and history will all shape their expectations. Furthermore, customers, on receiving the product or service, may each *perceive* it in different ways. One person may perceive a long-haul flight as an exciting part of a holiday; the person on the next seat may see it as a necessary chore to get to a business meeting. One person may perceive a car as a status symbol; another may see it merely as an expensive means of getting from home to work. Quality needs to be understood from a customer's point of view because, to the customer, the quality of a particular product or service is whatever he or she perceives it to be. If the passengers on a skiing charter flight perceive it to be of good quality, despite long queues at check-in or cramped seating and poor meals, then the flight really is of good perceived quality. If customers believe that expensive German cars are of good quality despite short service intervals, expensive parts and poor fuel consumption, then the car really is of high perceived quality.[5] Furthermore, in some situations, customers may be unable to judge the 'technical' operational specification of the service or product. They may then use surrogate measures as a basis for their perception of quality.[6] For example, after a visit to a dentist it might be difficult for a customer to judge the technical quality of the repair of a tooth except insofar as it does not give any more trouble. The customer may in reality perceive quality in terms of such things as the dress and demeanour of the dentist and technician and how they were treated.

Reconciling the operation's and the customer's views of quality

Customer expectations

Customer perception

GO TO WEB! 17B

The operation's view of quality is concerned with trying to meet **customer expectations**. The customer's view of quality is what he or she *perceives* the product or service to be. To create a unified view, quality can be defined as the degree of fit between customers' expectations and **customer perception** of the product or service.[7] Using this idea allows us to see the customers' view of quality of (and, therefore, satisfaction with) the product or service as the result of the customers comparing their expectations of the product or service with their perception of how it performs. This is not always straightforward (see the short case 'Tea and Sympathy'). Also, if the product or service experience was better than expected then the customer is satisfied and quality is perceived to be high. If the product or service was less than his or her expectations then quality is low and the customer may be dissatisfied. If the product or service matches expectations then the perceived quality of the product or service is seen to be **acceptable**. These relationships are summarized in Figure 17.3.

A customer's view of quality is shaped by the gap between perception and expectation

Short case **Tea and Sympathy**[8]

Defining quality in terms of perception and expectation can sometimes reveal some surprising results. For example, Tea and Sympathy is a British restaurant and café in the heart of New York's West Village. Over the last ten years it has become a fashionable landmark in a city with one of the broadest range of restaurants in the world. Yet it is tiny, around a dozen tables packed into an area little bigger than the average British sitting room. Not only expatriate Brits but also native New Yorkers and celebrities queue to get in. As the only British restaurant in New York, it has a novelty factor, but also it has become famous for the unusual nature of its service. '*Everyone is treated in the same way*,' says Nicky Perry, one of the two ex-Londoners who run it. '*We have a firm policy that we don't take any shit*.' This robust attitude to the treatment of customers is reinforced by 'Nicky's Rules' which are printed on the menu.

1 Be pleasant to the waitresses – remember Tea and Sympathy girls are always right.
2 You will have to wait outside the restaurant until your entire party is present: no exceptions.
3 Occasionally, you may be asked to change tables so that we can accommodate all of you.
4 If we don't need the table you may stay all day, but if people are waiting it's time to naff off.
5 These rules are strictly enforced. Any argument will incur Nicky's wrath. You have been warned.

Most of the waitresses are also British and enforce Nicky's Rules strictly. If customers object they are thrown out.

Source: © Peter Cassidy/Getty Images/Digital Vision

Nicky says that she has had to train 'her girls' to toughen up. '*I've taught them that when people cross the line they can tear their throats out as far as I'm concerned. What we've discovered over the years is that if you are really sweet, people see it as a weakness. People get thrown out of the restaurant about twice a week and yet customers still queue for the genuine shepherds pie, a real cup of tea and, of course, the service.*'

Questions

1 Why do you think 'Nicky's Rules' help to make the Tea and Sympathy operation more efficient?
2 The restaurant's approach to quality of service seems very different to most restaurants. Why do you think it seems to work here?

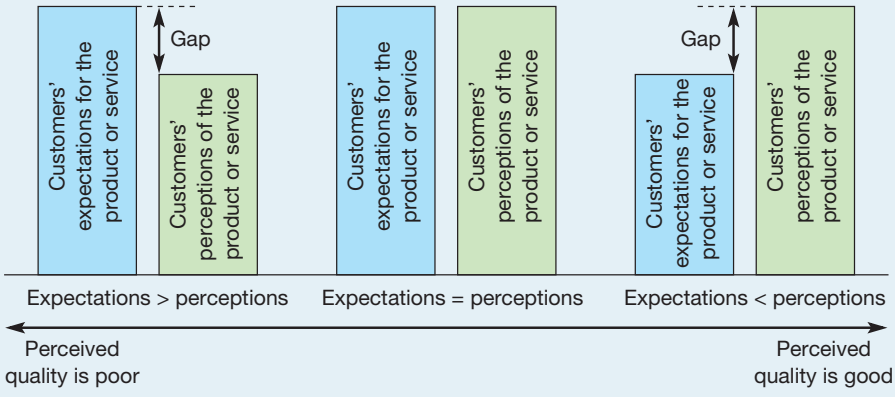

Figure 17.3 **Perceived quality is governed by the magnitude and direction of the gap between customers' expectations and their perceptions of the product or service**

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Both customers' expectations and perceptions are influenced by a number of factors, some of which cannot be controlled by the operation and some of which, to a certain extent, can be managed. Figure 17.4 shows some of the factors that will influence the gap between expectations and perceptions. This model of customer-perceived quality can help us understand how operations can manage quality and identifies some of the problems in so doing. The bottom part of the diagram represents the operation's 'domain' of quality and the top part the customer's 'domain'. These two domains meet in the actual product or service, which is provided by the organization and experienced by the customer. Within the operation's domain, management is responsible for designing the product or service and providing a specification of the quality to which the product or service has to be created. The specification of a car, for example, might include the surface finish of the body, its physical dimensions, reliability and so on. Within the customer's domain, his or her expectations are shaped by such factors as previous experiences with the particular product or service, the marketing image provided by the organization and word-of-mouth information from other

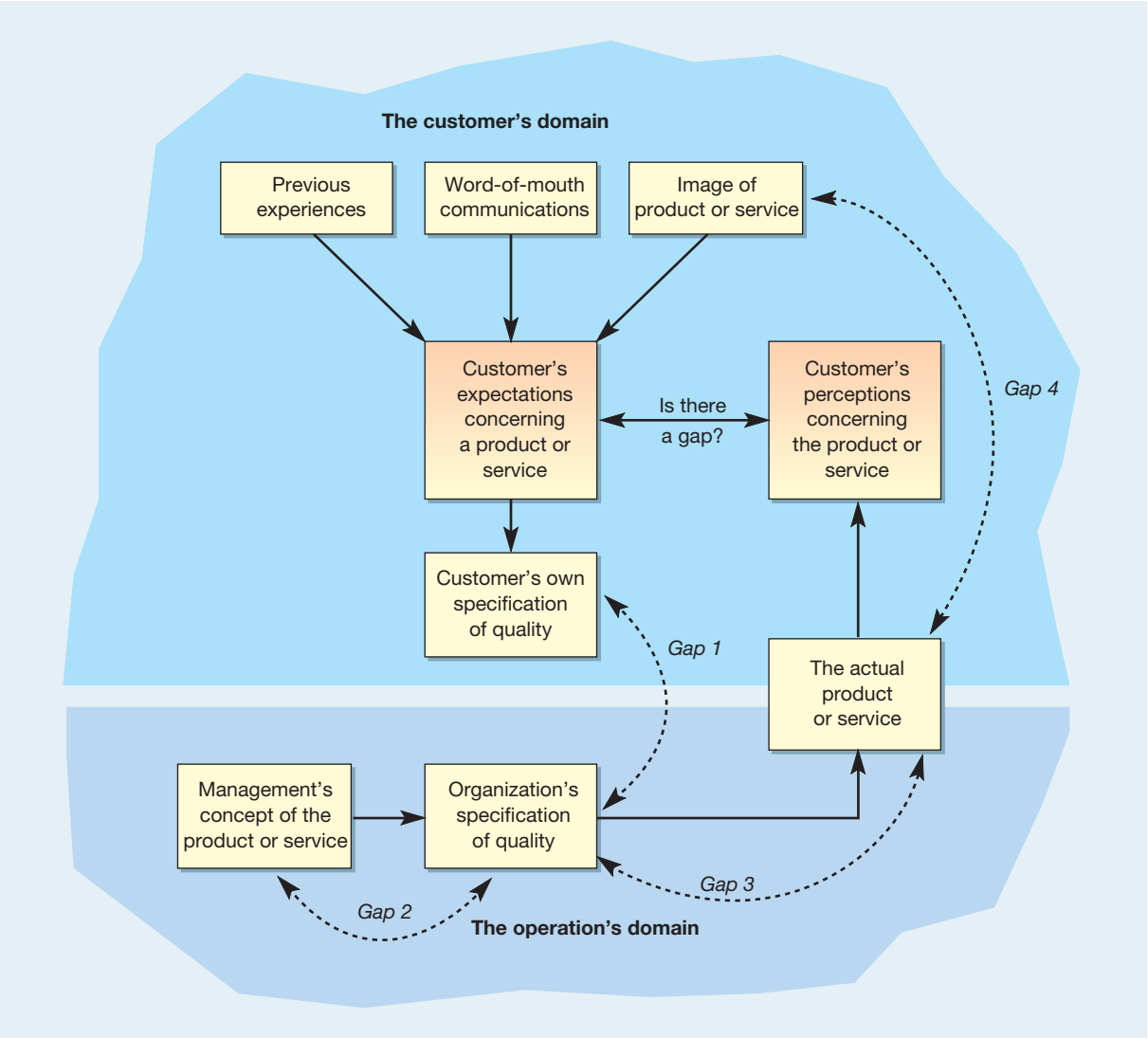


Figure 17.4 The customer's domain and the operation's domain in determining the perceived quality, showing how the gap between customers' expectations and their perception of a product or service could be explained by one or more gaps elsewhere in the model

Source: Adapted from Parasuraman, A. *et al.* (1985) 'A conceptual model of service quality and implications for future research', *Journal of Marketing*, Vol. 49, Fall, pp. 41–50. Reproduced with permission from the American Marketing Association.

users. These expectations are internalized as a set of quality characteristics. A customer's expectations about the car, for example, may include its appearance, performance, luggage space, fuel consumption, leg room and so on.

Diagnosing quality problems[9]

Figure 17.4 also shows how quality problems can be diagnosed. If the perceived quality gap is such that customers' perceptions of the product or service fail to match their expectations of it, then the reason (or reasons) must lie in other gaps elsewhere in the model. Four other gaps could explain a perceived quality gap between customers' perceptions and expectations.

Gap 1: The customer's specification–operation's specification gap

Perceived quality could be poor because there may be a mismatch between the organization's own internal quality specification and the specification which is expected by the customer. For example, a car may be designed to need servicing every 10,000 km but the customer may expect 15,000 km service intervals. An airline may have a policy of charging for drinks during the flight whereas the customer's expectation may be that the drinks would be free.

Gap 2: The concept–specification gap

Perceived quality could be poor because there is a mismatch between the product or service concept (see Chapter 5) and the way the organization has specified the quality of the product or service internally. For example, the concept of a car might have been for an inexpensive, energy-efficient means of transportation, but the inclusion of a catalytic converter may have both added to its cost and made it less energy-efficient.

Gap 3: The quality specification–actual quality gap

Perceived quality could be poor because there is a mismatch between the actual quality of the service or product provided by the operation and its internal quality specification. This may be the result, for example, of an inappropriate or unachievable specification, or of poorly trained or inexperienced personnel, or because effective control systems are not in place to ensure the provision of defined levels of quality. For example, the internal quality specification for a car may be that the gap between its doors and body, when closed, must not exceed 7 mm. However, because of inadequate equipment, the gap in reality is 9 mm. A further example is where, despite an airline's policy of charging for drinks, some flight crews might provide free drinks, adding unexpected costs to the airline and influencing customers' expectations for the next flight, when they may be disappointed.

Gap 4: The actual quality–communicated image gap

Perceived quality could also be poor because there is a gap between the organization's external communications or market image and the actual quality of the service or product delivered to the customer. This may be the result of either the marketing function setting unachievable expectations in the minds of customers or operations not providing the level of quality expected by the customer. For example, an advertising campaign for an airline might show a cabin attendant offering to replace a customer's shirt on which food or drink has been spilt, whereas such a service may not in fact be available should this happen.

The organizational responsibility for closing the gaps

The existence of any one of these gaps is likely to result in a mismatch between expectations and perceptions and, consequently, in poor perceived quality. It is therefore important that managers take action to prevent quality gaps. Table 17.1 shows the actions which will be required to close each of the gaps and indicates the parts of the organization that bear the main responsibility for doing so.

Table 17.1 **The organizational responsibility for closing quality gaps**

Gap	*Action required to ensure high perceived quality*	*Main organizational responsibility*
Gap 1	Ensure that there is consistency between the internal quality specification of the product or service and the expectations of customers	Marketing Operations Product/service development
Gap 2	Ensure that the internal specification of the product or service meets its intended concept or design	Marketing Operations Product/service development
Gap 3	Ensure that the actual product or service conforms to its internally specified quality level	Operations
Gap 4	Ensure that the promises made to customers concerning the product or service can in reality be delivered by the operation	Marketing

Conformance to specification

Conformance to specification means producing a product or providing a service to its design specification. During the design of any product or service, its overall concept, purpose, package of components and the relationship between the components will have been specified (see Chapter 5). This is the quality planning and control activity. Quality planning and control can be divided into six sequential steps. This chapter will deal with steps 1 to 4. Steps 5 and 6 are dealt with in Chapters 18, 19 and 20.

Step 1 Define the quality characteristics of the product or service.
Step 2 Decide how to measure each quality characteristic.
Step 3 Set quality standards for each quality characteristic.
Step 4 Control quality against those standards.
Step 5 Find and correct causes of poor quality.
Step 6 Continue to make improvements.

Step 1 – Define the quality characteristics

Much of the 'quality' of a product or service will have been specified in its design. But not all the design details are useful in controlling quality. For example, the design of a television may specify that its outer cabinet is made with a particular veneer. Each television is not checked, however, to make sure that the cabinet is indeed made from that particular veneer. Rather it is the *consequences* of the design specification which are examined – the appearance of the cabinet, for example. These consequences for quality planning and control of the design are called the **quality characteristics** of the product or service. Table 17.2 shows a list of the quality characteristics which are generally useful, but the terms need a little further explanation.

Quality characteristics
The various elements within the concept of quality, such as functionality, appearance, reliability, durability, recovery, etc.

Functionality means how well the product or service does its job. This includes its performance and features. *Appearance* refers to the sensory characteristics of the product or service: its aesthetic appeal, look, feel, sound and smell. *Reliability* is the consistency of the product's or service's performance over time, or the average time for which it performs within its tolerated band of performance. *Durability* means the total useful life of the product or service, assuming occasional repair or modification. *Recovery* means the ease with which problems with the product or service can be rectified or resolved. *Contact* refers to the nature of the person-to-person contact which might take place. For example, it could include the courtesy, empathy, sensitivity and knowledge of contact staff.

Table 17.2 Quality characteristics for a car, bank loan, and an air journey

Quality characteristic	*Car (material transformation process)*	*Bank loan (information transformation process)*	*Air journey (customer transformation process)*
Functionality	Speed, acceleration, fuel consumption, ride quality, road-holding, etc.	Interest rate, terms and conditions	Safety and duration of journey, onboard meals and drinks, car and hotel booking services
Appearance	Aesthetics, shape, finish, door gaps, etc.	Aesthetics of information, website, etc.	Decor and cleanliness of aircraft, lounges and crew
Reliability	Mean time to failure	Keeping promises (implicit and explicit)	Keeping to the published flight times
Durability	Useful life (with repair)	Stability of terms and conditions	Keeping up with trends in the industry
Recovery	Ease of repair	Resolution of service failures	Resolution of service failures
Contact	Knowledge and courtesy of sales staff	Knowledge and courtesy of branch and call centre staff	Knowledge, courtesy and sensitivity of airline staff

Quality characteristics of the total package

Many services are (as we discussed in Chapter 5) a whole package of several elements, each of which will have their own quality characteristics. Some aspects of quality may be influenced by two or more elements within the total package. To understand the quality characteristics of the whole package therefore it is necessary to understand the individual characteristics within and between each element of the package. For example, Figure 17.5 shows some of the quality characteristics for a web-based on-line grocery shopping service. To judge this service it is necessary to consider the website through which information is transmitted and orders are placed, the products that are sold through the site and the delivery service that transports purchases to the customer. Identifying where each characteristic of quality lies is useful because it is the first step towards understanding which part of the total service should be given responsibility for maintaining each aspect of quality.

Step 2 – Decide how to measure each characteristic

These characteristics must be defined in such a way as to enable them to be measured and then controlled. This involves taking a very general quality characteristic such as 'appearance' and breaking it down, as far as one can, into its constituent elements. 'Appearance' is difficult to measure as such, but 'colour match', 'surface finish' and 'number of visible scratches' are all capable of being described in a more objective manner. They may even be quantifiable.

The process of disaggregating quality characteristics into their measurable sub-components, however, can result in the characteristics losing some of their meaning. For example, a quantified list of colour match, the 'smoothness' of the surface finish and the number of visible scratches do not convey everything about the appearance of a product. Customers will react to more factors than these: for example, the shape and character of a product. Many of the factors lost by disaggregating 'appearance' into its measurable parts are those which are embedded in the design of the product rather than the way it is produced.

Some of the quality characteristics of a product or service cannot themselves be measured at all. The 'courtesy' of airline staff, for example, has no objective quantified measure. Yet operations with high customer contact, such as airlines, place a great deal of importance on the need to ensure courtesy in their staff. In cases like this, the operation will have to attempt to measure customer *perceptions* of courtesy.

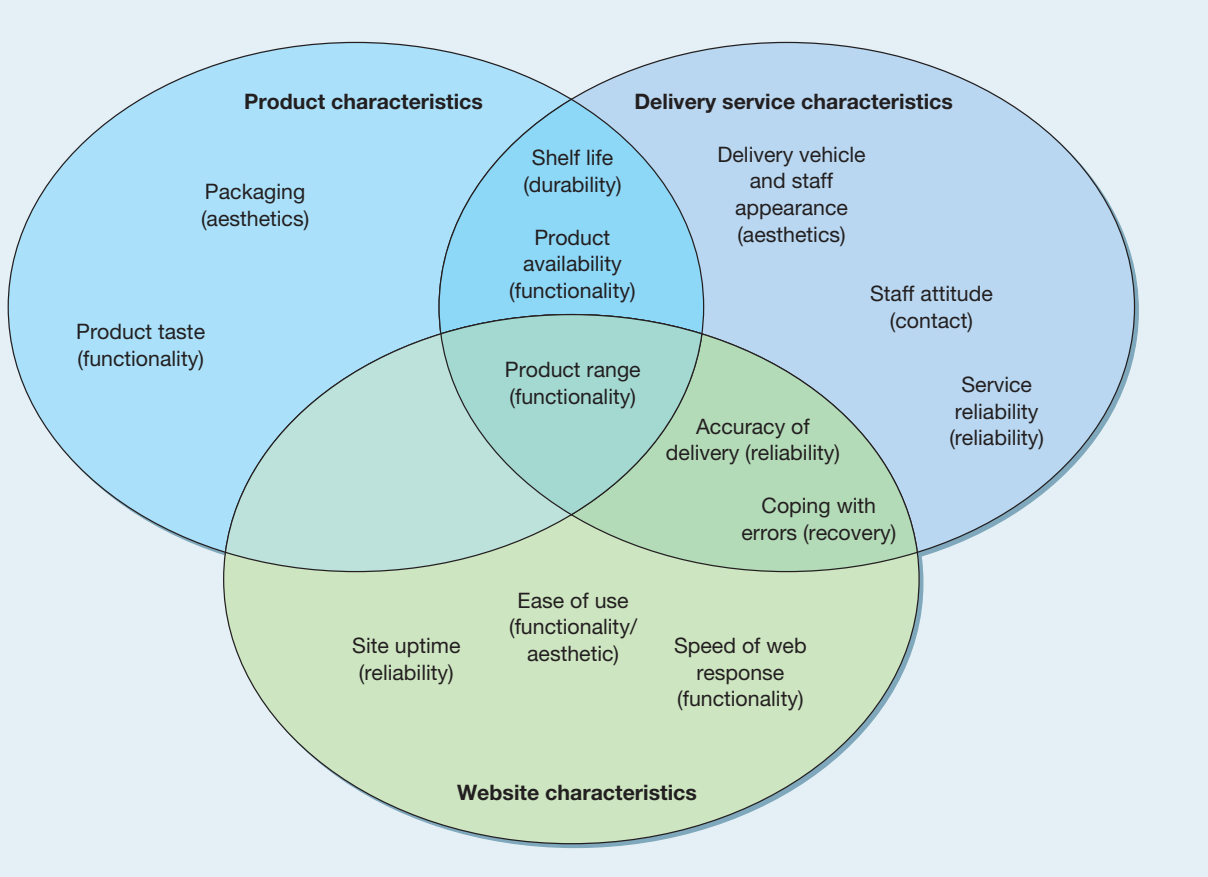


Figure 17.5 **Some quality characteristics for an on-line grocery shopping service**

Variables and attributes

Variables

Attributes

The measures used by operations to describe quality characteristics are of two types: **variables** and **attributes**. Variable measures are those that can be measured on a continuously variable scale (for example, length, diameter, weight or time). Attributes are those which are assessed by judgement and are dichotomous, i.e. have two states (for example, right or wrong, works or does not work, looks OK or not OK). Table 17.3 categorizes some of the measures which might be used for the quality characteristics of the car and the airline journey.

Step 3 – Set quality standards

When operations managers have identified how any quality characteristic can be measured, they need a quality standard against which it can be checked; otherwise they will not know whether it indicates good or bad performance. For example, suppose that, on average, one passenger out of every 10,000 complains about the food. Should the airline regard that as good because it seems that 9,999 passengers out of 10,000 are satisfied? Or should it regard it as bad because, if one passenger complains, there must be others who, although dissatisfied, did not bother to complain? Or, if that level of complaint is broadly similar to other airlines, should it regard its quality as just about satisfactory? While it might seem to be appropriate to have an absolute standard – that is, perfection – and indeed strive for it, to use perfection as an operational standard could be both demoralizing and expensive. Most manufactured products and delivered services are not 'perfect'. No car will last for ever. No airline could guarantee that there will always be seats available on its aircraft.

Table 17.3 Variable and attribute measures for quality characteristics

Quality characteristic	*Car*		*Airline journey*	
	Variable	*Attribute*	*Variable*	*Attribute*
Functionality	Acceleration and braking characteristics from test bed	Is the ride quality satisfactory?	Number of journeys which actually arrived at the destination (i.e. didn't crash!)	Was the food acceptable?
Appearance	Number of blemishes visible on car	Is the colour to specification?	Number of seats not cleaned satisfactorily	Is the crew dressed smartly?
Reliability	Average time between faults	Is the reliability satisfactory?	Proportion of journeys which arrived on time	Were there any complaints?
Durability	Life of the car	Is the useful life as predicted?	Number of times service innovations lagged competitors	Generally, is the airline updating its services in a satisfactory manner?
Recovery	Time from fault discovered to fault repaired	Is the serviceability of the car acceptable?	Proportion of service failures resolved satisfactorily	Do customers feel that staff deal satisfactorily with complaints?
Contact	Level of help provided by sales staff (1 to 5 scale)	Did customers feel well served (yes or no)?	The extent to which customers feel well treated by staff (1 to 5 scale)	Did customers feel that the staff were helpful (yes or no)?

The quality standard is that level of quality which defines the boundary between acceptable and unacceptable. Such standards may well be constrained by operational factors such as the state of technology in the factory, and the cost limits of making the product. At the same time, however, they need to be appropriate to the expectations of customers. The quality standard for the reliability of a watch might be ten maintenance-free years, for the availability of airline seats might be that seats should be available 95 per cent of the time, and so on.

Short case **Quality at Torres Wine**[10]

Back in 1870, Jaime Torres, having been forced to seek his fortune in Cuba when his elder brother inherited the family estates, returned to his native Catalonia. He founded the company which is now Spain's largest independently owned wine company with a turnover of around 17 million bottles of wine per year, together with around 6 million bottles of brandy. The (still family-owned) company's success is based firmly on the work it has put in to maintain the quality and consistency of its products. This starts with the vineyards themselves. Since the 1960s they have been experimenting with matching grape varieties to the individual micro climates in their estates, planting patterns which preserve water levels in the soil, and using environmentally friendly cultivation techniques such as the laser-guided plough, which eliminates the need for artificial chemical weed killers. Although much of the harvesting is still done by hand, mechanical harvesting (*see* picture) not only saves time and money but also allows the fruit to be collected cool during the night and early morning, which further enhances quality. The trailers and tractors which transport the harvested grapes are

Source: Miguel Torres (SA)

Mechanical harvesting

→

Source: Miguel Torres (SA)

Fermenting towers

unloaded into reception hoppers where precision-controlled systems, coordinated by computer electronics, enable immediate assessment of the quality and ripeness of grapes. The wines ferment in visually striking stainless steel towers (*see* picture). All these vats are equipped with cooling systems to ferment the grape juice at a controlled temperature, thus preserving its natural aromas. Torres' cellars, where the red wines are aged, extend through 2 km of cool, dark, underground galleries that house more than 11,000 oak barrels. The use of new oak barrels for ageing the finest wines requires substantial investment, but it is an essential factor in obtaining the highest quality. The wine is then bottled in the company's on-site modern bottling plant, after which it is bottle-aged in the company's headquarters at nearby Vilafranca.

Questions

1 What constitutes quality for Torres's products?
2 Chart the various stages in wine making and identify what influences quality at each stage.
3 What do you think Torres does, or can do, to pursue environmentally friendly production?

Step 4 – Control quality against those standards

After setting up appropriate standards the operation will then need to check that the products or services conform to those standards. There may well be times when products or services do not conform to those standards. Chapter 19 deals with the question of what operations can do when things do go wrong. Here we concern ourselves with how operations can try to ensure that it does things right, first time, every time. As far as operations managers are concerned, this involves three decisions:

1 Where in the operation should they check that it is conforming to standards?
2 Should they check every product or service or take a sample?
3 How should the checks be performed?

Where should the checks take place?

The key task for operations managers is to identify the critical control points at which the service, products or processes need to be checked to ensure that the product or services will conform to specification. There are three main places where checks may be carried out: at the start of the process, during the process and after the process.

At *the start of the process* the incoming transformed resources could be inspected to make sure that they are to the correct specification. For example, a car manufacturer may wish to check that the car headlights which are supplied to its production line are of the right specification. An airline might check that incoming food is satisfactory. A nightclub may wish to check that its incoming guests are dressed appropriately. A university will wish to screen applicants to try to ensure that they have a high chance of getting through the programme.

During the process checks may take place at any stage, or indeed all stages, but there are a number of particularly critical points in the process where inspection might be important:

- before a particularly costly part of the process;
- before a series of processes during which checking might be difficult;

- immediately after part of the process with a high defective rate or a fail point;
- before a part of the process that might conceal previous defects or problems;
- before a 'point of no return', after which rectification and recovery might be impossible;
- before potential damage or distress might be caused;
- before a change in functional responsibility.

Checks may also take place *after the process* itself to ensure that the product or service conforms to its specification or that customers are satisfied with the service they have received.

Check every product and service or take a sample?

Quality sampling
The practice of inspecting only a sample of products or services produced rather than every single one.

Having decided the points at which the goods or services will be checked, the next decision is how many of the products or services to **sample**. While it might seem ideal to check every single product being produced or every service being delivered, there are many good reasons why this might not be sensible:

- It might be dangerous to inspect the whole item or every constituent part. A doctor, for example, checks just a small sample of blood rather than taking all of a patient's blood because this would be life-threatening. The characteristics of this sample are taken to represent those of the rest of the patient's blood.
- The checking of every single product or every customer might destroy the product or interfere with the service. It would be inappropriate for a light bulb manufacturer to check the length of life of every single light bulb leaving the factory, as this would entail the destructive testing of each bulb. Likewise, it would not be appropriate for a head waiter to check whether his or her customers are enjoying the meal or having a good time every 30 seconds.
- Checking every product or service can be both time-consuming and costly. For example, it just might not be feasible to check every single item from a high-volume plastic moulding machine or to check the feelings of every single bus commuter in a major city every day.

The use of 100 per cent checking, moreover, does not guarantee that all defects or problems will be identified, for a number of reasons.

- Making the checks may be inherently difficult. For example, although a doctor may undertake all the correct testing procedures to check for a particular disease, he or she may not necessarily be certain to diagnose it.
- Staff may become fatigued over a period of time when inspecting repetitive items where it is easy to make mistakes. (For example, try counting the number of 'e's on this page. Count them again and see whether you get the same score!)

Source: RHM Ltd.

Not every loaf is sampled in this process, but regular checks are made to ensure that the products are within their specification limits

Short case **Security scanning**

Humans are not good at inspection, especially over extended periods. When inspection can be a matter of life and death, as in airport security, they need all the help from technology they can get. Although scanners and metal detectors are used at all the world's major airports, the technology on which they are based is getting much more sophisticated. For example, the technology company QinetiQ (pronounced kinetic) has developed an advanced imaging system that can detect weapons and explosives concealed under a person's clothing or in their baggage. Its 'multi-threat' airport security portal provides moving image scanning and could revolutionize transport and border security. What's more, because it operates in real time it could reduce queues at security scanners in airports and other public places.

The portal uses 'Millimetre Wave' technology that has its origins in a QinetiQ research programme that helps pilots to see through fog and cloud. '*We've actually come up with dozens of potential applications, from guiding airliners to their boarding gate in zero visibility to spotting people carrying concealed weapons going into football grounds or trying to conceal themselves in vehicles*,' says Jeremy Attree, Director of Sales for QinetiQ's Sensors and Electronics Division. '*The device works by detecting naturally occurring radiation as it reflects off different objects. Metal objects completely reflect naturally occurring radiation. Other plastic and ceramic weapons as well as explosives hidden under clothing or in baggage also appear on the scanner's display as distinct illuminated shapes. The human body reflects 30 per cent of the naturally occurring radiation around it and this enables the scanner to detect a person's actual body shape beneath their clothes. So, attempts to conceal items under clothing can be foiled by the device.*'

The system has a number of practical benefits. In contrast to active detection systems incorporating low-level radiation emissions (e.g. X-ray scanners), QinetiQ's airport security camera is a passive detection system and therefore does not expose individuals to harmful radiation. Also, because the system works in real-time and provides an accurate moving image, vehicles or people can be scanned without being stopped, thus greatly reducing transit time through security checkpoints. At one trial of the new technology, passengers were asked to be screened and then underwent a conventional 'pat-down' search, so that normal security procedures were also observed. Almost all participants preferred the far less invasive Millimetre Wave option. '*In the aftermath of September 11, airline passengers need additional reassurances that every effort is being made to ensure their safety. Because the system provides an accurate moving image, without compromising effective screening, transit time through security checkpoints can be significantly improved, without impacting on performance*,' explained Kevin Murphy, Product Manager for the Millimetre Wave Imager.

Source: © QinetiQ

QinetQ's 'Millimetre Wave' technology reveals that this man is carrying a knife

Questions

1 What do you think are the advantages and disadvantages of both human inspection and technology-assisted inspection in assisting airport security processes?

- Quality measures may be unclear and staff making the checks may not know precisely what to look for. For example, how can an interviewer, making offers for university places, really tell whether a student will actually have the right attitude to group work or will be diligent?
- Wrong information may be given. For example, although all the customers in a restaurant may tell the head waiter, when asked, that 'everything is all right', they may actually have serious reservations about the food or their treatment.

Type I and type II errors

Using a sample to make a decision about the quality of products or services, although requiring less time than 100 per cent checking, does have its own inherent problems. Like any decision activity, we may get the decision wrong. Take the example of a pedestrian waiting to cross a street. He or she has two main decisions: whether to continue waiting or to cross. If there is a satisfactory break in the traffic and the pedestrian crosses then a correct decision has been made. Similarly, if that person continues to wait because the traffic is too dense then he or she has again made a correct decision. There are two types of incorrect decisions or errors, however. One incorrect decision would be if he or she decides to cross when there is not an adequate break in the traffic, resulting in an accident – this is referred to as a type I error. Another incorrect decision would occur if he or she decides not to cross even though there is an adequate gap in the traffic – this is called a type II error. In crossing the road, therefore, there are four outcomes, which are summarized in Table 17.4.

Type I errors are those which occur when a decision was made to do something and the situation did not warrant it. Type II errors are those which occur when nothing was done, yet a decision to do something should have been taken as the situation did indeed warrant it. For example, if a school's inspector checks the work of a sample of 20 out of 1000 pupils and all 20 of the pupils in the sample have failed, the inspector might draw the conclusion that all the pupils have failed. In fact, the sample just happened to contain 20 out of the 50 students who had failed the course. The inspector, by assuming a high fail rate, would be making a type I error. Alternatively, if the inspector checked 20 pieces of work all of which were of a high standard, he or she might conclude that all the pupils' work was good despite having been given, or having chosen, the only pieces of good work in the whole school. This would be a type II error. Although these situations are not likely, they are possible. Therefore any sampling procedure has to be aware of these risks (see the short case on 'Surgical statistics').

How should the checks be performed?

In practice most operations will use some form of sampling to check the quality of their products or services. The decision then is what kind of sample procedure to adopt. There are two different methods in common use for checking the quality of a sample product or service so as to make inferences about all the output from an operation. Both methods take into account the statistical risks involved in sampling. The first, and by far the best known, is the procedure called **statistical process control (SPC)**. SPC is concerned with sampling the process during the production of the goods or the delivery of service. Based on this sample, decisions are made as to whether the process is 'in control', that is, operating as it should be. The second method is called **acceptance sampling** and is more concerned with whether to regard an incoming or outgoing batch of materials or customers as acceptable or not. The rest of this chapter is concerned with these two quality planning and control methods.

Statistical process control (SPC)
A technique that monitors processes as they produce products or services and attempts to distinguish between normal or natural variation in process performance and unusual or 'assignable' causes of variation.

Acceptance sampling
A technique of quality sampling that is used to decide whether to accept a whole batch of products (and occasionally services) on the basis of a sample; it is based on the operation's willingness to risk rejecting a 'good' batch and accepting a 'bad' batch.

Table 17.4 Type I and type II errors for a pedestrian crossing the road

	Road conditions	
Decision	*Unsafe*	*Safe*
Cross	Type I error	Correct decision
Wait	Correct decision	Type II error

Short case **Surgical statistics**[11]

Understanding the nature of type I and type II errors is an essential part of any surgeon's quality planning. Take the well-known appendectomy operation, for example. This is the removal of the appendix when it becomes infected or inflamed. Removal is necessary because of the risk of the appendix bursting and causing peritonitis, a potentially fatal poisoning of the blood. The surgical procedure itself is a relatively simple operation with expected good results but there is always a small risk associated with any invasive surgery needing a general anaesthetic. In addition, like any surgical procedure, it is expensive. The cost of the USA's approximately quarter-of-a-million appendectomies averages out to around $4500 per operation. Unfortunately, appendicitis is difficult to diagnose accurately. Using standard X-ray procedures a definite diagnosis can be obtained only about 10 per cent of the time. But now a new technique, developed in the Massachusetts General Hospital in Boston, claims to be able to identify 100 per cent of true appendicitis cases before surgery is carried out. The new technique (Focused Appendix Computed Tomography) uses spiral X-ray images together with a special dye. It scans only the relevant part of the body, so exposure to radiation is not as major an issue as with conventional X-ray techniques.

Source: Corbis/Robert Llewelly

The technique can also help in providing an alternative diagnosis when an appendectomy is not needed. Most significantly, the potential cost savings are very great. The test itself costs less than $250 which means that one single avoided surgery pays for around 20 tests.

Questions

1 How does this new test change the likelihood of type I and type II errors?

2 Why is this important?

Statistical process control (SPC)

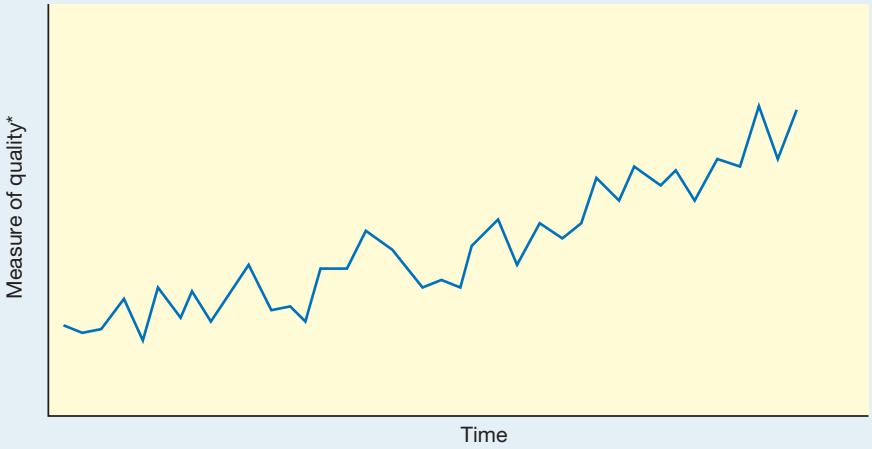
Statistical process control is concerned with checking a product or service during its creation. If there is reason to believe that there is a problem with the process, it can be stopped (where this is possible and appropriate) and the problem can be identified and rectified. For example, an international airport may regularly ask a sample of customers whether the cleanliness of its restaurants is satisfactory. If an unacceptable number of customers in one sample is found to be unhappy, airport managers may have to consider improving the procedures in place for cleaning tables. Similarly, a car manufacturer periodically will check whether a sample of door panels conforms to its standards so as to know whether the machinery which produces them is performing correctly. Again, if a sample suggests that there may be problems, the machines may have to be stopped and the process checked.

Control charts

Control charts
The charts used within statistical process control to record process performance.

The significant value of SPC, however, is not just to make checks of a single sample but to monitor the results of many samples over a period of time. It does this by using **control charts**, to see whether the process looks as though it is performing as it should, or alternatively whether it is going out of control. If the process does seem to be going out of control, steps can be taken *before* there is a problem.

Most operations chart their quality performance in some way. Figure 17.6, or something like it, could be found in almost any operation. The chart could, for example, represent the percentage of customers in a sample of 1000 who, each month, were dissatisfied with the



*e.g. A *variable* such as average impact resistance of samples of door panels
or
An *attribute* such as percentage of customer sample who are dissatisfied with cleanliness

Figure 17.6 Charting trends in quality measures

restaurant's cleanliness. While the degree of dissatisfaction may be acceptably small, management should be concerned that it has been steadily increasing over time and may wish to investigate why this is so. In this case, the control chart is plotting an attribute measure of quality (satisfied or not).

Alternatively, the chart could just as easily represent the average impact resistance of samples of door panels selected each week (a variable measure). Again there is evidence of a clear trend. This time, though, the quality measure seems to be getting better. Yet this chart could be equally as disturbing to the car manufacturers as the airport's survey results were to the airport management. If the impact resistance is moving above the 'necessary' level, it could indicate that too much material is being used in the process. Certainly, if the reasons for the upward trend are unknown, the management of the operation should want to investigate the causes.

Looking for trends is an important use of control charts. If the trend suggests the process is getting steadily worse, it will be worth investigating the process. If the trend is steadily improving, it may still be worthy of investigation to try to identify what is happening that is making the process better. This information might then be shared with other parts of the organization, or the process might be stopped as the cause could be adding unnecessary expense to the operation.

Variation in process quality

Common causes

The processes charted in Figure 17.6 showed an upwards trend. The trend was neither steady nor smooth, however. It varied, sometimes up, sometimes down. All processes vary to some extent. No machine will give precisely the same result each time it is used. All materials vary a little. The staff in the operation differ marginally in the way they perform each time they perform a task. Even the environment in which the processing takes place will vary. Given this, it is not surprising that the measure of quality (whether attribute or variable) will also vary. Variations which derive from these *common causes* can never be entirely eliminated (although they can be reduced).

For example, if a machine is filling boxes with rice, it will not place *exactly* the same weight of rice in every box it fills; there will be some variation around an average weight.

When the filling machine is in a stable condition (that is, no exceptional factors are influencing its behaviour), each box could be weighed and a histogram of the weights could be built up. Figure 17.7 shows how the histogram might develop. The first boxes weighed could lie anywhere within the natural variation of the process but are more likely to be close to the average weight (see Figure 17.7a). As more boxes are weighed they clearly show the tendency to be close to the process average (see Figure 17.7b and c). After many boxes have been weighed they form a smoother distribution (Figure 17.7d) which can be drawn as a histogram (Figure 17.7e) which will approximate to the underlying process variation distribution (Figure 17.7f).

Usually this type of variation can be described by a normal distribution with 99.7 per cent of the variation lying within ± 3 standard deviations. In this case the weight of rice in the boxes is described by a distribution with a mean of 206 grams and a standard deviation of 2 grams. The obvious question for any operations manager would be: 'Is this variation in the process performance acceptable?' The answer will depend on the acceptable range of weights which can be tolerated by the operation. This range is called the **specification range**. If the weight of rice in the box is too small then the organization might infringe labelling regulations; if it is too large, the organization is 'giving away' too much of its product for free.

Specification range

Process capability

Process capability
An arithmetic measure of the acceptability of the variation of a process.

Process capability is a measure of the acceptability of the variation of the process. The simplest measure of capability (C_p) is given by the ratio of the specification range to the 'natural' variation of the process (i.e. ± 3 standard deviations):

$$C_p = \frac{\text{UTL} - \text{LTL}}{6s}$$

where UTL = the upper tolerance limit
LTL = the lower tolerance limit
s = the standard deviation of the process variability.

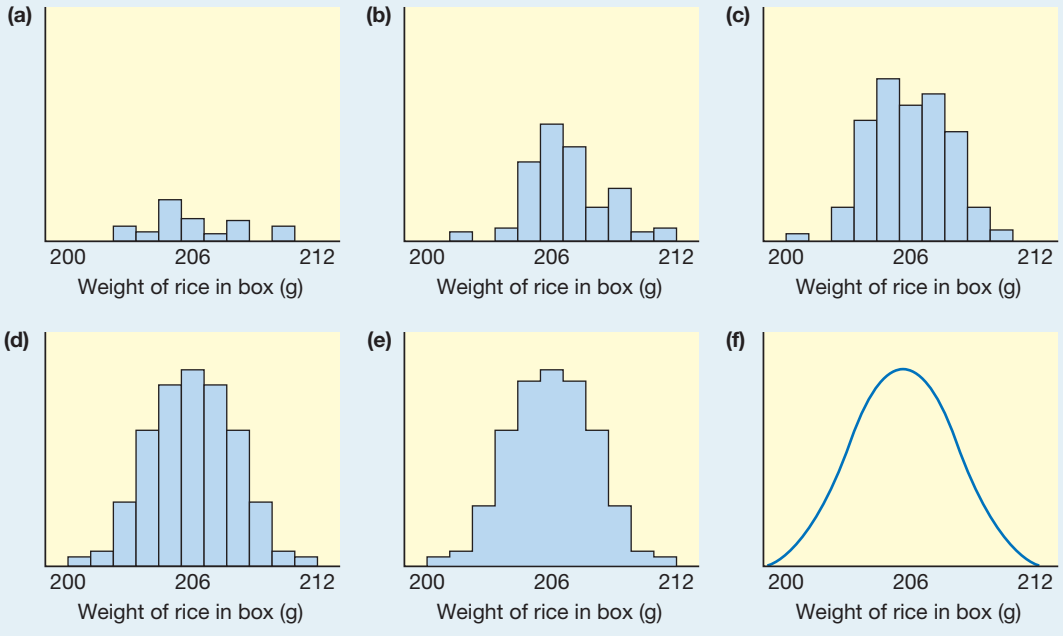


Figure 17.7 **The natural variation in the filling process can be described by a normal distribution**

Generally, if the C_p of a process is greater than 1, it is taken to indicate that the process is 'capable', and a C_p of less than 1 indicates that the process is not 'capable', assuming that the distribution is normal (see Figure 17.8 a, b and c).

The simple C_p measure assumes that the average of the process variation is at the mid-point of the specification range. Often the process average is offset from the specification range, however (see Figure 17.18d). In such cases, *one-sided* capability indices are required to understand the capability of the process:

$$\text{Upper one-sided index } C_{pu} = \frac{\text{UTL} - X}{3s}$$

$$\text{Lower one-sided index } C_{pl} = \frac{X - \text{LTL}}{3s}$$

where X = the process average.

Sometimes only the lower of the two one-sided indices for a process is used to indicate its capability (C_{pk}):

$$C_{pk} = \min(C_{pu}, C_{pl})$$

Assignable causes of variation

Not all variation in processes is the result of common causes. There may be something wrong with the process which is assignable to a particular and preventable cause. Machinery may have worn or been set up badly. An untrained member of staff may not be following the prescribed procedure for the process. The causes of such variation are called *assignable*

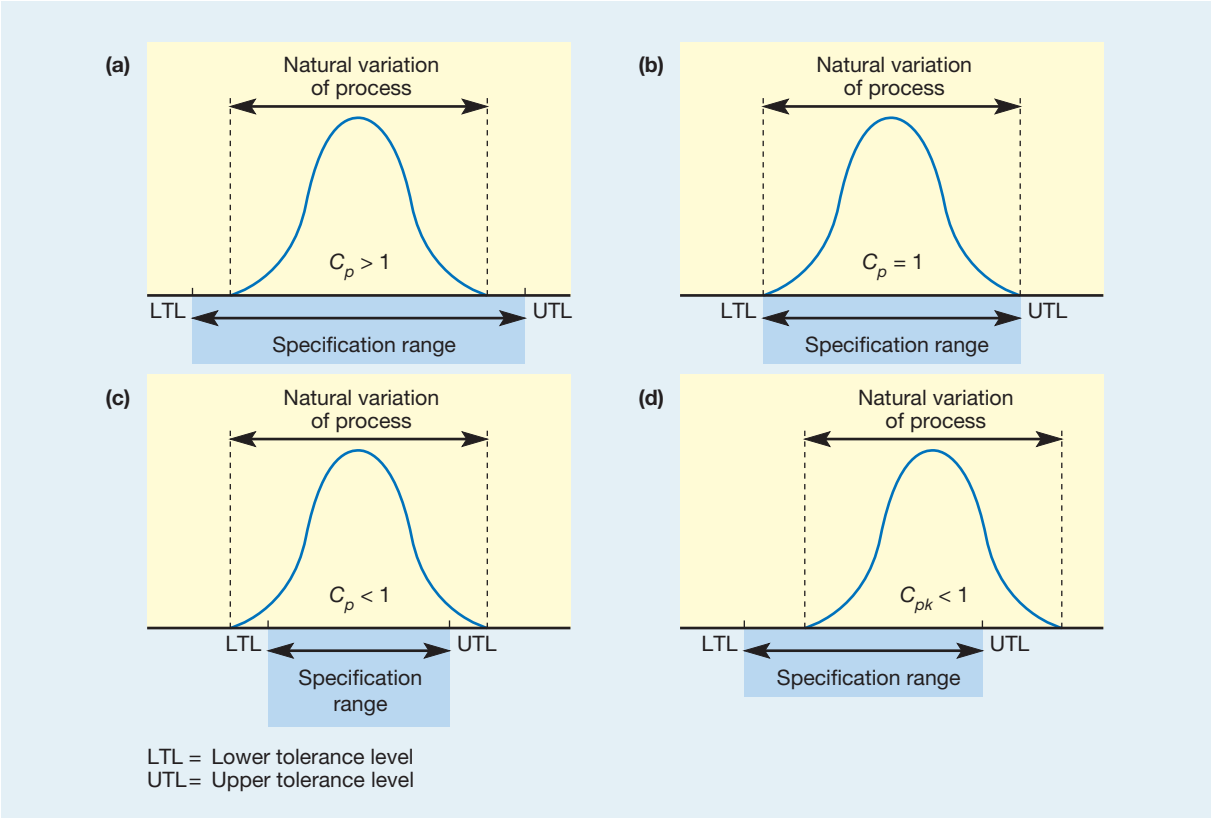


Figure 17.8 **Process capability compares the natural variation of the process with the specification range which is required**

Worked example

In the case of the process filling boxes of rice, described previously, process capability can be calculated as follows:

$$\begin{aligned}
\text{Specification range} &= 214 - 198 = 16 \text{ g} \\
\text{Natural variation of process} &= 6 \text{ standard deviation} \\
&= 6 \times 2 = 12 \text{ g} \\
C_p &= \text{process capability} \\
&= \frac{\text{UTL} - \text{LTL}}{6s} \\
&= \frac{214 - 198}{6 \times 2} = \frac{16}{12} \\
&= 1.333
\end{aligned}$$

If the natural variation of the filling process changed to have a process average of 210 grams but the standard deviation of the process remained at 2 grams:

$$C_{pu} = \frac{214 - 210}{3 \times 2} = \frac{4}{6} = 0.666$$

$$C_{pl} = \frac{210 - 198}{3 \times 2} = \frac{12}{6} = 2.0$$

$$C_{pk} = \min(0.666, 2.0)$$

$$= 0.666$$

causes. The question for operations management is whether the results from any particular sample, when plotted on the control chart, simply represent the variation due to common causes or due to some specific and correctable, *assignable cause*. Figure 17.9 shows the control chart for the average impact resistance of samples of door panels taken over time. Like any process the results vary, but the last three points seem to be lower than usual. The ques-

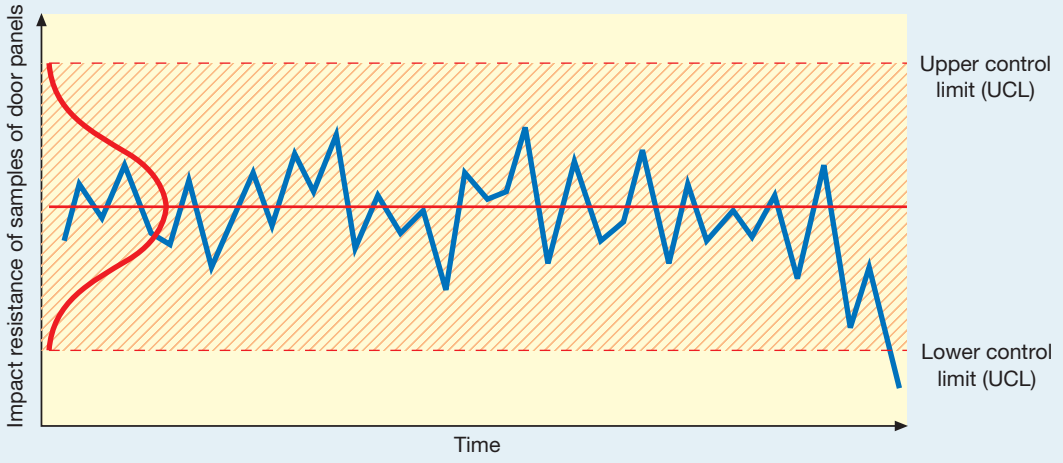


Figure 17.9 Control chart for the impact resistance of door panels, together with control limits at ± 3 standard deviations

tion is whether this is natural variation or the symptom of some more serious cause. Is the variation the result of common causes or does it indicate assignable causes in the process?

Control limits
The lines on a control chart used in statistical process control that indicate the extent of natural or common-cause variations; any points lying outside these control limits are deemed to indicate that the process is likely to be out of control.

To help make this decision, **control limits** can be added to the control chart (the red dotted lines) which indicates the expected extent of 'common-cause' variation. If any points lie outside these control limits (the shaded zone) then the process can be deemed out of control in the sense that variation is likely to be due to assignable causes. These control limits could be set intuitively by examining past variation during a period when the process was thought to be free of any variation which could be due to assignable causes. For example, if the monthly survey of airport customers usually includes between 3 and 4 per cent of customers who are dissatisfied with the cleanliness of the airport's restaurants, an upper control limit could be set at 4 per cent complaints per month. If the actual proportion is ever 4 per cent or more then the situation is investigated.

Control limits can be set in a more statistically revealing manner, however, based on the probability that the mean of a particular sample will differ by more than a set amount from the mean of the population from which it is taken. For example, if the process which tests door panels had been measured to determine the normal distribution which represents its common-cause variation, then control limits can be based on this distribution. Figure 17.9 also shows how control limits can be added; here put at ±3 standard deviations (of the population of sample means) away from the mean of sample averages. It shows that the probability of the final point on the chart being influenced by an assignable cause is very high indeed. When the process is exhibiting behaviour which is outside its normal 'common-cause' range, it is said to be 'out of control'.

GO TO WEB! 17E

From this evidence alone, however, we cannot be absolutely certain that the process is out of control. There is a small but finite chance that the (seemingly out of limits) point is just one of the rare but natural results at the tail of the distribution which describes perfectly normal behaviour. Stopping the process under these circumstances would represent a type I error because the process is actually in control. Alternatively, ignoring a result which in reality is due to an assignable cause is a type II error (see Table 17.5).

Control limits are usually set at three standard deviations either side of the population mean. This would mean that there is only a 0.3 per cent chance of any sample mean falling outside these limits by chance causes (that is, a chance of a type I error of 0.3 per cent). The control limits may be set at any distance from the population mean, but the closer the limits are to the population mean, the higher the likelihood of investigating and trying to rectify a process which is actually problem-free. If the control limits are set at two standard devia-

Critical commentary

This approach to process control was how its statistically obsessed originators first described it more than half a century ago. Then, the key issue was only to decide whether a process was 'in control' or not. Now, we expect more from such techniques. We expect them to reflect common sense as well as statistical elegance and we expect them to promote continuous operations improvement. This is why two particular criticisms have been levelled at the traditional approach to SPC (in fact, both criticisms are related).

The first is that SPC seems to assume that any values of process performance which lie within the control limits are equally acceptable, while any values outside the limits are not. However, surely a value close to the process average or 'target' value will be more acceptable than one only just within the control limits. For example, a service engineer arriving only one minute late is a far better 'performance' than one arriving 59 minutes late, even if the control limits are 'quoted time ± one hour'. Also, arriving 59 minutes late would be almost as bad as 61 minutes late! Second, trying to keep performance within control limits may indicate that the process is not deteriorating, but it does not help the process to improve. Rather than seeing the control limits of SPC as a fixed characteristic of a process, it would be better to view them as a reflection of how the process is being improved. Therefore we should expect any improving process to have progressively narrowing control limits.

Table 17.5 Type I and type II errors in SPC

	Actual process state	
Decision	*In control*	*Out of control*
Stop process	Type I error	Correct decision
Leave alone	Correct decision	Type II error

tions, the chance of a type I error increases to about 5 per cent. If the limits are set at one standard deviation then the chance of a type I error increases to 32 per cent. When the control limits are placed at ±3 standard deviations away from the mean of the distribution which describes 'normal' variation in the process, they are called the **upper control limit (UCL)** and **lower control limit (LCL)**.

Upper control limit

Lower control limit

The Taguchi loss function

Genichi Taguchi proposed a resolution of both the criticisms of SPC described in the critical commentary box.[12] He suggested that the central issue was the first problem – namely that the consequences of being 'off-target' (that is, deviating from the required process average performance) were inadequately described by simple control limits. Instead, he proposed a **quality loss function (QLF)** – a mathematical function which includes all the costs of poor quality. These include wastage, repair, inspection, service, warranty and generally what he termed 'loss to society' costs. This loss function is expressed as follows:

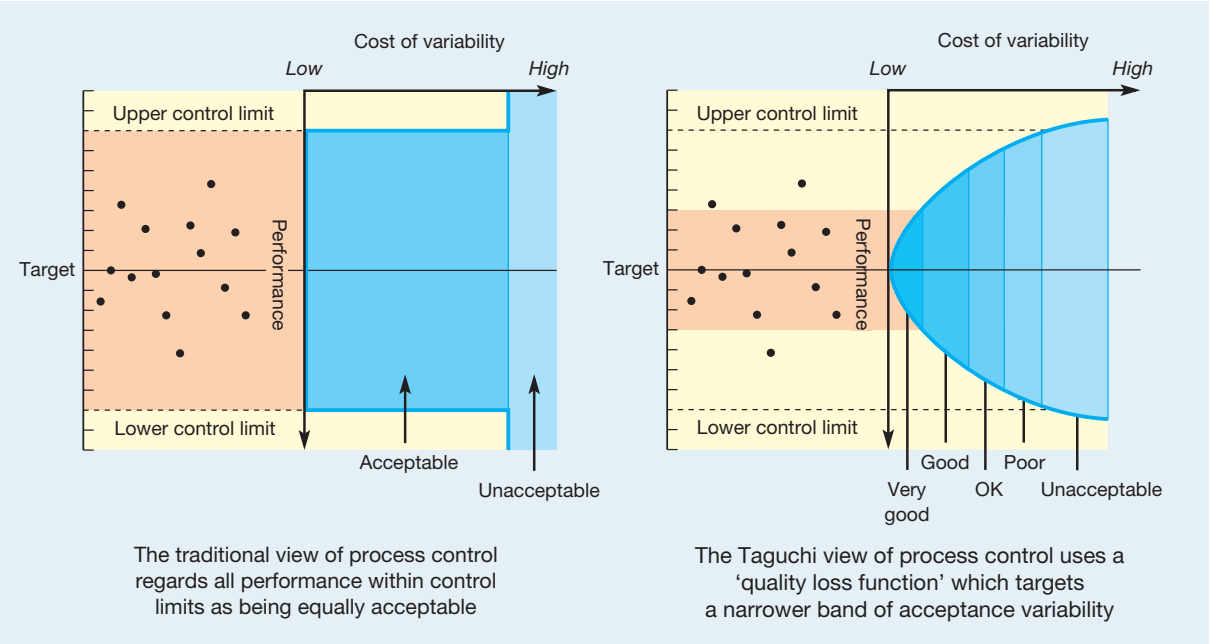
Quality loss function (QLF)
A mathematical function devised by Genichi Taguchi that includes all the costs of deviating from a target performance.

$$L = D^2C$$

where L = total loss to society costs
D = deviation from target performance
C = a constant

Figure 17.10 illustrates the difference between the conventional and Taguchi approaches to interpreting process variability. The more graduated approach of the QLF also answers the second problem raised in the critical commentary box. With losses increasing quadratically as performance deviates from target, there is a natural tendency to progressively reduce process variability. This is sometimes called a **target-oriented quality** philosophy.

Target-oriented quality



The traditional view of process control regards all performance within control limits as being equally acceptable

The Taguchi view of process control uses a 'quality loss function' which targets a narrower band of acceptance variability

Figure 17.10 The conventional and Taguchi views of the cost of variability

Why variability is a bad thing

Although the prime purpose of SPC is to distinguish between common causes of variation and assignable causes of variation, it is increasingly seen as a mechanism for reducing both types of variation. Assignable variation is a signal that something has changed in the process which therefore must be investigated. But normal variation is itself a problem because it masks any changes in process behaviour. Figure 7.11 shows the performance of two processes, both of which are subjected to a change in their process behaviour at the same time. The process on the left has such a wide natural variation that it is not immediately apparent that any change has taken place. Eventually it will become apparent because the likelihood of process performance violating the lower (in this case) control limit has increased, but this may take some time. By contrast, the process on the right has a far narrower band of natural variation. Because of this, the same change in average performance is more easily noticed (both visually and statistically). So, the narrower the natural variation of a process, the more obvious are changes in the behaviour of that process. And the more obvious are process changes, the easier it is to understand how and why the process is behaving in a particular way. Accepting any variation in any process is, to some degree, admitting to ignorance of how that process works.

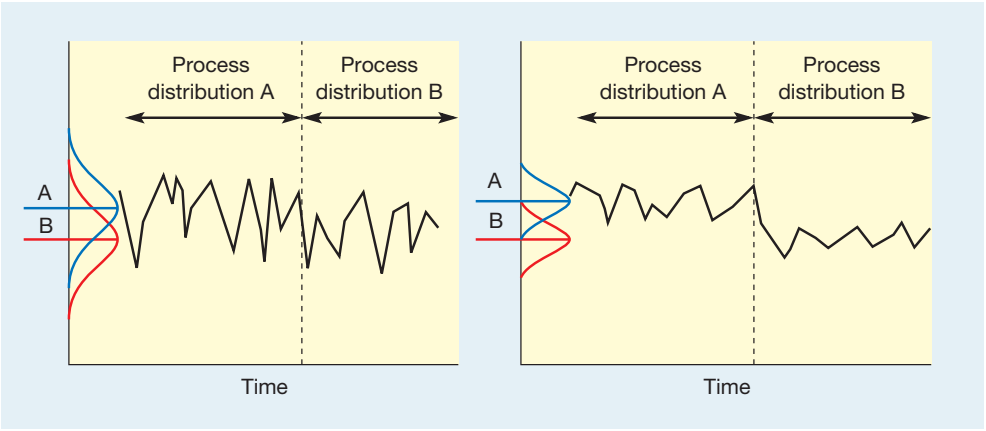


Figure 17.11 **Low process variation allows changes in process performance to be readily detected**

Short case **Process control at Walkers**

Walkers Snack Foods Limited, part of the worldwide Pepsico Company, operates in a highly competitive sector of the fast-moving consumer goods (FMCG) market. With increasingly discriminating customers, it needs the competitive edge of high-quality manufacturing to help it retain customer satisfaction. This means that it must keep close control of all its manufacturing processes, a task which is especially difficult when success of your products means booming sales and therefore continually increasing production volumes. Walkers uses a version of statistical process control, which it calls 'control point management' (CPM), to maintain and improve its quality levels. The control points in the manufacturing process where process variables are measured are all specified for each production line. If any measurements fall outside the control limits, procedures in the form of decision trees help to guide the production technicians in bringing the process back within standard.

Questions

1 What do you think are the characteristics of product quality for Walkers products which influence overall customer satisfaction? (Sample a packet and discuss this with friends!)

2 Why is it important that direct production staff, as opposed to managers or engineers, collect and analyze process data?

3 What purpose do the 'corrective' decision trees serve in controlling the process?

Control charts for attributes

Attributes have only two states – 'right' or 'wrong', for example – so the statistic calculated is the proportion of wrongs (p) in a sample. (This statistic follows a binomial distribution.) Control charts using p are called 'p-charts'.

In calculating the limits, the population mean ($\bar{p}$) – the actual, normal or expected proportion of 'defectives' or wrongs to rights – may not be known. Who knows, for instance, the actual number of city commuters who are dissatisfied with their journey time? In such cases the population mean can be estimated from the average of the proportion of 'defectives' ($\bar{p}$), from m samples each of n items, where m should be at least 30 and n should be at least 100:

$$\bar{p} = \frac{p^1 + p^2 + p^3 \ldots p^n}{m}$$

One standard deviation can then be estimated from:

$$\sqrt{\frac{\bar{p}\,(1-\bar{p}\,)}{n}}$$

The upper and lower control limits can then be set as:

UCL = $\bar{p}$ + 3 standard deviations
LCL = $\bar{p}$ – 3 standard deviations

Of course, the LCL cannot be negative, so when it is calculated to be so it should be rounded up to zero.

Worked example

A credit card company deals with many hundreds of thousands of transactions every week. One of its measures of the quality of service it gives its customers is the dependability with which it mails customers' monthly accounts. The quality standard it sets itself is that accounts should be mailed within two days of the 'nominal post date' which is specified to the customer. Every week the company samples 1000 customer accounts and records the percentage which was not mailed within the standard time. When the process is working normally, only 2 per cent of accounts are mailed outside the specified period, that is, 2 per cent are 'defective'.

Control limits for the process can be calculated as follows:

Mean proportion defective, $\bar{p} = 0.02$

Sample size $n = 1000$

$$\text{Standard deviation } s = \sqrt{\frac{\bar{p}\,(1-\bar{p}\,)}{n}}$$

$$= \sqrt{\frac{0.02(0.98)}{1000}}$$

$$= 0.0044$$

With the control limits at $\bar{p} \pm 3s$:

Upper control limit (UCL) = 0.02 + 3(0.0044) = 0.0332
= 3.32%

and lower control limit (LCL) = 0.02 – 3(0.0044) = 0.0068
= 0.68%

Figure 17.12 shows the company's control chart for this measure of quality over the last few weeks, together with the calculated control limits. It also shows that the process is in control. Sometimes it is more convenient to plot the actual number of defects (c) rather than the proportion (or percentage) of defectives, on what is known as a c-chart. This is very similar to the p-chart but the sample size must be constant and the process mean and control limits are calculated using the following formulae:

$$\text{Process mean } \bar{c} = \frac{c_1 + c_2 + c_3 \ldots c_m}{m}$$

$$\text{Control limits} = c \pm 3\sqrt{c}$$

where c = number of defects
m = number of samples

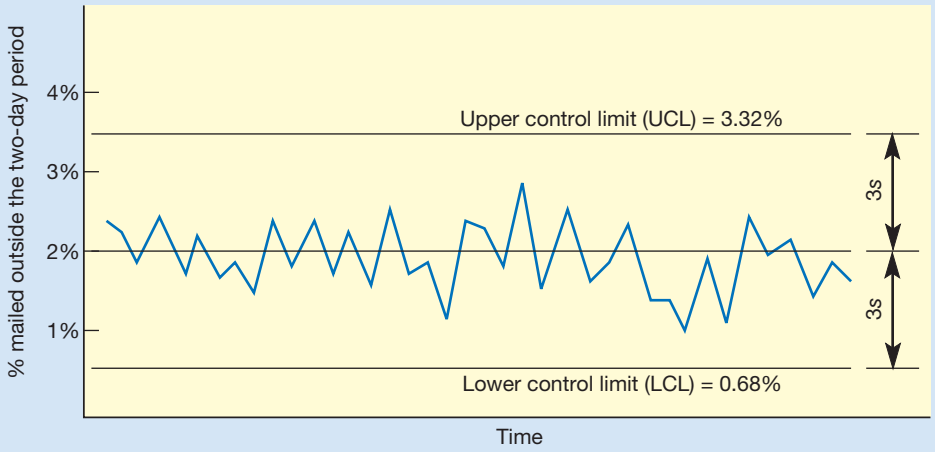


Figure 17.12 Control chart for the percentage of customer accounts which are mailed outside their two-day period

Control chart for variables

The most commonly used type of control chart employed to control variables is the $\bar{X}$–R *chart*. In fact, this is really two charts in one. One chart is used to control the sample average or mean ($\bar{X}$). The other is used to control the variation within the sample by measuring the range (R). The range is used because it is simpler to calculate than the standard deviation of the sample.

The means ($\bar{X}$) chart can pick up changes in the average output from the process being charted. Changes in the means chart would suggest that the process is drifting generally away from its supposed process average, although the variability inherent in the process may not have changed (see Figure 17.13).

The range (R) chart plots the range of each sample, that is the difference between the largest and the smallest measurement in the samples. Monitoring sample range gives an indication of whether the variability of the process is changing, even when the process average remains constant (see Figure 17.13).

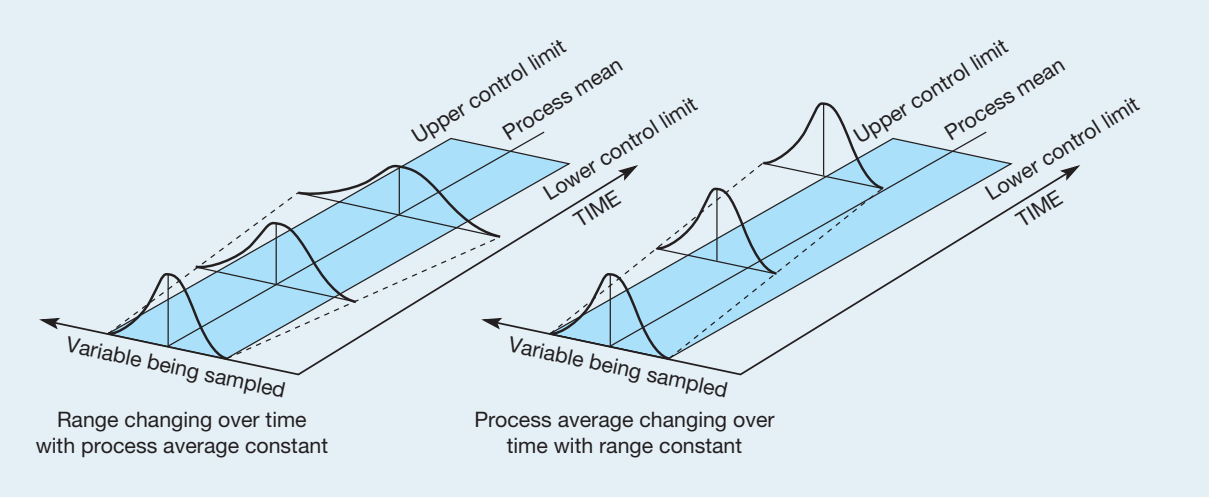


Figure 17.13 **The process mean or the process range (or both) can change over time**

Control limits for variables control chart

As with attributes control charts, a statistical description of how the process operates under normal conditions (when there are no assignable causes) can be used to calculate control limits. The first task in calculating the control limits is to estimate the grand average or population mean ($\bar{\bar{X}}$) and average range ($\bar{R}$) using m samples each of sample size n.

The population mean is estimated from the average of a large number (m) of sample means:

$$\bar{\bar{X}} = \frac{\bar{X}_1 + \bar{X}_2 + \ldots \bar{X}_m}{m}$$

The average range is estimated from the ranges of the large number of samples:

$$\bar{R} = \frac{R_1 + R_2 + \ldots R_m}{m}$$

The control limits for the sample means chart are:

$$\text{Upper control limit (UCL)} = \bar{\bar{X}} + A_2\bar{R}$$
$$\text{Lower control limit (LCL)} = \bar{\bar{X}} - A_2\bar{R}$$

The control limits for the range charts are:

$$\text{Upper control limit (UCL)} = D_4\bar{R}$$
$$\text{Lower control limit (LCL)} = D_3\bar{R}$$

The factors A_2, D_3 and D_4 vary with sample size and are shown in Table 17.6.

The LCL for the means chart may be negative (for example, temperature or profit may be less than zero) but it may not be negative for a range chart (or the smallest measurement in the sample would be larger than the largest). If the calculation indicates a negative LCL for a range chart then the LCL should be set to zero.

Table 17.6 Factors for the calculation of control limits

Sample size n	A_2	D_3	D_4
2	1.880	0	3.267
3	1.023	0	2.575
4	0.729	0	2.282
5	0.577	0	2.115
6	0.483	0	2.004
7	0.419	0.076	1.924
8	0.373	0.136	1.864
9	0.337	0.184	1.816
10	0.308	0.223	1.777
12	0.266	0.284	1.716
14	0.235	0.329	1.671
16	0.212	0.364	1.636
18	0.194	0.392	1.608
20	0.180	0.414	1.586
22	0.167	0.434	1.566
24	0.157	0.452	1.548

Worked example

GAM (Groupe As Maquillage) is a contract cosmetics company, based in France but with plants around Europe, which manufactures and packs cosmetics and perfumes for other companies. One of its plants, in Ireland, operates a filling line which automatically fills plastic bottles with skin cream and seals the bottles with a screw-top cap. The tightness with which the screw-top cap is fixed is an important part of the quality of the filling line process. If the cap is screwed on too tightly, there is a danger that it will crack; if screwed on too loosely it might come loose when packed. Either outcome could cause leakage of the product during its journey between the factory and the customer. The Irish plant had received some complaints of product leakage which it suspected was caused by inconsistent fixing of the screw-top caps on its filling line. The 'tightness' of the screw tops could be measured by a simple test device which recorded the amount of turning force (torque) that was required to unfasten the tops. The company decided to take samples of the bottles coming out of the filling-line process, test them for their unfastening torque and plot the results on a control chart. Several samples of four bottles were taken during a period when the process was regarded as being in control. The following data were calculated from this exercise:

The grand average of all samples $\overline{\overline{X}} = 812$ g/cm^3

The average range of the sample $\overline{R} = 6$ g/cm^3

Control limits for the means ($\overline{X}$) chart were calculated as follows:

$$\begin{aligned} \text{UCL} &= \overline{\overline{X}} + A_2\overline{R} \\ &= 812 + (A_2 \times 6) \end{aligned}$$

From Table 17.6, we know, for a sample size of four, $A_2 = 0.729$. Thus:

$$\begin{aligned} \text{UCL} &= 812 + (0.729 \times 6) \\ &= 816.37 \end{aligned}$$

$$\begin{aligned} \text{LCL} &= \overline{\overline{X}} - (A_2\overline{R}) \\ &= 812 - (0.729 \times 6) \\ &= 807.63 \end{aligned}$$

Control limits for the range chart (R) were calculated as follows:

$$\begin{aligned} \text{UCL} &= D_4 \times \bar{R} \\ &= 2.282 \times 6 \\ &= 13.69 \end{aligned}$$

$$\begin{aligned} \text{LCL} &= D_3 \bar{R} \\ &= 0 \times 6 \\ &= 0 \end{aligned}$$

After calculating these averages and limits for the control chart, the company regularly took samples of four bottles during production, recorded the measurements and plotted them as shown in Figure 17.14. The control chart revealed that only with difficulty could the process average be kept in control. Occasional operator interventions were required. Also the process range was moving towards (and once breaking) the upper control limit. The process seemed to be becoming more variable. After investigation it was discovered that, because of faulty maintenance of the line, skin cream was occasionally contaminating the torque head (the part of the line which fitted the cap). This resulted in erratic tightening of the caps.

GAM *Quality Counts*

PART NO. 73/10328A			CHART
PROCESS Torque Cap #3	PRODUCT Ski Ian 707	TOLERANCE 807 - 817	
MACHINE M732	OPERATOR CH	UNITS g / cm³	

Date		2/6																					
Time		6:00	6:30	7:00	7:30	8:00	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30		
Sample measurements	1	811	813	811	817	812	813	813	817	808	805	813	812	811	808	812	808	808	804	804	813		
	2	812	814	813	814	813	814	815	813	813	808	812	805	813	806	813	809	818	813	812	819		
	3	813	815	815	812	812	814	813	814	811	806	816	806	811	803	808	813	819	812	812	813		
	4	812	814	813	813	811	815	811	815	813	807	809	808	809	805	804	814	821	808	820	807		
	5																						
Sum		3248	3256	3252	3248	3248	3256	3252	3259	3245	3225	3250	3231	3244	3222	3237	3244	3266	3237	3248	3252		
Mean, X		812	814	813	814	812	814	813	815	811	807	813	808	811	806	809	811	817	809	812	813		
Range, R		2	2	4	5	2	2	4	4	5	3	7	7	4	5	9	6	13	9	16	12		

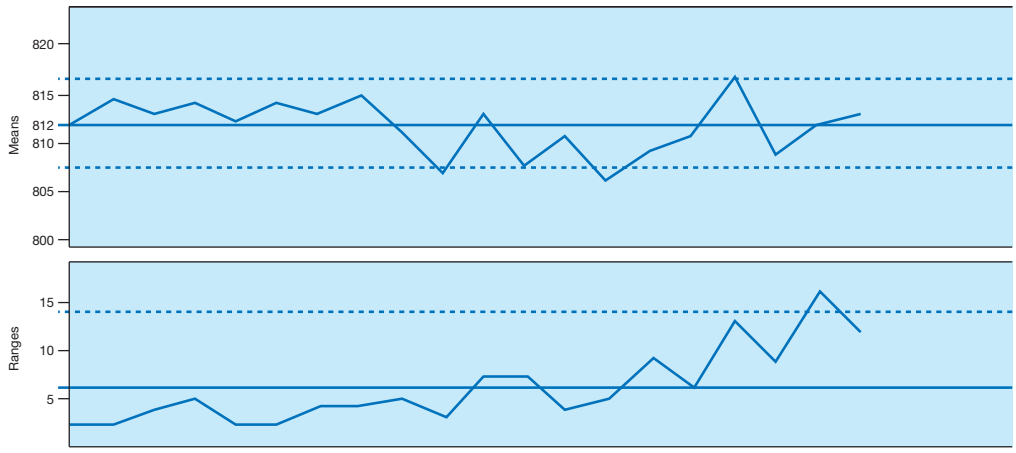


Figure 17.14 **The completed control form for GAM's torque machine showing the mean ($\bar{X}$) and range ($\bar{R}$) charts**

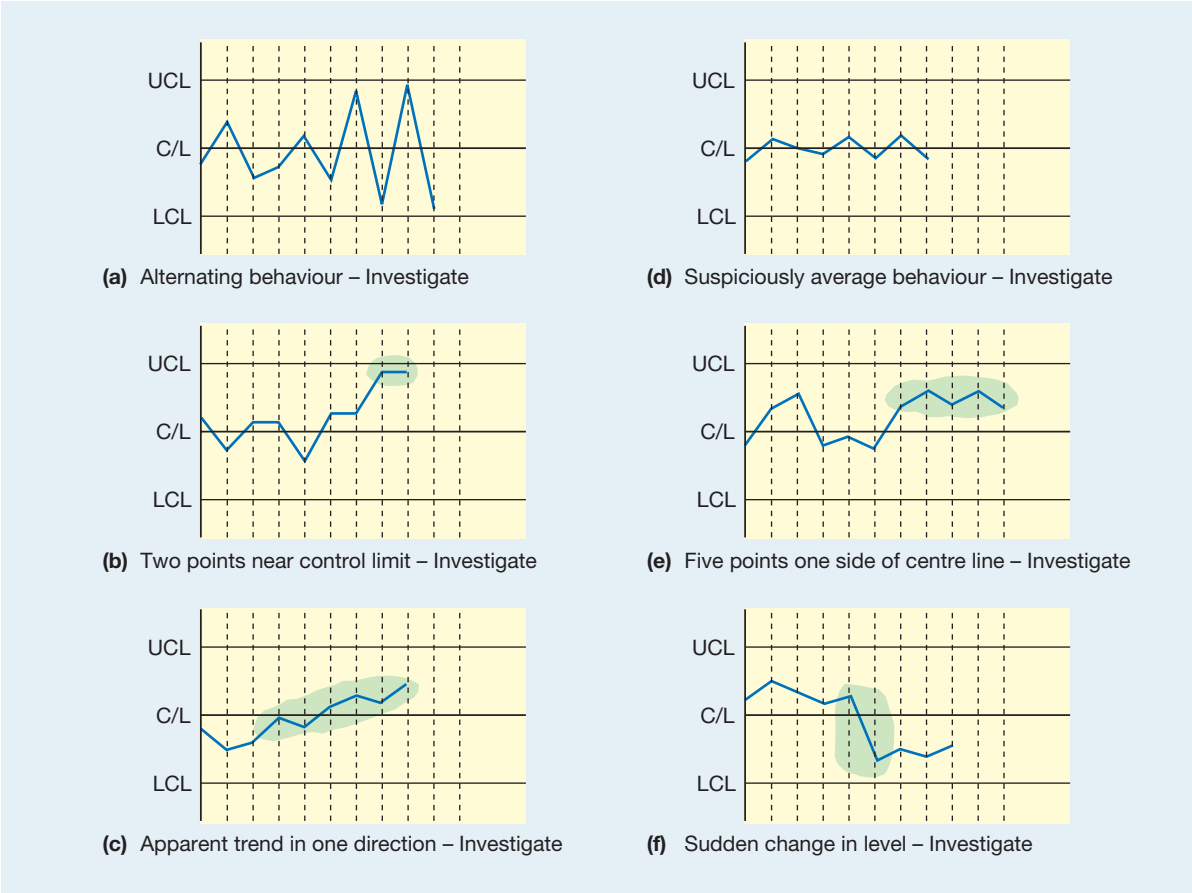


Figure 17.15 **In addition to points falling outside the control limits, other unlikely sequences of points should be investigated**

Interpreting control charts

GO TO WEB! 17F

Plots on a control chart which fall outside control limits are an obvious reason for believing that the process might be out of control and therefore for investigating the process. This is not the only clue which could be revealed by a control chart, however. Figure 17.15 shows some other patterns which could be interpreted as behaviour sufficiently unusual to warrant investigation.

Process control, learning and knowledge

In recent years the role of process control, and SPC in particular, has changed. Increasingly, it is seen not just as a convenient method of keeping processes in control but also as an activity which is fundamental to the acquisition of competitive advantage. This is a remarkable shift in the status of SPC. Traditionally it was seen as one of the most *operational*, immediate and 'hands-on' operations management techniques. Yet it is now being connected with an operation's *strategic* capabilities.[13] This is how the logic of the argument goes:

1 SPC is based on the idea that process variability indicates whether a process is in control or not.
2 Processes are brought into *control* and improved by progressively reducing process variability. This involves eliminating the assignable causes of variation.

3 One cannot eliminate assignable causes of variation without gaining a better understanding of how the process operates. This involves *learning* about the process, where its nature is revealed at an increasingly detailed level.

Process knowledge

4 This learning means that **process knowledge** is enhanced, which in turn means that operations managers are able to predict how the process will perform under different circumstances. It also means that the process has a greater capability to carry out its tasks at a higher level of performance.

5 This increased *process capability* is particularly difficult for competitors to copy. It cannot be bought 'off-the-shelf'. It comes only from time and effort being invested in controlling operations processes. Therefore, process capability leads to strategic advantage.

In this way, process control leads to learning which enhances process knowledge and builds difficult-to-imitate process capability.

The Six Sigma approach

The power of process control, and in particular the importance of reducing variation in process performance, has provided the basis for what has become an important improvement concept. The **Six Sigma** quality approach was first popularized by Motorola, the electronics components, semi-conductors and communications systems company. When the company set its quality objective as 'total customer satisfaction' in the 1980s, it started to explore what the slogan would mean to its operations processes. It decided that true customer satisfaction would be achieved only when its products were delivered when promised, with no defects, with no early-life failures and when the product did not fail excessively in service. To achieve this, Motorola initially focused on removing manufacturing defects. However, it soon came to realize that many problems were caused by latent defects, hidden within the design of its products. These might not show initially but eventually could cause failure in the field. The only way to eliminate these defects was to make sure that design specifications were tight (i.e. narrow tolerances) and its processes very capable (in terms of capability as discussed earlier in this chapter).

Six Sigma
An approach to improvement and quality management that originated in the Motorola Company but which was widely popularized by its adoption in the GE Company in America. Although based on traditional statistical process control, it is now a far broader 'philosophy of improvement' that recommends a particular approach to measuring, improving and managing quality and operations performance generally.

Motorola's Six Sigma quality concept was so named because it required the natural variation of processes (± 3 standard deviations) should be half their specification range. In other words, the specification range of any part of a product or service should be ± 6 the standard deviation of the process. The Greek letter sigma (σ) is often used to indicate the standard deviation of a process, hence the Six Sigma label. Figure 17.16 illustrates the effect of progressively narrowing process variation on the number of defects produced by the process, in terms of **defects per million**. The defects per million measure is used within the Six Sigma approach to emphasize the drive towards a virtually **zero defect** objective.

Defects per million

Zero defect
The idea that quality management should strive for perfection as its ultimate objective even though in practice this will never be reached.

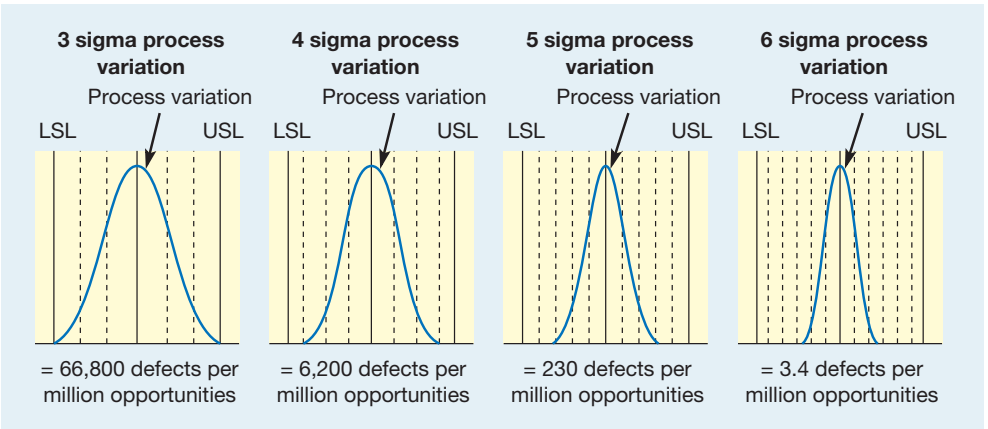


Figure 17.16 **Process variation and its impact on process defects per million**

Measuring performance

The Six Sigma approach uses a number of related measures to assess the performance of operations processes.

- *A defect* is a failure to meet customer required performance (defining performance measures from a customer's perspective is an important part of the Six Sigma approach).
- *A defect unit or item* is any unit of output that contains a defect (i.e. only units of output with no defects are not defective, defective units will have one or more than one defects).
- *A defect opportunity* is the number of different ways a unit of output can fail to meet customer requirements (simple products or services will have few defect opportunities, but very complex products or services may have hundreds of different ways of being defective).
- *Proportion defective* is the percentage or fraction of units that have one or more defects.
- *Process yield* is the percentage or fraction of total units produced by a process that are defect free (i.e. 1-proportion defective).
- *Defects per unit (DPU)* is the average number of defects on a unit of output (the number of defects divided by the number of items produced).
- *Defects per opportunity* is the proportion or percentage of defects divided by the total number of defect opportunities (the number of defects divided by (the number items produced × the number of opportunities per item)).
- *Defects per million opportunities (DPMO)* is exactly what it says, the number of defects which the process will produce if there were 1 million opportunities to do so.
- *The Sigma measurement* is derived from the DPMO and is the number of standard deviations of the process variability that will fit within the customer specification limits.

Worked example

An insurance process checks details of insurance claims and arranges for customers to be paid. It samples 300 claims at random at the end of the process. They find that 51 claims had one or more defects and there were 74 defects in total. Four types of error were observed: coding errors, policy conditions errors, liability errors and notification errors.

$$\text{Proportion defective} = \frac{\text{number of defects}}{\text{number of units processed}}$$

$$= \frac{51}{300} = 0.17 \text{ (17\% defective)}$$

$$\text{Yield} = 1 - \text{proportion of defectives}$$

$$= 1 - 0.17 = 0.83 \text{ or (83\% yield)}$$

$$\text{Defects per unit} = \frac{\text{number of defects}}{\text{number of units processed}}$$

$$= \frac{74}{300} = 0.247 \text{ (or 24.7) DPU}$$

$$\text{Defects per opportunity} = \frac{\text{number of defects}}{\text{number of units produced} \times \text{number of opportunities}}$$

$$= \frac{74}{300 \times 4} = 0.062 \text{ DPO}$$

$$\text{Defects per million opportunities} = \text{DPO} \times 10^6$$

$$= 62{,}000 \text{ DPMO}$$

Six Sigma as a broad improvement concept

In fact, Six Sigma as it is usually practised is far broader than a simple examination of process variation, even though this is an important part of process control, learning and improvement. Some elements within the broad Six Sigma concept as it is practised by consultants and operations managers have already been covered in this book. Other elements will be covered later. Table 17.7 identifies some of the elements commonly held to be within the broad sphere of Six Sigma-based improvement and the chapters in this text that discuss them.

Table 17.7 Six Sigma is a broad approach to the improvement of operations process. Most of its elements are discussed in this text

Some elements with the Six Sigma improvement concept	*Chapters where the issue is discussed*
Customer-driven objectives	Chapters 2 and 12
Use of evidence	Chapter 18
Structured improvement cycle	Chapter 18
Structured training and organization of improvement	Chapter 20
Process capability and control	Chapter 17
Process design	Chapter 4
Process improvement	Chapters 18, 19 and 20

Acceptance sampling

Process control is usually the preferred method of controlling quality because quality is being 'built in' to the process rather than being inspected afterwards. However, sometimes it may be necessary to inspect batches of products or services either before or after a process. The purpose of acceptance sampling is to decide whether, on the basis of a sample, to accept or reject the whole batch. Examples include incoming component parts from a supplier, a batch of finished products or a large number of examination scripts from an internal examiner. Acceptance sampling is usually carried out on attributes rather than variables. It uses the proportion of wrongs to rights or defectives to acceptables. Again, in acceptance sampling, like process control, it is important to understand the risks inherent in using a sample to make a judgement about a far larger batch. Table 17.8 illustrates the risks of acceptance sampling in the form of type I and type II errors.

In acceptance sampling the type I risk is often referred to as the producer's risk because it is the risk that the operation rejects a batch that is actually of good quality. The type II risk is usually called the consumer's risk because it is the risk of accepting a batch that is actually poor and sending it to the consumer of the product or service.

Table 17.8 The risks inherent in acceptance sampling

	The batch actually is	
Decision	*OK*	*Not OK*
Reject batch	Type I error	Correct decision
Accept batch	Correct decision	Type II error

Sampling plans

Sampling plan

Acceptance sampling involves a sample being taken from a batch and a decision to accept or reject the batch being made by comparing the number of 'defects' found in the sample to a predetermined acceptable number. The **sampling plan** which describes this procedure is defined by two factors, n and c, where:

n = the sample size
c = the acceptance number of defects in the sample.

If x = number of defects actually found in the sample, a decision is made based on the following simple decision rule:

If $x \leqslant c$ then accept the whole batch.
If $x > c$ then reject the whole batch.

Unlike control charts it is not necessary for organizations to create their own acceptance plans. A set of tables called the Dodge–Romig Sampling Inspection Tables provides values for n and c for a given set of risks. The ability of this plan to discriminate between good batches and bad ones is based upon the binomial distribution and is described by an operating characteristic (OC) curve. The OC curve for a sampling plan shows the probability of accepting a batch as the actual percentage of defects varies. An ideal OC curve would look like the red line in Figure 17.17.

In this example the level of defects which is regarded as acceptable is 0.4 per cent and the sampling plan is perfect at discriminating between acceptable and unacceptable batches. The probability of accepting a batch whose actual level of defects is less than 0.4 per cent is 100 per

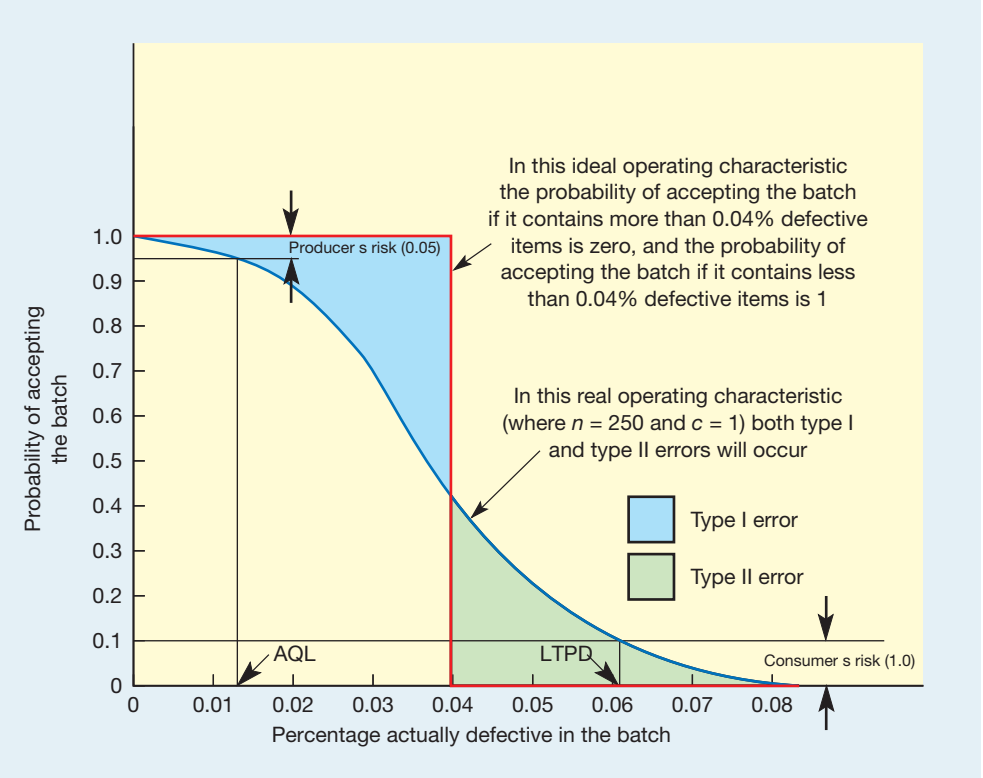


Figure 17.17 Ideal and real operating characteristics showing acceptable quality level (AQL), lot tolerance percentage defective (LTPD), producer's risk and consumer's risk

cent and there is no chance of ever accepting a batch whose actual level of defects is more than 0.4 per cent. However, in practice, no procedure based on sampling, and therefore carrying risk, could ever deliver such an ideal curve. Only 100 per cent inspection using a perfect inspector could do so. Any use of sampling will have to accept the existence of type I and type II errors. Figure 17.17 also shows the blue line which represents a sampling plan for sampling 250 items ($n = 250$) and rejecting the batch if there is more than one defect ($c = 1$) in the sample. A batch is acceptable if it contains 0.4 per cent or fewer defects (1/250 = 0.04 per cent).

What is not known is the actual percentage of defective items in any one batch, and because the procedure relies on a sample, there will always be a probability of rejecting a good batch because the number of defects in the sample is two or more despite the batch in fact being acceptable (type I risk shown by the top shaded area). There is also a probability that in spite of accepting a batch (because the number of defects it contains is zero or one), the actual number of defects in the whole batch might be greater than 0.04 per cent (type II risk shown in the lower blue shaded area of Figure 17.17). If the sizes of these risks are felt to be too great, the sample size can be increased, which will move the shape of the curve towards the ideal. However, this implies increased time and cost in inspecting the batch.

To create an appropriate sampling plan (that is, to decide the values of n and c), the levels of four factors need to be specified. These have been identified on the operating characteristic curve in Figure 17.17. These four factors are then fed into the Dodge–Romig tables to give the respective values for c and n. (Using these tables is beyond the scope of this book.) The four factors are type I error, type II error, acceptable quality level (AQL) and lot tolerance percentage defective (LTPD):

- *Type I error*. The usual value used for producer's risk (type I error) is often set with a probability of 0.05. This means that management is willing to take a 5 per cent chance that a batch of good quality will be rejected when it is actually acceptable. This also implies that there is a 95 per cent chance that a good-quality batch will be accepted.
- *Type II error*. The value for the consumer's risk (type II error) is often set with a probability of 0.1. This means that management is willing to risk at most a 10 per cent chance that a poor-quality batch will be accepted, implying that there is a 90 per cent chance that a poor-quality batch will actually be rejected.
- *AQL*. The acceptable quality level is the actual percentage of defects in a batch which the organization is willing to reject mistakenly (by chance) 5 per cent of the time (assuming a 0.05 type I error) when the batch is actually acceptable.
- *LTPD*. The lot tolerance percentage defective is the actual percentage of defects in a batch that management is willing to accept mistakenly 10 per cent of the time (assuming a 0.1 type II error).

Critical commentary

A frequently made criticism of acceptance sampling is that it assumes that some amount of defects and failure is acceptable to the organization or its customers. By accepting the inevitability of failure and poor quality, it is argued, the operation will become 'lazy' at trying to eliminate the causes of bad quality. Rather than see quality as primarily something to be improved, acceptance sampling views it as being almost 'predetermined' by the characteristics of the process. The main task is to measure output and understand the risks involved, not to get to the root causes of poor quality. More recent approaches to quality management (such as TQM, see Chapter 20) suggest that 'right first time every time' is the only acceptable approach and that organizations should strive to produce zero defective items rather than some 'acceptable quality level'.

Summary answers to key questions

*The Companion Website to the book – **www.pearsoned.co.uk/slack** – also has a brief 'Study Guide' to each chapter.*

How can quality be defined?

- In several ways. Among the approaches are the transcendent approach which views quality as meaning 'innate excellence'; the manufacturing-based approach which views quality as being 'free of errors'; the user-based approach which views quality as 'fit for purpose'; the product-based approach which views quality as a 'measurable set of characteristics'; and the value-based approach which views quality as a balance between 'cost and price'.
- The definition of quality used in this book combines all these approaches to define quality as 'consistent conformance to customers' expectations'.

How can quality problems be diagnosed?

- At a broad level, quality is best modelled as the gap between customers' expectations concerning the product or service and their perceptions concerning the product or service.
- Modelling quality this way will allow the development of a diagnostic tool which is based around the perception–expectation gap. Such a gap may be explained by four other gaps:
  - the gap between a customer's specification and the operation's specification;
  - the gap between the product or service concept and the way the organization has specified it;
  - the gap between the way quality has been specified and the actual delivered quality;
  - the gap between the actual delivered quality and the way the product or service has been described to the customer.

What steps lead towards conformance to specification?

- There are six steps:
  - define quality characteristics;
  - decide how to measure each of the quality characteristics;
  - set quality standards for each characteristic;
  - control quality against these standards;
  - find and correct the causes of poor quality;
  - continue to make improvements.
- Most quality planning and control involves sampling the operation's performance in some way. Sampling can give rise to erroneous judgements which are classed as either type I or type II errors. Type I errors involve making corrections where none is needed. Type II errors involve not making corrections where they are in fact needed.

How can statistical process control help quality planning and control?

- Statistical process control (SPC) involves using control charts to track the performance of one or more quality characteristics in the operation. The power of control charting lies in its ability to set control limits derived from the statistics of the natural variation of processes. These control limits are often set at ± 3 standard deviations of the natural variation of the process samples.

- Control charts can be used for either attributes or variables. An attribute is a quality characteristic which has two states (for example, right or wrong). A variable is one which can be measured on a continuously variable scale.
- Process control charts allow operations managers to distinguish between the 'normal' variation inherent in any process and the variations which could be caused by the process going out of control.

How can acceptance sampling help quality planning and control?

- Acceptance sampling helps managers to understand the risks they are taking when they make decisions about a whole batch of products on the basis of a sample taken from that batch. The risks of any particular sampling plan are shown on its operating characteristic (OC) curve. However, some of its assumptions make acceptance sampling controversial.

Case study
Turnround at the Preston plant

Source: Getty Images/Digital Vision

'Before the crisis, the quality department was just for looks, we certainly weren't used much for problem solving, the most we did was inspection. Data from the quality department was brought to the production meeting and they would all look at it, but no one was looking ***behind*** *it.'* (Quality Manager, Preston Plant)

The Preston plant of Rendall Graphics was located in Preston, Vancouver, across the continent from the headquarters in Massachusetts. The plant had been bought from the Georgetown Corporation by Rendall in March 2000. Precision-coated papers for ink-jet printers accounted for the majority of the plant's output, especially paper for specialist uses. The plant used coating machines that allowed precise coatings to be applied. After coating, the conversion department cut the coated rolls to the final size and packed the sheets in small cartons.

In October 1999, Tom Branton, previously accountant for the business, was appointed as Managing Director.

The curl problem

In late 1998 Hewlett-Packard (HP), the plant's main customer for ink-jet paper, informed the plant of some problems it had encountered with paper curling under conditions of low humidity. There had been no customer complaints to HP, but its own personnel had noticed the problem and wanted it fixed. Over the next seven or eight months a team at the plant tried to solve the problem. Finally, in October 1999, the team made recommendations for a revised and considerably improved coating formulation. By January 2000 the process was producing acceptably. However, 1999 had not been a good year for the plant. Although sales were reasonably buoyant, the plant was making a loss of around $2 million for the year.

Slipping out of control

In the spring of 2000, productivity, scrap and re-work levels continued to be poor. In response to this the operations management team increased the speed of the line and made a number of changes to operating practice in order to raise productivity. '*Looking back, changes were made without any proper discipline and there was no real concept of control. We were always meeting specification, yet we didn't fully understand how close we really were to not being able to make it. The culture here said, 'If it's within specification then it's OK' and we were very diligent in making sure that the product which was shipped* ***was*** *in specification. However, Hewlett-Packard gets 'process charts' that enables them to see more or less exactly what*

→

is happening right inside your operation. We were also getting all the reports but none of them was being internalized, we were using them just to satisfy the customer. By contrast, HP have a statistically based analytical mentality that says to itself, 'You might be capable of making this product but we are thinking two or three product generations forward and asking ourselves, will you have the capability then, and do we want to invest in this relationship for the future?' (Tom Branton)

The spring of 2000 also saw two significant events. First, Hewlett-Packard asked the plant to bid for the contract to supply a new ink-jet platform, known as the Vector project, a contract that would secure healthy orders for several years. Second the plant was acquired by Rendall. '*What did Rendall see when they bought us? They saw a small plant on the Pacific coast losing lots of money*.' (Finance Manager, Preston Plant)

Rendall was not impressed by what it found at the Preston plant. It was making a loss and had only just escaped incurring a major customer's disapproval over the curl issue. If the plant did not get the Vector contract, its future looked bleak. Meanwhile, the chief concern continued to be productivity. But also, once again, there were occasional complaints about quality levels. However, HP's attitude caused some bewilderment to the operations management team. '*When HP asked questions about our process, the operations guys would say, 'Look, we're making roll after roll of paper, it's within specification. What's the problem?*' (Quality Manager, Preston Plant)

But it was not until summer that the full extent of HP's disquiet was made. '*I will never forget June of 2000. I was at a meeting with HP in Chicago. It was not even about quality. But during the meeting one of their engineers handed me a control chart, one that we supplied with every batch of product. He said, 'Here's your latest control chart. We think you're out of control and you don't know that you're out of control and we think that we are looking at this data more than you are.' He was absolutely right and I fully understood how serious the position was. We had our most important customer telling us we couldn't run our processes just at the time we were trying to persuade them to give us the Vector contract.*' (Tom Branton)

The crisis

Tom immediately set about the task of bringing the plant back under control. They first of all decided to go back to the conditions which prevailed in the January, when the curl team's recommendations had been implemented. This was the state before productivity pressures had caused the process to be adjusted. At the same time the team worked on ways of implementing unambiguous 'shut-down rules' that would allow operators to decide under what conditions a line should be halted if they were in doubt about the quality of the product they were making. '*At one point in May of 2000 we had to throw away 64 jumbo rolls of out-of-specification product. That's over $100,000 of product scrapped in one run. Basically that was because they had been afraid to shut the line down. Either that or they had tried to tweak the line while it was running to get rid of the defect. The shut-down guidelines in effect say, 'We are not going to operate when we are not in a state of control'. Until then our operators just couldn't win. If they failed to keep the machines running we would say, 'You've got to keep productivity up'. If they kept the machines running but had quality problems as a result, we criticized them for making garbage. Now you get into far more trouble for violating process procedures than you do for not meeting productivity targets.*' (Engineer, Preston Plant)

This new approach needed to be matched by changes in the way the communications were managed in the plant. '*We did two things that we had never done before. First, each production team started holding daily reviews of control chart data. Second, one day a month we took people away from production and debated the control chart data. Several people got nervous because we were not producing anything. But it was necessary. For the first time you got operators from the three shifts meeting together and talking about the control chart data and other quality issues. Just as significantly we invited HP up to attend these meetings. Remember, these weren't staged meetings, it was the first time these guys had met together and there was plenty of heated discussion, all of which the Hewlett-Packard representatives witnessed*.' (Engineer, Preston Plant)

At last something positive was happening in the plant and morale on the shop floor was buoyant. By September 2000 the results of the plant teams' efforts were starting to show results. Process were coming under control, quality levels were improving and, most importantly, personnel both on the shop floor and in the management team were beginning to get into the 'quality mode' of thinking. Paradoxically, in spite of stopping the line periodically, the efficiency of the plant was also improving.

Yet the Preston team did not have time to enjoy their emerging success. In September of 2000 the plant learned that it would not get the Vector project because of the recent quality problems. Then Rendall decided to close the plant. '*We were losing millions, we had lost the Vector project, and it was really no surprise. I told the senior management team and said that we would announce it probably in April of 2001. The real irony was that we knew that we had actually already turned the corner*.' (Tom Branton)

Notwithstanding the closure decision, the management team in Preston set about the task of convincing Rendall that the plant could be viable. They figured it would take three things. First, it was vital that they continue to improve quality. Progressing with their quality initiative involved establishing full statistical process control. Second, costs had to be brought down. Working on cost reduction was inevitably going to be painful. The first task

was to get an understanding of what should be an appropriate level of operating costs. '*We went through a zero-based assessment to decide what an ideal plant would look like, and the minimum number of people needed to run it*.' (Tom Branton)

By December of 2000 there were 40 per cent fewer people in the plant than two months earlier. All departments were affected. The quality department shrank more than most, moving from 22 people down to 6. '*When the plant was considering downsizing they asked me, 'How can we run a lab with six technicians? I said, 'Easy. We just make good paper in the first place and then we don't have to inspect all the garbage. That alone would save an immense amount of time*.' (Quality Manager, Preston Plant)

Third, the plant had to create a portfolio of new product ideas which could establish a greater confidence in future sales. Several new ideas were under active investigation, the most important of which was 'Protowrap', a wrap for newsprint that could be repulped. It was a product that was technically difficult. However, the plant's newly acquired capabilities allowed the product to be made economically.

Out of the crisis

In spite of their trauma, the plant's management team faced Christmas of 2000 with increasing optimism. They had just made a profit for the first time for over two years. By spring of 2001 even HP, at a corporate level, was starting to take notice. It was becoming obvious that the Preston plant really had made a major change. More significantly, HP had asked the plant to bid for a new product. April 2001 was a good month for the plant. It had chalked up three months of profitability and HP formally gave the new contract to Preston. Also in April, Rendall reversed its decision to close the plant.

Questions

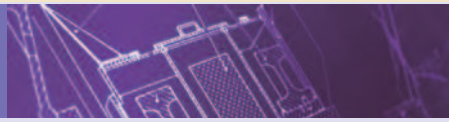
1 What are the most significant events in the story of how the plant survived because of its adoption of quality-based principles?

2 The plant's processes eventually were brought under control. What were the main benefits of this?

3 SPC is an operational-level technique of ensuring quality conformance. How many of the benefits of bringing the plant under control would you class as strategic?

Other short cases and worked answers are included in the Companion Website to this book – **www.pearsoned.co.uk/slack**

Problems



1 A call centre for a bank answers customers' queries about their loan arrangements. All calls are automatically timed by the call centre's information system and the mean and standard deviation of call lengths is monitored periodically. The bank decided that only on very rare occasions should calls be less than 0.5 minutes because customers would think this was impolite even if the query was so simple that it could be answered in this time. Also, the bank reckoned that it was unlikely that any query should ever take more than 7 minutes to answer satisfactorily. The figures for last week's calls show that the mean of all call lengths was 3.02 minutes and the standard deviation was 1.58 minutes. Calculate the C_p and the C_{pk} for the call centre process.

2 In the above call centre, if the mean call length changes to 3.2 minutes and the standard deviation to 0.9 minutes, how does this affect the C_p and C_{pk}? Do you think this is an appropriate way for the bank to monitor its call centre performance?

3 A vaccine production company has invested in an automatic tester to monitor the impurity levels in its vaccines. Previously all testing was done by hand on a sample of batches of serum. According to the company's specifications, all vaccine must have impurity levels of less than 0.03 milligrams per 1000 litres. In order to test the effectiveness of its new automatic sampling equipment, the company runs a number of batches through the process with known levels of impurity. The following table shows the level of impurity of each batch and whether the new process accepted or rejected the batch. From these data, estimate the type I and type II error levels for the process.

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0.035 (rejected)	0.028 (accepted)	0.031 (accepted)	0.029 (accepted)	0.028 (accepted)	0.034 (accepted)	0.031 (accepted)
0.040 (rejected)	0.011 (accepted)	0.028 (rejected)	0.025 (accepted)	0.019 (accepted)	0.018 (accepted)	0.033 (rejected)
0.022 (accepted)	0.029 (rejected)	0.012 (accepted)	0.034 (accepted)	0.027 (accepted)	0.017 (accepted)	0.021 (accepted)
0.031 (rejected)	0.015 (accepted)	0.037 (rejected)	0.030 (accepted)	0.025 (accepted)	0.034 (rejected)	0.020 (accepted)

4 A utility has a department which does nothing but change the addresses of customers on the company's information systems when customers move house. The process is deemed to be in control at the moment and a random sample of 2000 transactions shows that 2.5 per cent of these transactions had some type of error. If the company is to use statistical process control to monitor error levels, calculate the mean, upper control level (UCL) and lower control level (LCL) for its SPC chart.

5 A firm of tax advisers is offering a new phone-in service where, for a small fee, customers can get 10 minutes of tax advice over the phone. The firm wants to monitor the length of calls so as not to give customers more time than they have paid for, or to give them less time than they expect. The following table shows samples of six calls taken on different days during a period when the service had 'settled in'.

(**a**) Calculate the mean, upper control limit and lower control limit for an $\overline{X}$ and R chart that could be used to monitor calls.
(**b**) Plot the results for the nine days shown in the table. Do you have any comments about these results?

Ten-minute tax call advice sampled call lengths in minutes

	Date								
Sampled calls	*12/3*	*14/3*	*17/3*	*19/3*	*20/3*	*23/3*	*24/3*	*27/3*	*29/3*
1	10	8	11	9	12	10	9	8	9
2	17	9	10	13	10	10	9	10	7
3	9	8	11	10	9	11	11	8	10
4	8	12	11	8	9	9	11	11	13
5	12	12	10	10	11	11	10	12	12
6	11	9	8	8	10	12	9	11	12

Study activities

Some study activities can be answered by reading the chapter. Others will require some general knowledge of business activity and some might require an element of investigation. All have hints on how they can be answered on the Companion Website for this book that also contains more discussion questions – **www.pearsoned.co.uk/slack**

1 Find two products, one a manufactured food item (for example, a pack of breakfast cereals, packet of biscuits, etc.) and the other a domestic electrical item (for example, electric toaster, coffee maker, etc.).

(**a**) Identify the important quality characteristics for these two products.
(**b**) How could each of these quality characteristics be specified?
(**c**) How could each of these quality characteristics be measured?

2 Many organizations check up on their own level of quality by using 'mystery shoppers'. This involves an employee of the company acting the role of a customer and recording how they are treated by the operation. Choose two or three high-visibility operations (for example, a cinema, a department store, the branch of a retail bank, etc.) and discuss how you would put together a mystery shopper approach to testing their quality. This may involve you determining the types of characteristics you would wish to observe, the way in which you would measure these characteristics, an appropriate sampling rate, and so on. Try out your mystery shopper plan by visiting these operations.

3 Visit the website of a local airport or airline or train company or bus company etc. that publishes the proportion of late arrivals for a given time period. (For example, some airports regularly publish the proportion of flights late each day.) Chart this data over time in the form of an SPC chart. Calculate the upper and lower control limits for the chart.

4 (**Advanced**) *Step 1* – Decide on some timed event that you can regularly sample, either by yourself or (preferably) as a group. This could be the arrival time of your colleagues at work each morning, the start time of lectures and so on.

Step 2 – Devise a method of charting the data you collect in the form of an $\bar{X}$ and R chart.

Step 3 – Calculate the relevant control limits for these charts.

Notes on chapter

1 Source: Interview with Karen Earp, General Manager, Four Seasons Canary Wharf Hotel.
2 Garvin, D. (1984) 'What Does "Product Quality" Really Mean?', *Sloan Management Review*, Fall.
3 Based on Gummesson, E. (1993) 'Service Productivity, Service Quality and Profitability', *Proceedings of the 8th International Conference of the Operations Management Association*, Warwick, UK.
4 Gummesson, E. *op. cit.*
5 Parasuraman, A., Zeithaml, V.A. and Berry, L.L. (1985) 'A Conceptual Model of Service Quality and Implications for Future Research', *Journal of Marketing*, Vol. 49, Fall, pp. 41–50; and Gummesson, E. (1987) 'Lip Service: A Neglected Area in Services Marketing', *Journal of Services Marketing*, Vol. 1, No. 1, pp. 19–23.
6 Haywood-Farmer, J. and Nollet, J. (1991) *Services Plus: Effective Service Management*, Morin.
7 Berry, L.L. and Parasuraman, A. (1991) *Marketing Services: Competing Through Quality*, The Free Press.
8 Mechling, L. (2002) 'Get Ready for a Storm in a Tea Shop', *The Independent*, 8 March and company website.
9 Based on Parasuraman, A., Zeithaml, V.A. and Berry, L.L. (1985) 'A Conceptual Model of Service Quality and Implications for Future Research', *Journal of Marketing*, Vol. 49, Fall, pp. 41–50.
10 Source: Information from company.
11 Source: *The Sunday Times* (1997) 'Scan Avoids Needless Appendectomy', 23 February.
12 For more details of the Taguchi approach, see Stuart, G. (1993) *Taguchi Methods: A Hands-on Approach*, Addison-Wesley.
13 Based on Betts, A. and Slack, N. (2000) 'Control, Knowledge and Learning in Process Development', Warwick Operations Working Paper.

Selected further reading

Dale, B.G. (ed.) (2003) *Managing Quality*, Blackwell, Oxford. This is the latest version of a long-established, comprehensive and authoritative text.

Garvin, D.A. (1988) *Managing Quality*, The Free Press. Somewhat dated now but relates to our discussion at the beginning of this chapter.

George, M.L., Rowlands, D. and Kastle, B. (2003) *What Is Lean Six Sigma?*, McGraw-Hill Publishing Co. Very much a quick introduction on what Lean Six Sigma is and how to use it.

Pande, P.S., Neuman, R.P. and Kavanagh, R.R. (2000) *The Six Sigma Way*, McGraw-Hill, New York. There are many books written by consultants for practising managers on the now fashionable Six Sigma approach. This is as readable as any.

Useful websites

http://www.quality-foundation.co.uk/ The British Quality Foundation is a not-for-profit organization promoting business excellence.

http://www.juran.com The Juran Institutes mission statement is to provide clients with the concepts, methods and guidance for attaining leadership in quality.

http://www.asq.org/ The American Society for Quality site. Good professional insights.

http://www.quality.nist.gov/ American Quality Assurance Institute. Well-established institution for all types of business quality assurance.

http://www.gslis.utexas.edu/~rpollock/tqm.html Non-commercial site on total quality management with some good links.

http://www.iso.org/iso/en/ISOOnline.frontpage Site of the International Organisation for Standardisation that runs the ISO 9000 and ISO 14000 families of standards. ISO 9000 has become an international reference for quality management requirements.

www.opsman.org Definitions, links and opinion on operations management.