UNIT 6

QUALITY MANAGEMENT

Introduction

This unit deals with an area that has always been important, but which leapt to the top of many corporate agendas in the early 1990s. Quality is a huge subject that is even taught as a subject in its own right. So, necessarily, this is an overview of some of the more important concepts. Quality is a stimulating field, not just for experts, but for everyone in every organisation.

Objectives

By the end of this unit, you should be able to:

- appreciate the multifaceted views of what 'quality' means
- understand its importance and significance
- know some views of some leading figures in quality management
- know the basic techniques of quality management
- have an appreciation of the meaning of total quality management
- have an insight into some of the more advanced techniques and concepts, particularly as they apply to quality improvement.

SECTION 1

What is Quality?

Introduction

In May 1995 the BBC magazine *Top Gear* published the results of its second survey of customer satisfaction of car ownership in Britain. The survey was carried out in association with J D Power, a consulting company that has been undertaking similar surveys in the USA for 25 years. The results probably came as no surprise to those who have followed these surveys in the USA, but for Britain's 'home-grown' car industry, which has been making much of its progress on quality over the past few years, the results were almost certainly a disappointment. Of the top 20 most-liked cars in Britain none were 'home-grown' if we exclude the made-in-Britain Japanese cars by Toyota, Honda, and Nissan. The first European car on the list was a Mercedes Benz coming in at fifteenth place. The 'top' car was a Toyota Corolla.

The survey is interesting for the measures it uses. Performance is weighted 26%, problems encountered 23%, customer care 17%, warranty 15%, service costs 6%, and parts and service 13%. Of course, you may disagree with the findings. Your own measures of satisfaction almost certainly differ from those of J D Power. Then there are the intangibles. Writing in the *Sunday Times* of 23 April 1995, Jeremy Clarkson discussed the 'irrationality' of new car buyers, the vast majority of whom do not take test drives nor rely on road tests but are influenced by image and advertisements, many of which have no technical content at all. Most people feel they 'know quality when they see it', but if you ask them to be more specific, then the problems begin.

What is 'quality', and how do we make up our minds about what is a quality product or quality service? Many academics, consultants and market researchers, including J D Power, have attempted to answer this illusive but vital question.

In 1993, Mintel, a British market research organisation, undertook a survey of what customers value in products and in services. The top factors, in priority order, were:

Products	**Services**
Well made	Helpful staff
Safe to use	Efficient service
Value for money	Knowledgeable staff
Reliable	Clear pricing
Durable	Guarantees

It is interesting to contrast these with the views of academics. David Garvin, a professor at Harvard Business School, has identified eight 'dimensions' of quality which he maintains cover various meanings of quality held by managers and customers (1984). These are particularly appropriate in the product area. In the service area, Zeitham et al have extensively researched the 'dimensions of service quality' (1990). Their conclusions are:

Garvin's dimensions (in no particular order)	**Zeithaml et al's service dimensions (in order)**
Performance	Reliability (ability to perform the promised service)
Features	Responsiveness (willingness to help)
Reliability	Assurance (knowledge and courtesy, ability to convey trust, confidence)
Conformance (to specification)	Empathy (caring, individualised attention)
Durability	Tangibles (appearance of facilities, staff)
Serviceability	
Aesthetics	
Perceived quality ('feel', 'finish', reputation)	

ACTIVITY 1

How closely does the Mintel product survey match up with (a) Garvin's dimensions; (b) Zeithaml et al's dimensions?

There appears to be quite close agreement between Mintel and Garvin. One factor listed by Mintel but not by Garvin is value for money, although most customers would expect more on performance, features and probably several other dimensions if they paid more for a product. In other words, we are talking about expectations. In the following section we will discuss two views of ‘quality’. We should stress once again that there is no one view used by everyone, but that each view increases our understanding of customers and their needs.

1.1 Two views of quality

JOHN GUASPARI

John Guaspari (1988), consultant and well-known author of a series of stimulating books on quality management, puts forward the view that:

$$\text{Quality} = S + E + e$$

Here ‘*S*’ stands for **specifications**, and is to do with the closeness with which the product or service matches the specification or requirements. This is the traditional or ‘engineering’ view. Thus, for example, the required diameter of a shaft is given as 250 mm plus or minus 0.5 mm. This latter dimension is known as the **tolerance limit**. If the diameter of the shaft is between 249.5 mm and 250.5 mm it conforms to requirements, otherwise it does not. But this engineering view is applicable in service operations also: a service manager might specify that a telephone call must be answered before it rings four times, or British Rail customers are entitled to a discount if more than a certain percentage of trains run late. This aspect concerns internal controls; without such specifications there is less chance that a customer’s expectations will be satisfied because the organisation will lack focus in its goals and operations.

‘*E*’ concerns **macro expectations**. A macro expectation is the expectation customers have for the type of product or service category under consideration. It is not brand-specific, but concerns the general expectations for that class of product. For example, today we would expect certain minimum standards of reliability, fuel economy, performance, safety features, instrumentation, and so forth, from any new car that we buy. This is a moving target. Sometimes, macro expectations derive from legal requirements such as the necessity to provide seat belts and an air bag. These macro expectations reflect the industry norm, and they might vary from country to country. In Germany, you expect the trains to be on time, in India this would be unrealistic. Clearly, an organisation cannot do much about macro expectations other than to ensure that they are understood by the organisation, and that at least minimum standards are achieved.

‘*e*’ concerns **micro expectations**. These are expectations that arise out of an organisation’s communications and advertisements to potential customers, and also as a result of word-of-mouth communications from existing customers. The message here is that an organisation must not ‘over-promise and under-deliver’. A customer is likely to be much happier to be offered a ten-day service on a broken-down personal computer and receive it back within seven days, than if a four-day service had been promised and it was repaired in the same seven-day period! Over the last few years a recurring theme in TV consumer programmes has been travel agents that have been taken to task by their clients over expectations built up in glossy holiday brochures. This aspect concerns the externally communicated message, and is largely within the organisation's own control. But it does require co-ordination and clarity of message between functions such as marketing, sales, operations, and service.

Both *'E'* and *'e'* are influenced by price. You would naturally expect better performance, better service, and a quieter ride from a Jaguar than from a Skoda. Yet in the BBC *Top Gear* survey a Skoda ranks higher in customer satisfaction than a Jaguar. Almost certainly this has to do with the high *'E'* and *'e'* that Jaguar customers have.

In Guaspari's view a good quality product or service is achieved where there is maximum overlap between *'S'*, *'E'*, and *'e'*. This, of course, means that the product or service must conform to, or exceed, specification and expectation in design, operation, build and delivery, to both the external industry standards and expectations for the particular class and price, and must also conform to, or exceed, internally-generated specifications and communications. Quality can only be achieved by a 'total' effort involving everyone in the organisation, from design to manufacturing, and from suppliers to delivery.

THE KANO MODEL

A useful complementary model to Guaspari's is one proposed by Noriaki Kano (see Joiner, 1994). You may recall we mentioned this model briefly in Unit 1. Kano suggests that there are three categories of human perception: the *'must be'*, the *'more is better'*, and the *'delighters'*. This model is useful in both manufacturing where it has been extensively used in design, and in services. We can represent the Kano model as in Figure 1.

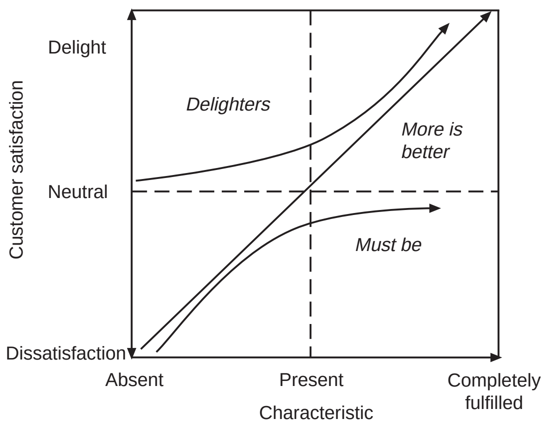


Figure 1: The Kano model (adapted from Joiner, 1994)

The *must be* category are those features and characteristics that we simply expect to be there. We hardly notice their presence, but definitely notice their absence. Thus we expect a restaurant to have fresh napkins and clean cutlery. We expect a CD player to be able to select any track. Students expect a lecturer to turn up for lectures and to have prepared reasonably well. If all expected features are there we will be reasonably contented, but hardly delighted. By contrast, if the features are absent we are likely to be quite upset and liable to complain.

In the *more is better* category, as the name suggests, the greater, or faster, or better the feature provided, the more we are satisfied. We can almost never have too much, or be fast enough. This might be the case with speed of room service in a hotel, with fuel efficiency in a car, with sound quality in a hi-fi system, or with manufacturing or delivery time. It is the extremes, however, that are important. In the middle range, roughly corresponding to Guaspari's macro expectations, where service or product performance is average, we are hardly impressed. But at low levels we are extremely unimpressed or unhappy, and at exceptional levels we are very happy, even delighted.

Finally, the *delighters* are features that are unexpected, and pleasantly surprise us. Generally, this is hard for a product to achieve, but may be an important source of competitiveness in services. In 1994, Marriott Hotels ran a series of advertisements telling of the exceptional levels of service undertaken by some of their staff, such as following a guest to the airport with an important item that he had left behind in the hotel. Delighters can be on different levels, ranging from remembering the name of a client at a hairdresser to an architect going out of his way to advise on possible and innovative alternatives, and then to check and continuously inform on the progress of building a house.

The Kano model can be thought of in much the same way as Maslow's hierarchy of needs, which you have probably met in your organisational behaviour studies. Lower level needs, such as safety and security, have to be in place before 'self actualising' targets become meaningful. In the Kano model case it is the *must be* category, and at least attaining a satisfactory level in the *more is better* category, that need to be in place before the *delighters* can make an impact. For example, if the bank has got your statement wrong you are not likely to be impressed by the standard of decor. The value of the Kano model is that it challenges an organisation to identify the various operations categories in relation to their products and services, and then to work on them appropriately.

ACTIVITY 2

Think of your business studies programme. List as many factors that you can think of that make a difference to the 'quality' of your learning experience at your university or college. Then classify them into *must be*, *more is better*, and *delighters*. It may be that you do not list any under the last category. In this case think of features or events that would *delight* you as a 'customer' of your university or college.

Under the *must be* category you will probably list factors such as a clear programme for each course, regularly scheduled lectures, good textbooks, access to the library, and good lecture room conditions. The *more is better* category might include access to relevant journals in the library, library opening hours, computer facilities, clarity of lectures, time for assignments, good lecture handouts, relevant time on the Internet, feedback from lecturers on assignments, fast assignment turnaround time and small tutorial group size. *Delighters* could include external visits, talks by practising managers, stimulating educational games used on the course, and personal help from a lecturer.

1.2 Customer expectations: moments of truth

Returning to the Guaspari concept, we noted that quality is the extent to which *SeE* overlap. We will now explore this further. The front line of quality is the interface between customer expectations and the operations of the organisation. Jan Carlzon, Chief Executive of Scandinavian Airlines System made this very clear by his simple but powerful concept of **moments of truth**. The concept was made even more popular by Albrecht and Zemke in their book *Service America!* (1985).

A moment of truth is that moment when a customer comes into contact with the products, systems, people, or procedures of an organisation and as a result leads him or her to make a judgement about the quality of that organisation's products or services. It is clear that many, even hundreds, of moments of truth are likely as a single customer interacts with a company. Carlzon emphasised that each one is a potential point of dissatisfaction, indifference, or delight. They all count, and good service results when all employees appreciate and work towards making the most out of each opportunity. This is where the Kano model proves useful.

In service organisations, the customer has little or no tangible product that remains after the service is complete. All that the customer is left with is a memory of perhaps hundreds of moments of truth, of which a few will count very heavily. This leads into operations. The problem from a quality management viewpoint is that most moments of truth take place away from the eyes of management, but in interaction with front line staff. So it is desirable to have a systematic approach to preparing for these events in advance. A moments of truth analysis should be constructed from two viewpoints, that of the customer and that of the operation. This can be most usefully done by drawing a circle. Albrecht and Zemke call this a **cycle of service**. Around the outside of the circle are written all the events experienced by a customer as he or she moves though the cycle, from the first enquiry to the last handshake or even beyond. These events are described from the point of view of the customer, not the organisation. Each is a moment of truth. The sequence, of course, ignores organisational boundaries about which the customer does not care. Then, within the circle, the corresponding actions taken by the organisation are constructed, including what are termed 'front office' operations, where there is direct contact with customers, and the supporting 'back office' operations. This leads to thorough, systematic preparation of operations.

ACTIVITY 3

Construct a cycle of service diagram for a car service. Follow the procedure given above. Consider both the external (customer) experiences, and the internal operations. Now compare the external moments of truth with your own experiences. Classify each action as a *must be*, a *more is better*, or a potential *delighter*. Then relate your diagram to your own experiences of a car service, and to your lasting impressions. Which moments of truth were positive, and which were negative?

A sample diagram is given below in Figure 2. Yours may well be very different.

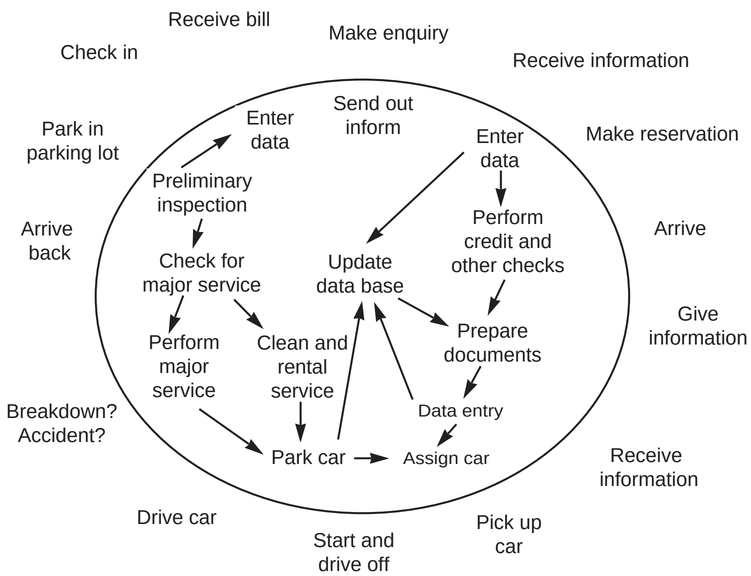


Figure 2: Cycle of service diagram for a car service

You should now ask how many of the activities are under the sole control of front line staff, how many are under management's control or influence, and how many are not within the organisation's control at all. These questions are important when attempting to improve your experience as a customer. A moments of truth analysis should also help to overcome the perception that 'no complaints is good news'.

ACTIVITY 4

If you have a tutorial group or seminar group, go around the room and ask for good and bad experiences with customer service and products. Ask the group members about their feelings towards the organisation concerned. Think of your own experiences.

You will often get interesting responses, some of them quite heated. Now compare these with the following research.

A US Technical Assistance Research Programs survey, reported in Desatnik and Detzel (1993), showed:

- 96% of consumers who experience a problem with a ‘small-ticket’ (i.e., low value) product do not complain to the manufacturer, but of these 63% will not buy again.
- 45% of consumers who experience a problem with a small-ticket service do not complain, but of these 45% will not buy again.
- only 27% of unhappy consumers of large-ticket (i.e., high value) durable products do not complain, but of these 41% will not buy again.
- 37% of unhappy consumers of large-ticket services do not complain, but of these 50% will not buy again.
- 13% of dissatisfied consumers tell their experience to more than 20 people.
- Each consumer whose complaint is satisfactorily resolved can be expected to tell eight other people.
- 92% of purchasers of small-ticket items and 70% of purchasers of large-ticket items whose complaints are satisfactorily resolved will go on to buy again.

The conclusion is that we need to make it easier to complain, and to encourage complaints! If customers can be made to express their dissatisfaction, they are more likely to remain valued customers.

1.3 Customer expectations: gap analysis

Of course it is not easy for management to pin down the causes of service failure or customer dissatisfaction. However, Zeithaml et al have provided an excellent framework for matching customer expectations with specifications by developing a model of what they term **service gaps**. The value of the model is that it provides insight into how customer expectations are developed, how operations specifications and communications are built up, and hence how gaps develop and how they may be closed or reduced. An adapted version of the model is shown in Figure 3 (over page).

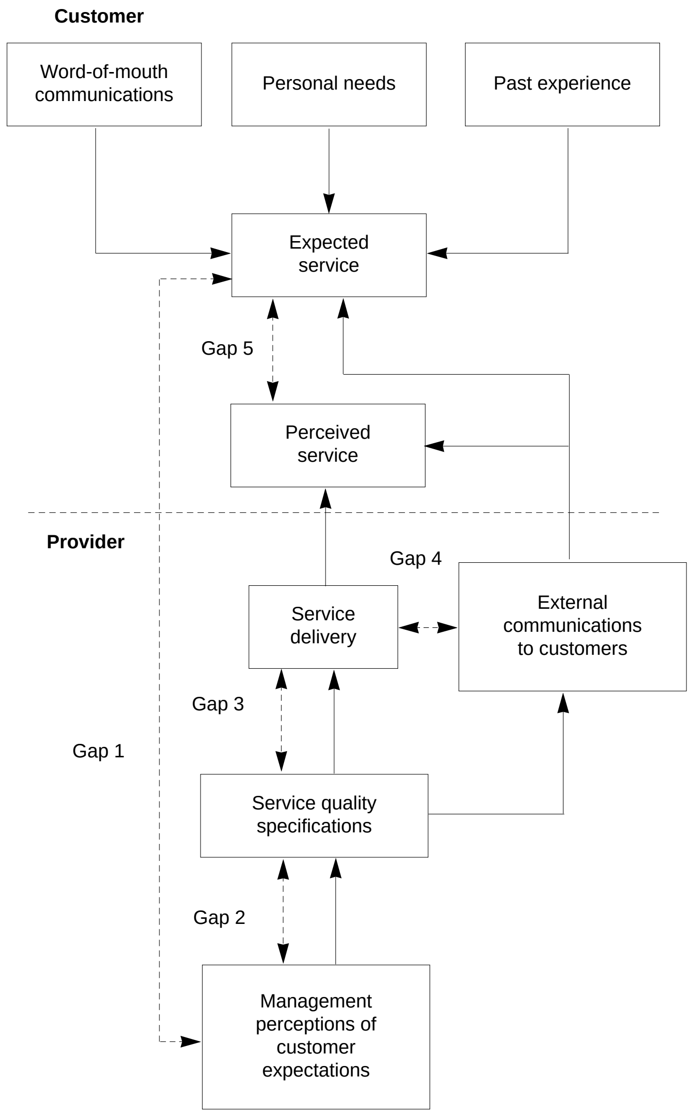


Figure 3: Conceptual model of service quality
(reprinted with permission from Zeithaml et al, 1990)

Gap 1 is due to management not knowing what customers expect. As we have seen with the SeEQ model, customer expectation is built up as a result of micro- and macro-expectations. In the Zeithaml et al model it results from management misunderstanding of the expected service which in turn stem from the four factors of word-of-mouth communication, personal needs, past experience and external communications (advertisements).

Gap 2 develops from having inadequate quality standards. This can result from management laziness or preoccupation with other activities, or from a belief that it is too difficult to set standards, or that such standardisation that does exist is inadequate. Yet, someone has to set the standards. If management does not, then operators have to do so by default; management should not then complain. In service operations, particularly, this can be quite a challenge. You must allow front-line staff the freedom to serve customers well, but within specified limits. This is sometimes called 'loose-tight' task specification.

Gap 3 is caused by a difference between what is specified and what is done. All sorts of possible factors are at work here, from behavioural (motivation, employee selection, teamworking, etc.) to technical (selection of, and training on, equipment).

Gap 4 results when performance does not match promises. There are several possible lines that can go wrong here: operations to marketing, marketing to customer, differences between operations in different branches, as well as a 'propensity to overpromise'.

Gap 5 is the difference between expected and perceived service, and the key to closing it is to close Gaps 1 to 4 and keep them closed. See Zeithaml *et al* (1990) for details of closing the gaps.

ACTIVITY 5

Brainstorm possible ways to close the gaps described. In each case, identify the function responsible in the organisation. Brainstorming is best done in a group if you can do this. You can get started on this activity by referring to the possible causes given in the last section.

Summary

In this section we have learned that quality has much to do with expectations. As John Guaspari says 'customers have all the votes'. But quality is also about getting the standards right, so that people delivering the products or services know what is expected of them.

Various authorities have produced models of the dimensions of quality. These are useful because they provide insight into the many facets of quality. Finally, we looked at a model which conceptualises the gaps that exist between an organisation and its customers.

SECTION 2

Some Quality 'Gurus'

Introduction

In this section, we will consider the contributions of some of the leading figures, or 'gurus', in quality management. They include Deming, Juran and Crosby.

2.1 Deming

Dr W Edwards Deming is probably the most revered figure in quality management. In the 1950s, Deming taught quality to the Japanese by insisting that top management attend his courses. They did, and prospered. Originally Deming taught statistical process control (SPC) to the Japanese and has always maintained that management must have an appreciation of statistical variation. Today Deming is mainly associated with quality management theories, particularly his **14 point plan**, the **Deming cycle** and his **deadly diseases** (1982).

Appreciation of statistical variation begins with the concept that very little in management is absolutely consistent, and that chance will account for a certain mount of **natural variation**. For example, a salesperson cannot sell exactly the same amount every month. He or she will have good and bad months, and the differences between good and bad are mainly explained by chance rather than by variations in skills. Therefore, merely to reward him or her for the good months, and to penalise for the bad, could be de-motivating and poor management. On the other hand, truly superior performance can produce sales which are significantly and consistently better. Here, special reward would be justified as would penalties in the case of consistently poor performance. Deming used to demonstrate this by asking people to draw coloured beads from a bowl. One colour represents poor performance and another colour good performance. Those people who draw the bad beads are castigated. Everyone quickly realises how unjust this is.

Management must distinguish between the natural variation and the significantly different variation. Deming maintains that many managers do not do this, and that performance suffers as a result. The two types of variation are known as **common causes** and **special causes** (or **assignable causes**). This is the basis of **statistical process control**, which we deal with later in this unit.

Common causes are inherent in the process but special causes are not, and these special causes need to be identified. Poor sales is one example but the same would apply to many other areas of both human-based and machine-based performance. For machines, this is the basis of SPC. Moreover, true performance improvement is very seldom within the sole power of an operator, salesman or supervisor. For example, a machine has natural variation and may be producing a certain percentage of defects. The operator can do little about it. Without management action or support, significant improvement can seldom be made. Deming's rule of thumb is that perhaps 80% of improvement requires management effort, while only 20% is actionable solely by front-line employees. Encouragements and incentives to produce better quality will have only limited results.

THE 14 POINTS

Deming's 14 point plan is a complete philosophy of management, not just quality management. Books have been written on the subject. Here we attempt only a brief summary.

1 There should be a consistent message about quality, throughout the organisation. It should not vary by department, by pressure of work, by time of the month, or by customer. Usually a clear statement is required from management, with actions that demonstrate that it means what is says.

2 The new age of quality requires a commitment continuously to improve. The competition is doing this; so must you in order to survive. Customers have increasing expectations about quality.

3 Switch from defect detection to defect prevention. Inspect the process than the product. Work to understand and reduce the natural variation in processes, the less the variation, the less the chance of defects.

4 In dealing with suppliers, end the practice of awarding business on price. Move towards quality of product, reliability of delivery, and willingness to co-operate and improve. In other words, build partnerships with suppliers. There should be advantages for both parties.

5 Constantly improve. Use the PDCA cycle (see the next section). Improvement is not confined to products and their direct processes, but to all supporting services and activities also.

6 Train in a modern way. Let employees understand the concept of variation, basic SPC, improvement, and the total approach to quality. The idea is to make everyone responsible for their own quality.

7 Supervision must change from chasing to coaching and support.

8 'Drive out fear' of improvement. Management must create the environment which removes all possibility that improvement in quality will somehow penalise operators, through more work, loss of jobs, financial loss, or whatever.

9 Remove any organisational barrier that prevents quality improvement. This means improved visibility between sections and also easier communications. Aim to remove any barrier that prevents the requirements and reactions of the customer being moved rapidly and without distortion to the point where action can be taken.

10 Don't have silly slogans that mean nothing. Don't have unrealistic targets. Remember, management has most of the power to make real improvements.

11 Work standards and numerical quotas should be eliminated. This is controversial, unless interpreted with the understanding of natural variation. Natural variation says that no standard or quota can be exact and without variation. If the natural variation is understood, the quotas and standards that are beyond the control of employees should not be penalised, nor rewarded, for undeserved performance.

12 Remove barriers that prevent employees having pride in their work. These barriers may include unrealistic quotas and time pressure, short-term requirements for profit rather than quality, lack of investment in the right machines or tools, individual incentive schemes based on output rather than group-based schemes based on quality and improvement, and lack of management support or consistency.

13 Train and educate. This follows from point 6 but emphasises that education must be widely based and continuing. Despite being point number 13, it is usually the starting point, after point 1.

14 Create an organisational structure that will support all the previous points. This is important because the 14 point plan is not a short-term implementation, but rather a long-term philosophy.

ACTIVITY 6

Take Deming's 14 points and apply them to your business studies programme at your university or college. Not all the points will be relevant, but discuss how your business studies programme could be improved if Deming's points were applied. Do this in a group if you can. Alternatively, consider their application in the organisation where you work.

Some quite radical ideas can come out of these discussions. They might include, for example, suggesting a curriculum that is continuously evaluated and improved, with student participation, no set deadlines for assignments, and a changed relationship staff and students. In the USA, it was reported in *Quality Progress* that some university departments are experimenting with the application of Deming's 14 points.

THE DEMING CYCLE (OR PDCA CYCLE)

Deming maintains that the **PDCA (plan, do, check, act)** cycle is a universal improvement methodology. Deming originally called the cycle **the Shewhart cycle** after the founder of statistical quality control, but it is now named after Deming himself. The idea is constantly to improve so as to reduce the difference in the requirements of customers and the performance of the process.

First **plan** what to do. This may be improvement in the design of the product and its features, or in the process which produces the product. Typically Pareto analysis (see Section 4 of this unit) is used to identify the most pressing need or problem. Then **do**. This means small-scale experimentation. Explore the problems, come up with possible causes, investigate them, identify the most likely ones. Then **check**. Try out what you have found to see if your ideas are valid. Then **act**. Implement widely if it is a success, or abandon if it is not. Where a new procedure is adopted, standardise it and make it part of the culture.

Note that the cycle is about learning and about ongoing improvement. You learn what works and what does not, in a systematic way. And the cycle repeats. After one cycle is complete, another is started, as shown in Figure 4.

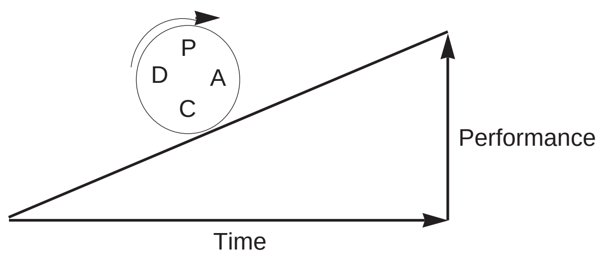


Figure 4: The Deming cycle

The deadly diseases

The seven **deadly diseases** of quality, as Deming terms them, are a severe criticism of Western management and organisational practices. The first five are closely related. They are always worth considering, and re-considering:

1 **Lack of constancy of purpose** appears in Deming's 14 point plan. It is a reminder about inconsistent policy on quality, particularly as the end-of-period rush begins! The twin of this point is point 2.

2 **Emphasis on short-term profits** is a reminder to take a more consistent view, without being influenced by the end-of-period financial performance. And this may be brought about by point 3.

3 **Over-emphasis on performance appraisal and merit rating**, particularly when judged solely on financial performance. In our introductory section on Deming, we discussed variation. If variation is not understood, appraisal can be literally destructive. Deming is particularly worried by the emphasis on short-term results rather than on coaching and helping staff to develop their potential. This is made worse by the next two diseases, points 4 and 5.

4 **Too much staff mobility**, where managers do not get to learn the real problems and requirements of an organisation.

5 **Over-dependence on figures**, particularly financial, which can be massaged to look good in the short term, while the longer term suffers.

6,7 These last two points relate to **excessive medical costs** and **excessive legal costs**, which Deming believes are paralysing competitiveness. Some would regard these as being typically American problems, but they may be a foretaste of problems to come in Europe.

ACTIVITY 7

Not all managers agree with Deming. What are your views ? For example, do you favour performance-related pay? Deming does not. Some of your friends or colleagues may have examples of people who have been rewarded or promoted unjustly. How do you 'drive out fear' of job loss whilst improving quality and productivity?

The Ford Motor Company has been a committed Deming enthusiast for several years. Some Ford executives, including its then president, have cited the adoption of the Deming philosophy as being a principal reason for the turn-round in profits during the latter years of the 1980s.

2.2 Juran

Like Deming, Dr Joseph Juran (1979, 1988) is given credit for developing Japanese quality in the 1950s. His books on quality since then have had a profound influence around the world, and are so wide-ranging it is difficult to highlight particular contributions from the many that have been made. Perhaps the best known Juran concepts are his definitions of quality, the concepts of **breakthrough** and the **internal customer**, and the **quality trilogy**. Juran also was responsible for **Pareto analysis** as applied to problem solving, for work on the costing of quality, and for the idea of a **quality council** within the organisation.

Juran believes quality is associated with product satisfaction and product dissatisfaction. Both require consideration. **Satisfaction** occurs when a product has superior performance or features. **Dissatisfaction** occurs when there are deficiencies or defects in the product or in its service or support. Thus there are two dimensions, an external one concerned with matching customer requirements, and an internal one concerned with building the product or service correctly. Juran has proposed the well-known definition of quality as **fitness for purpose**. This is not as simple as it sounds. We need to ask, 'for whose purpose?', and 'what is the real purpose?'. There may be many possible customers, both internal to the company and external, who may use the product in different ways. Quality begins with a close understanding of who the users will be and how and where the product will be used. Without this customer orientation, good quality is not possible.

And what is an **internal customer?** Each person along the chain, from product designer to final user is both a supplier and a customer. Also, of course, the person will be a 'process', carrying out some transformation or activity. The process is subject to all the concepts of process control. Taking these together, this is what Juran calls the **three role model**, that is each stage is a supplier, a process, and a customer or user. So our customer orientation applies internally as well. At each stage there is the opportunity to improve the product, perhaps making it easier to handle, or fit together, or maintain, or update.

Juran emphasises the necessity for ongoing quality improvement. He maintains that this is only achieved through **project-by-project** improvement, in other words by a succession of small improvement projects carried out throughout the organisation. Projects may be suggested by management, by operators, by quality specialists or by Pareto analysis of existing problems. Juran was the first to name the **Pareto principle** and to describe it as a universal problem-solving methodology. The Pareto principle simply sets out to identify the 'vital few' as opposed to the 'trivial many' or the 'useful many'. This is the well-known phenomenon that there will always be a relatively few processes or people or defects or problems that take up most of the time or effort or cost. Hence it makes sense to identify these and to tackle them first. Pareto analysis is one of the seven tools, considered in Section 4.

Improvement projects can also be identified through costs and Juran was responsible for suggesting that **quality costs,** or the costs of not getting something right first time, should be recorded and classified. Money is the prime language of management, so that if the costs of poor quality are known this not only gets management attention but helps identify where effort should be made. For Juran, it is necessary for middle managers in the quality area to be able to translate the language of things into the language of money and vice versa. To do this we need a classification system.

Quality costs can be classified into:

- **failure costs:** both internal, such as scrap and rework; and external, such as guarantee claims and perhaps loss of custom,
- **appraisal costs**, such as inspection,
- **prevention costs**, such as education and SPC implementation.

Such costs can be obtained relatively rapidly by careful interviews or perhaps more accurately by a parallel accounting system, but in any case should be assembled in order to direct and evaluate progress on quality improvement. We deal with quality costs in Section 6

Project-by-project improvement is perhaps similar to the Deming cycle and leads straight into the quality trilogy. The **quality trilogy**, according to Juran, comprises

quality planning, quality control, and **quality improvement**. These can be seen as being parallel to the financial processes of budgeting, cost control, and cost reduction. Good quality management requires the quality actions to be planned out, improved, and controlled. We can view the process as achieving control at one level of quality performance, then planning to be better, project by project using various tools and techniques, then eventually achieving **breakthrough** to an improved level, and then once again controlling at the new level.

This series of actions will not take place by chance or by a series of unco-ordinated actions. Rather, they must be organised in a systematic way. This is where the **quality council** comes in. This body, typically consisting of senior managers, has the responsibility for co-ordinating the quality improvement actions and projects. They would, for example, set goals, identify needs, establish training, ensure measurements, such as quality costs, undertake co-ordination, and in general liaise between quality projects and top management.

In another parallel with the Deming cycle, the Juran **breakthrough sequence** sees the improvement process as taking two 'journeys': the 'journey from symptom to cause' and the 'journey from cause to remedy'. The first journey moves one from the problem to the 'diagnosis' and may be seen as parallel to the 'P'(plan) and 'D' (do) stages of the Deming cycle. Here we are concerned with identification, using, for example, Pareto, and with the generation of and testing of hypotheses as to what might be the contributing causes. The second journey moves the 'diagnosis' to the 'solution' and may be seen as parallel to the 'C' (check) and 'A' (act) stages of the Deming cycle. Here we select the appropriate cause, implement the necessary actions, and then replicate the improvements where possible in other areas.

More recently, Juran has spoken about **Big Q**. This is to emphasise that quality is not just the concern of production or even of total quality within the organisation, but extends further into the linkage between organisations, and includes all service organisations and operations.

2.3 Crosby

Like Juran, Phil Crosby (1979, 1989) has been a prolific writer on quality. Unlike Juran, who uses much quantitative and statistical techniques, Crosby concentrates on quality philosophy, particularly relating to management. Crosby's dynamic speaking style and stimulating writing style have gained him a large following.

Crosby is perhaps best known for his **four absolutes** of quality, his phrase 'quality is free', his 14 point plan which is different from Deming's 14 points, and his commonsense approach to a wide range of quality topics.

Crosby's four absolutes are :

1 **The definition of quality is conformance to requirements**. This very specific definition of quality leaves very little in doubt, which is probably what Crosby

intends. According to Crosby, once the requirements are specified then quality is judged solely on the criteria of whether it is met or not; aesthetics or feelings don't come into it. It is then the duty of management to specify those requirements very clearly, to say what they want, and this, Crosby believes, is one of the major failings of management. Of course, if management does not decide what is needed then by default, operators are going to have to make that decision for the company!

2 **The system of quality is prevention**. In other words, prevention is better than detection or appraisal. This is very much in line with the philosophy behind SPC; understand the process, look at what can go wrong, and take preventative actions before the process begins to deal with customers.

3 **The performance standard is zero defect**, or 'ZD', as Crosby calls it. Here Crosby is stating that nothing less than perfect quality has to be the aim. Setting targets below 100% is the start of a downward spiral. Of course, traditional quality management has taken zero defects to be uneconomic, and there should be a trade-off between prevention costs and failure costs. The Crosby view is now supported by a developing view that prevention costs, particularly where 'total quality' is in place, do not necessarily rise massively as we approach zero defects, but in fact rise by no more than failure costs fall. In other words, zero defect may well be optimal from a cost point of view, but again it comes back to getting the requirements right in the first place.

4 **Measurement of quality is the price of non-conformance**. Like Juran, Crosby believes in costing quality as a prime motivator for management. Here Crosby's famous phrase 'quality is free' is appropriate. As he says, 'it's not a gift, but it's free' or, in other words, if you put effort into improving quality it will more than pay for itself through improved productivity, reduced rework and claims, and improved customer satisfaction. Crosby classifies costs into:

- **PONC:** the price of non-conformance, all the costs involved in not getting the product or service right
- **POC:** the price of conformance, what it costs to do things right; prevention, detection, etc.

Crosby's **quality vaccine** can be related to the Deming 14 point plan. In typical stimulating style, Crosby's vaccine is preventive medicine for management against poor quality. The vaccine comprises practical advice on 21 areas, subdivided into five sections. The quality vaccine is in fact a succinct summary of what is needed for total quality management.

- The first section deals with **integrity**. This is really about taking quality seriously, from chief executive to every employee. If quality is taken as 'first among equals' – the others being marketing, finance, operations, and so on, then everyone understands that their own future and the future of the company will be judged on performance on quality.
- The second section deals with **systems** – for quality costs, for education, for quality performance, for review and improvement, and for customer satisfaction. All of these must be designed and put in place.

- The third section deals with the need for **communication** and for communication systems that will make clear the requirements and specifications, and which will communicate improvement opportunities within the organisation. Crosby often emphasises the importance of listening to customers, and to those front line employees who often know what is needed but perhaps have never been asked. Also external communications, in advertising, letters, and product information must convey a consistent message.
- The fourth section deals with **operations**, including working with and developing suppliers. Processes must be prepared prior to use and made capable, and process improvement must become the norm.
- And lastly, Crosby maintains that **policies** must be made clear and consistent throughout the organisation.

2.4 Other quality gurus

Several other people may qualify for the title of 'quality guru'. We will not discuss their contributions at length here but summarise a few points. For more details see Bicheno (1994).

Armand Feigenbaum, an American engineer, is known as the originator of **total quality control**. He referred to the **industrial cycle** which brings new products to market, and stressed the necessity for marketing, design, purchasing, manufacturing, production, inspection, packaging, distribution, and service all to play roles.

The late Kaoru Ishikawa is regarded as the leading Japanese contributor to quality management. His contributions are extensive but perhaps the most noteworthy are his total quality viewpoint, his work on statistical process control, his emphasis on the human side of quality, and his invention of the Ishikawa diagram and the use of the **seven tools** (see Section 4**)**. He is revered as the father of **quality circles**, since it was he who furthered the concept of circles and popularised their practice in Japan.

Genichi Taguchi is a Japanese statistician and engineer whose concepts began to make an impact in the West during the 1980s. His principal contribution has been to our understanding of what specifications really mean, and how such specification can be translated into cost effective design and production. This is done by **Taguchi Methods** which we briefly discuss in Section 6.

Summary

In this section we discussed the contributions of leading quality management figures, principally Deming, Juran, Crosby. We also mentioned other quality 'gurus' like Feigenbaum, Ishikawa and Taguchi.

SECTION 3

Total Quality Management

Introduction

In this section, we will bring together definitions of quality and the views of the quality ‘gurus’, and gain an insight into how we can integrate everything into total quality management (TQM). We will look at two ‘systems’ of quality: the ISO 9000 standard and the quality awards. The ISO standard sets the framework for the procedures of total quality. The awards go beyond this, to consider the total picture and how quality should be related to the rest of the organisation.

3.1 Overview of TQM

TQM became popular in the late 1980s. It was widely adopted in service and manufacturing firms and probably reached ‘fad’ status in the early 1990s before slipping back on the list of corporate priorities. Nonetheless it remains an important development, the effects of which are likely to remain in all good organisations. TQM can be seen as a natural extension and consolidation of the views of the quality ‘gurus’ together with the realisation that poor quality does cost in terms of hard cash and loss of future market share, and that good quality can offer a definite competitive edge. All of the techniques and tools discussed in later sections are relevant to TQM. TQM integrates all of these, plus other concepts particularly from marketing and organisational behaviour.

TQM explicitly recognises that good quality is not the preserve of the quality department, nor is it even the responsibility of operations, but requires involvement across the board. The concept is of a **chain of quality** involving everyone and every process from product, or service, concept and market survey, to design, to engineering, to manufacturing, to packaging, to sales, to distribution, to field service. In other words, the complete cycle of service, all moments of truth, the closing of all gaps, and the perception that each link or process in the chain has as its customer the next link or process. It demands participation by all. It demands awareness of the costs of quality, not just departmentally but by process. And it recognises that quality is only as good as the weakest link.

This is truly a bold vision. It is also proven to be a most difficult vision to achieve, one that only perhaps one-third of companies have managed.

On a rather simplistic level we can contrast the TQM view with the traditional view by looking at Figure 5. The traditional view is inspection-based. Quality is seen as inspecting and controlling incoming materials and inspecting finished products. The TQM view, by contrast, begins with the customer, seeking to understand his or her needs and expectations, and designing quality into the product. It then works with suppliers so as to achieve component and material delivery of good quality without relying on receiving goods inspection. Finally, it controls the processes, through, for instance, SPC and process capability, but also through involving everyone and every process. This avoids the necessity for finished goods inspection. This is undoubtedly an oversimplified view of TQM, but it serves as a quick overview.

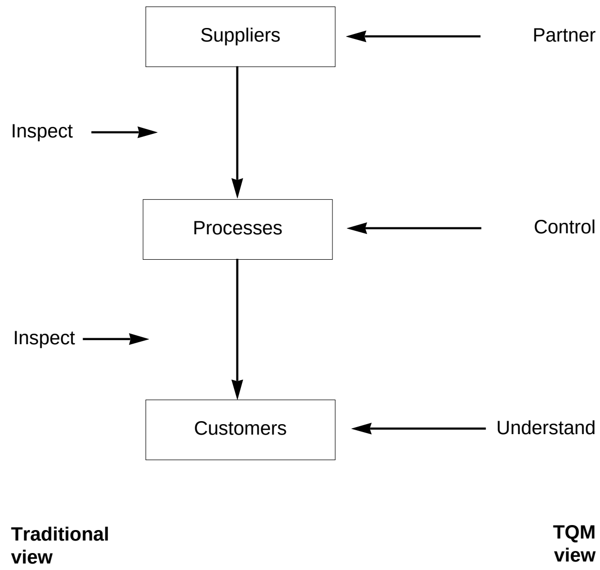


Figure 5: Flow process view of quality

THE OAKLAND MODEL

A more comprehensive conceptual view of TQM has been proposed by Professor John Oakland (1995) of Bradford Management Centre. The Oakland concept is shown in Figure 6. At the centre, is the **process chain**. This conveys several messages:

- quality should be seen as a customer-serving process rather than a department
- chains of linked processes go all the way from product concept to product delivery and beyond
- quality can only be as good as the weakest link in the chain.

Along a chain there are processes each with customers and suppliers, some of them internal some external. TQM is driven by teams, often cross-functional, rather than individuals who work together for improvement and control. The teams use 'tools' such as the seven tools we discuss in Section 4, and make use of 'systems' such as ISO 9000 and others particular to the organisation. Systems are linked to tools for policies regarding training, updating, and maintenance. And TQM requires top management commitment and indeed commitment by everyone. It requires a culture of insistence on standards, of continuous improvement, of support and 'no fear' as Deming would say. Further the quality message, including clear standards and specifications, must be clearly communicated. The Oakland model (see Figure 6) is therefore a concise way of tying together much of what we have discussed throughout this unit.

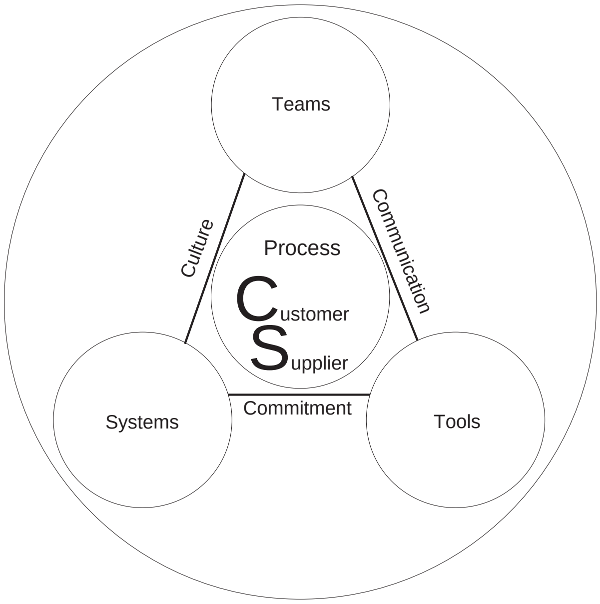


Figure 6: The Oakland TQM model: major features

Referring to the Oakland model (Figure 6), we will not deal with the 'teams' aspect in this unit, even though it is a vital part of TQM. The teams and organisational aspects are better dealt with in your organisational behaviour studies.

In the following sections, we will look at two of the 'systems' of quality: the ISO 9000 standard, and the quality awards. The ISO standard sets the framework for the procedures of total quality. The awards go beyond this, to consider the total picture and how quality should be related to the rest of the organisation.

These systems are best thought of in the order in which we present them. The ISO 9000 system sets the procedures in place, which can then be followed by wider considerations.

In Section 4, we look at some tools of quality.

3.2 The ISO 9000 system

The International Standard 9000 is now the world standard code of practice for quality assurance systems. Two common misconceptions must be cleared up immediately. Firstly, these are recommended standards for quality systems, they are not about actual product or service quality. It is possible for an organisation to be registered under ISO 9000 and still be producing products which are defective and not to customer requirements. Product quality is not necessarily better than that in non-registered companies. Secondly, the standards do not lay down a set of procedures to be followed. To some, especially smaller companies, ISO 9000 is unnecessary bureaucracy. But to many it is a way of demonstrating, internationally, that the company takes quality seriously and has thought through its quality system. It has become a marketing advantage and a trade facilitator.

What the standards do is to require conformity to documented practices specified in the company's own quality systems. The standards give the areas that need to be considered: the company installs its own most suitable response, documents it, maintains it, updates it, and guarantees that its own procedures are followed. Unannounced external audits are necessary to ensure compliance of the company with its own standards. Certification can only be awarded by an accredited third-party registrar. Certification would involve a company in (at least) preparing a written policy statement, writing a quality manual on its own systems and procedures, as well as making available all documents and controls as required.

The standards follow the logic of what is required to run a controlled business. To illustrate, consider the next activity.

ACTIVITY 8

The idea for this activity comes from the British Standards Institute. Imagine you are running a business for making and distributing orange juice from fresh oranges. You have contracts for the supply of oranges, and a laboratory which tests different formulations of juice from oranges from several countries. You would obviously like to have close controls on the product and processes. What controls and procedures do you consider necessary? Perhaps it would be helpful to construct a flowchart, or process chain, of the steps involved. Be as thorough as you can; consider all possibilities.

Your process chart would probably contain at least the following activities:

- draw up contracts with suppliers,
- decide incoming test procedures,
- formulate the mixes,
- carry out the mixing,
- keep records of what you have mixed,
- sample the mix,
- throw away poor quality product safely,
- pack,
- distribute,
- maintain the equipment,
- maintain the test equipment, etc.

Now compare your activities with what ISO 9000 would recommend you to do. This is summarised below.

Quality system requirements: summary of main sections of ISO 9000

1 Management responsibility

1 Policy: ‘shall define and document its policy... and commitment...’

2 Organisation: ‘the responsibility, authority, and interrelation, (particularly for those who initiate action, identify and record problems, initiate or recommend solutions, verify implementation, control conformance).

3 ‘Verification’ (resources and personnel concerned with inspect, test).

4 A representative who shall have responsibility for maintenance of the standard.

5 ‘Shall be reviewed at appropriate intervals...’

2 Quality system: ‘shall establish and maintain a documented quality system’.

3 Contract review: ‘establish and maintain procedures’ for contracts entered into.

4 Design

1 ‘...procedures to control and verify the design of the product...’

2 Design shall be assigned to qualified personnel.

3 Design input requirements shall be identified, documented. Incomplete, ambiguous, conflicting requirements shall be resolved.

4 Design output shall be documented (requirements, calculations).

5 Verification: shall plan and use competent personnel.

6 Design changes: establish and maintain procedures.

5 Document control

1 Document approval: maintain, distribute, destroy obsolete documents.

2 Document changes: procedures for review, keep master list, reissue.

6 Purchasing

1 General: ensure purchased material conforms to specification.

2 Assessment: Select suppliers on the basis of meeting requirements.

3 Data: documents shall contain data clearly describing the product.

4 Verification: purchasers shall be allowed to verify at source.

7 **Purchaser supplied product**: procedures established for verification, storage and maintenance of supplied product, and for damage reporting.

8 **Product identification and traceability**: where appropriate traceability from drawings, and from all stages of production.

9 **Process control**:

General: plan the production and ensure that processes are carried out under controlled conditions including documentation, monitoring, approval, criteria, standards.

Special processes: for processes where results cannot be verified, monitoring and records are required.

10 **Inspection and testing**

Receiving: incoming product is not used until verified.

In process: inspect, test, hold product until verified, identify non-conforming.

Final inspection: planned and carried out, not released until completed.

Test records: establish and maintain records which show that product has passed.

11 **Inspection, measurement and test equipment**

Control, calibrate and maintain equipment by whoever owned. Shall be used in a defined manner consistent with capability:

identify measurements to be made

identify, calibrate and adjust all equipment that can affect product quality

establish, document, maintain calibration procedures

ensure that inspection equipment is capable of required accuracy

show the calibration status on each piece

maintain records

assess and document the validity of previous inspections when calibrations are found to be needing adjustment

ensure that environmental conditions are suitable for testing

ensure that handling of test equipment is careful

safeguard test facilities.

12 **Inspection and test status of products**: shall be shown by suitable markings, stamps, tags, etc. Identify the authority responsible for release.

13 **Control of non-conforming product**: establish and maintain procedures. Non-conforming product shall be reviewed by documented procedures.

14 **Corrective action**: 'establish, document, and maintain procedures for':
investigating the cause of non-conforming material
analysing all processes, operations, complaints, potential problems
initiating preventative actions
applying controls to ensure preventative actions are taken
implementing and recording changes.

15 **Handling, storage**, **packaging and delivery**: establish, document, maintain records for each.

16 **Quality records**: establish and maintain procedures for identification, collection, storing, etc. Records of achievement shall be maintained. All records identifiable to the product involved. Readily retrievable.

17 **Internal quality audits**: a comprehensive system of planned and documented audits to determine the effectiveness of the quality system. Results documented and brought to attention of responsible personnel.

18 **Training**: procedures for identifying needs and providing for training. Training records kept.

19 **Servicing**: where there is servicing, records shall be maintained.

20 **Statistical techniques**: where appropriate, procedures established for process capability.

Note: this is summarised from ISO 9000.

How did this list compare? You can see that ISO 9000 could be regarded as just good business practice. Do you agree? Some do not! Notice that ISO 9000 expects you to improve, so it is compatible with the continuous improvement or Kaizen philosophy, with the Deming Cycle, and with Juran's breakthrough sequence.

3.3 The Baldridge and European Quality Awards

THE BALDRIDGE AWARD

The Malcolm Baldridge National Quality Award was established as a US Public Law in 1987 and is administered by the US National Institute of Standards and Technologies (NIST). The aims of the Baldridge are to:

- stimulate companies to improve quality
- recognise achievement in quality
- establish guidelines for self-evaluation
- publicise successes in quality and learn from the winners.

The real purpose of the Baldridge is to educate. It is not an alternative to ISO 9000, which addresses many of the same categories, but you should regard them as complementary.

Although the Baldridge is a competition for US companies it has become perhaps the most comprehensive statement on just what total quality really means and requires. As such the framework can be used by any company, US-based or not. Many British companies use Baldridge as a measure of their TQM efforts, even though they are not eligible to enter the competition. Awards are made in three categories: manufacturing, small business, and service, and are presented by the President of the USA. For US companies, there is considerable prestige and market advantage in winning, or even reaching the site visit stage, but entering itself forces a comprehensive discipline for the company and commitment by management.

The award is structured around four basic elements, seven areas, and 28 categories, which should form a dynamic relationship. 1,000 points are identified. A brief summary follows:

The driver

1 Senior executive leadership. This examines the personal commitment of senior management to quality and customer focus. Customer focus is expected to be integrated into everyday leadership, and leadership should demonstrate a concern, amongst others, for ethics and public health and safety.

The system

2 *Information and analysis*. This examines how information is used to support prevention-based quality. Information must be timely and reviewed regularly. Benchmarking must be done and kept up-to-date.

3 *Strategic quality planning*. This examines the process of planning for, and retaining, quality leadership. Quality plans must be integrated into business plans, and measures to track performance of both the company and its suppliers kept.

4 *Human resource development and management*. This examines how human resourcees are planned and managed as part of quality. How are employees involved, and how they are educated, trained, and recognised? Their morale is also considered. Performance measures must be in place, and attention given to ergonomics, health and safety.

5 *Management of process quality*. This covers the processes used in design, production, support, supplier management, and quality assessment. The conversion of customer needs into products and services must be demonstrated. Prevention must be emphasised, and continuous improvement must be used.

Measures of progress

6 *Quality and operational results*. This examines the measurement system applied to products, services, suppliers, business processes, and operating

results. Quality levels in these areas must be compared with competing companies.

The goal

7 *Customer focus and satisfaction*. This important area covers the company's knowledge of, interaction with, and commitment to customers. The methods used are examined, and how customers feel about the company in relation to its competitors.

THE EUROPEAN QUALITY AWARD (EQA)

The European Foundation for Quality Management (EFQM), a consortium from leading European companies, launched a European version of the Baldridge in 1992 (EQA). Like the Baldridge, the EQA is an interesting definition of just what is needed for total quality. The EQA differs from the Baldridge in as far as it sees TQM having an impact, not only on business results, but also on customer satisfaction, employee satisfaction, and eventually an impact on society. The first winner of the EQA was Rank Xerox.

The EFQM categories are subdivided into the **Enablers** and the **Results** and are as follows:

Enablers	**1993 Points (max.)**	**Area**
Leadership	100	behaviour of all managers
Policy and strategy	80	mission, values, vision, direction
People management	90	management of company people
Resources	90	management, utilisation, preservation
Processes	140	all value adding activities
Results		
Customer satisfaction	200	perception of external customers
People satisfaction	90	people's feelings about the company
Impact on society	60	perception amongst the community
Business results	150	business performance

The awards have not been without their critics. Phil Crosby has entered a debate which has ranged across several magazines and journals, including *Harvard Business Review* and *Quality Progress*. Crosby claims that the Baldridge is positively detrimental, resulting in diverting attention away from improving the lot of customers to being more concerned with the internal procedures and documentation necessary to win the award. Crosby's critics say that by undertaking all the steps required for the award, customers will ultimately benefit, and anyway the award is really about good business practice. Whatever the arguments, it is a fact that the number of organisations entering the Baldridge competition is sharply down from the heydays of the early 1990s. It will be interesting to follow the trends of the EQA. Perhaps you could investigate yourself; it is bound to be controversial for several years to come.

ACTIVITY 9

Read the article 'The straining of quality' (Resource Item 6.1) for an update on the progress of TQM. After reading the article, consider whether TQM is destined to be yet another management 'fad' or something permanent and substantial.

It might be easy to conclude that TQM has become, or will soon become, just another 'has-been' management concept. But remember that the companies discussed in the article are all world leaders in quality: most companies are nowhere near achieving the quality levels of, say, Motorola. The article is also interesting because it ties in with topics we discuss in Unit 9, *Time Based Operations*.

Summary

In this section, we have brought together definitions of quality, the views of the quality 'gurus', and integrated them into TQM. 'Total' in TQM means *total* processes, *total* people, *total* materials, and *total* ongoing improvement. TQM demands participation by teams, using tools and systems. Some specific systems or models were looked at, namely ISO 9000 and the Baldridge and European Quality Awards.

All this rests on 'culture, commitment, and communication', factors that we briefly looked at in the meaning of quality and gap analysis.

In the next sections, we will expand upon some of the tools and concepts referred to in the Oakland model.

SECTION 4

Seven Tools of Quality

Introduction

This section introduces the **seven tools of quality**, which were originally assembled by Kaoru Ishikawa for use with quality circles. In this respect, and referring to the Oakland total quality model, tools are used by teams in relation to the quality process chain. The seven tools, when used together or even individually, are a 'first line' attacking force for quality improvement. They are taught to a large proportion of operators in Japan and are now increasingly used by operators worldwide.

The seven tools are widely used in service and manufacturing. Each year the National Society for Quality through Teamwork holds its national conference in Britain. Teams from a wide variety of companies make presentations. The use of two or more of the seven tools is cited in virtually every presentation.

We present the tools in the order in which they are commonly used, although many variations are possible.

4.1 The process chart

The **process chart** lists every step that is involved in the manufacture of a product or in the delivery of a service. It has long been used by work study officers, who usually use special symbols to indicate 'operation', 'delay', 'move', 'store', and 'inspect'. We look at these issues in detail in Unit 7. The process chart helps identify wasteful actions, and documents the process completely. Good communication is an important reason to do this. The systematic record helps reveal the possible sources of quality and productivity problems. Two important variations of the process chart are the flowchart and the **cycle of service** diagram, that you met earlier.

It is a good idea to draw the process chart using the standard symbols (see Figure 7) because this aids clarity. The chart can be plotted against a time scale if time is critical. Process charts should also be used to document a process after it has been changed. This serves as a future record and can be used for 'auditing' the process, to see if it is still being carried out in the way it was designed.

Many companies already have process charts. If they are available, beware! There are often differences between the 'official' process charts and the way things actually happen in practice. The team or analyst should take the time to follow through a number of products, services or customers, documenting all apparent wastes and noting any major problems that occur. Often several actions and 'rework loops' unknown to management will be discovered. But it is not the purpose of the chart to be used for 'policing'. Often a team will draw up a chart for their own use and is not obliged to turn it over to management.

Some process charts can be very long and complicated. If so, break them up into sections of responsibility. Also use a hierarchy, with the overall process shown in outline and the detail on several sub-charts.

In the service sector, process charts can be made more effective by dividing the page into two halves. On one half, show those actions where there is direct interaction with external customers. On the other half, show actions that are entirely internal. For example, in the process chart of checking a guest out of a hotel, the front desk sequence of actions are shown on the left and the accounts office actions on the right. The two halves are, of course, linked by the complete sequence of events.

A **flow chart** is similar to a process chart and is often used when there are decisions involved. The symbol for a decision, a diamond, would lead to branching as a result of different decisions. Flow charts are often used with computer systems and usually do not include the standard process chart symbols. However there is no reason why these symbols should not be combined.

Whether using a process chart, a flow chart, or a cycle of service, these charts are best assembled using a team approach, preferably the people who are 'front line'. Using the charts, the team can begin systematically to document the nature of quality problems and defects. This leads onto the next tool. Examples of a process chart and a flow chart are given in Figure 7.

4.2 Pareto analysis

Pareto analysis is known by several names including **ABC analysis** and the **80/20** rule. Whatever the name, it is one of the most effective yet simple tools available. Pareto analysis recognises the fact that, invariably, a small number of problem types account for a large percentage of the total number of problems that occur. The name 80/20 is representative of this; perhaps 80% of all problems are due to 20% of all the types of problem that occur. Often 90/10 would be more typical. The name ABC is also a good one. This suggests that the range of types of problem be classified into A, B, and C categories, designating their importance. Pareto analysis is also good practice in many other fields of management, for example, inventory control, forecasting, marketing, and personnel.

It makes good sense to tackle the most pressing problems first; the 'vital few' as Juran calls them. When these are successfully eliminated or reduced, of course, another problem will head the list. So now tackle that one. And so on. Continuing in this way is an effective on-going improvement methodology.

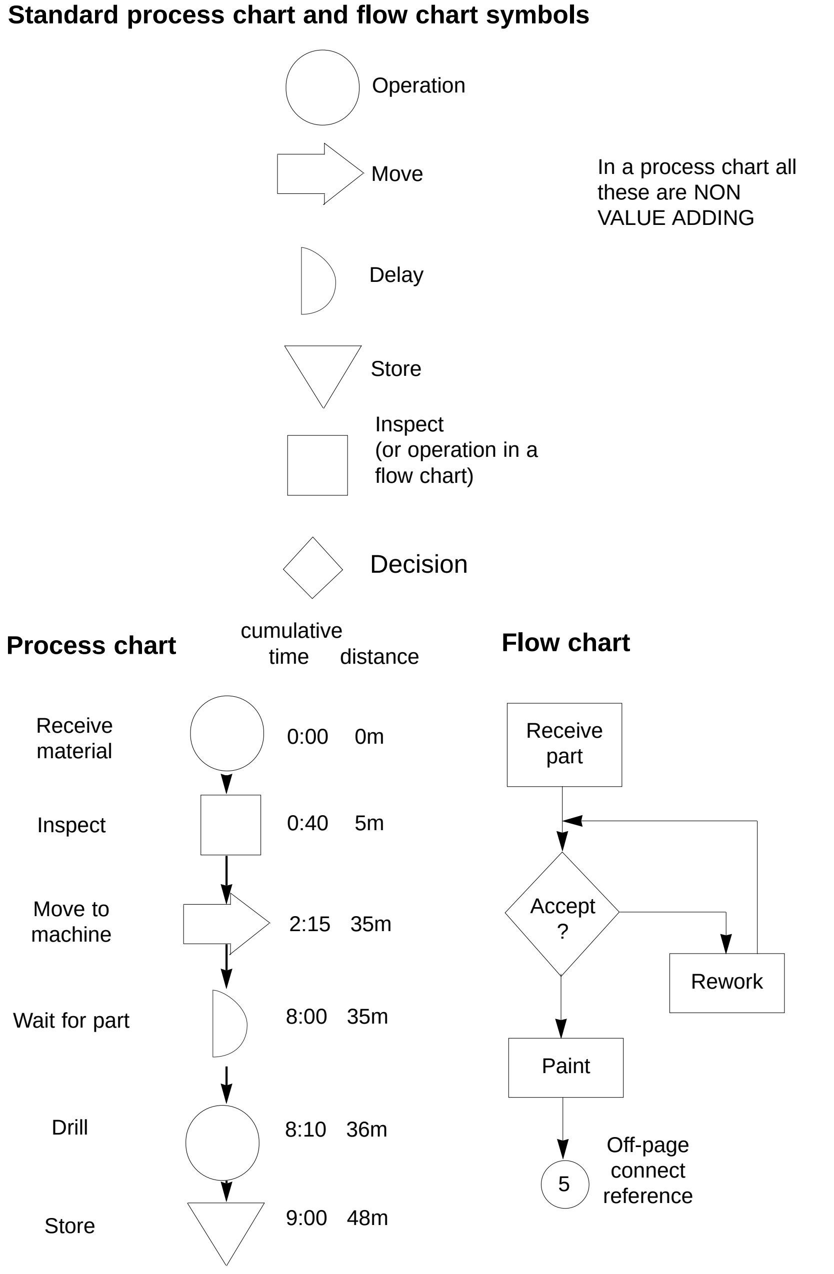


Figure 7: The process chart and flow chart

Pareto analysis begins by ranking problems from highest to lowest. Then the cumulative number of problems can be plotted on the vertical axis of the graph. Along the horizontal axis are arranged the problems in descending order. You can see that the resulting graph rises rapidly then tails off to an almost flat plateau (see Figure 8). Now it is easy to pick out how many problems need top priority attention.

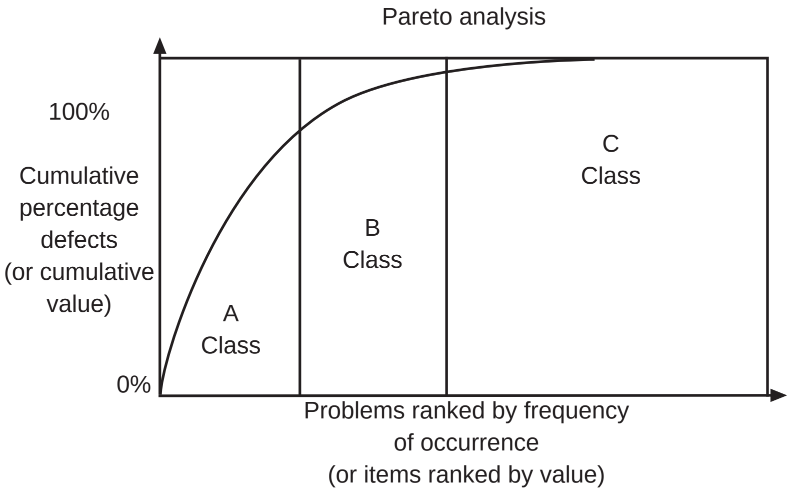


Figure 8: Pareto analysis diagram

Now the team has used the process chart to list and classify the problems, and Pareto analysis to identify the most serious problems. In the next stage, the team would begin to explore possible causes and their solution.

4.3 The Ishikawa diagram

The Ishikawa diagram, also known as the **cause and effect** diagram and the **fishbone** diagram, is used to brainstorm out possible contributing causes of a particular problem or defect. It follows directly from the Pareto diagram, with the most pressing problem becoming the spine of the 'fish'. An example is shown Figure 9. The name 'fishbone' clearly represents the shape of the diagram.

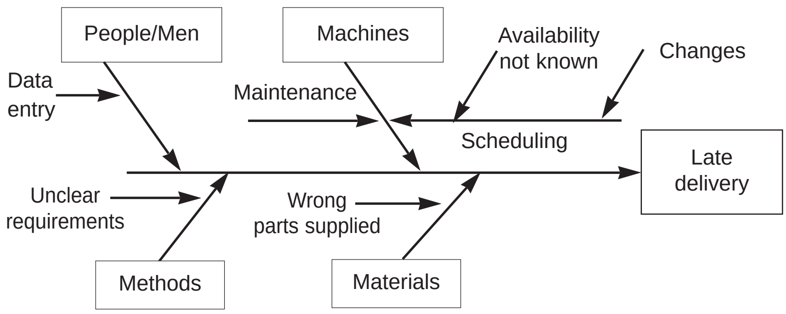


Figure 9: The Ishikawa fishbone diagram

As you can see, contributing causes are written on the diagram, arranged in a hierarchy. Hence the name cause and effect. If you experience some difficulty in starting off the diagram, use the '4 Ms' (men/people, machines, methods, materials) as four initial 'bones'. Usually the diagram is built up by one person writing in points on it while team members contribute their ideas.

ACTIVITY 10

Brainstorm ways in which your business studies programme or any course or class that you are currently taking could be improved. Enter them on the Ishikawa diagram.

You do not need to use the 4 Ms framework as the main fishbones. You could, for example, use lectures, seminars, materials, and back-up (for example, library, computers). The Ishikawa diagram offers a concise and visual way in which contributing causes can be documented on one diagram. It requires only seconds of instruction in order for any employee to understand.

A variation on the Ishikawa diagram is the **CEDAC** diagram, originally developed by Fakuda. CEDAC stands for **cause and effect diagram with addition of cards**. It is the same Ishikawa diagram except that cards, containing notes and ideas on each particular cause, are added to the diagram. Usually there are slots made for each cause, giving access to a pocket into which cards are placed. This addition is very useful because it allows elaboration on the thinking. The diagram can be kept on display, and as further information or thoughts are acquired, they are added to the pockets. This prevents 'reinventing the wheel'. Fakuda has developed the CEDAC concept into a complete improvement methodology. Here, a team brainstorms out possible improvements, writes them up on cards, and places them on the left side of each fishbone. When the idea is implemented it is moved to the right side of the fishbone. Thus, we maintain a visible record of ideas already implemented and to be implemented.

Now with the range of possible causes identified, it is a good idea to firm up on the information that is available. This is where the next tool comes in: the histogram and measles chart.

4.4 The histogram and measles chart

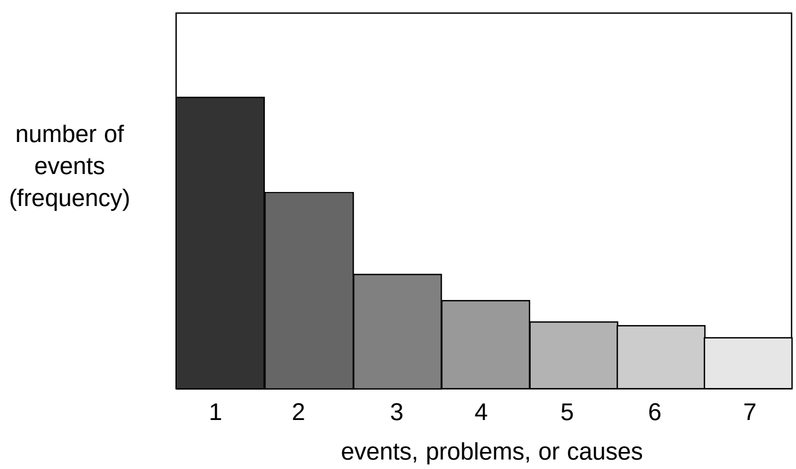
The **histogram** has much in common with the Pareto diagram. It is used to show graphically the relative number of occurrences of a range of events. Using vertical bars, it plots frequency on the vertical axis against events, arranged one after the other on the horizontal axis. You should already be familiar with histograms from your studies in quantitative methods.

Following from the Ishikawa diagram, data is collected and classified according to each of the causes suggested. This data is shown on a histogram, from which the most important causes should be apparent. As with the Pareto diagram, it is then clear which causes require further investigation.

Histograms can be used to collect data as it happens. For example, a flip chart is set up right at the work station. As problems occur they are written down on the flip chart. When the same problem recurs, a tick is placed next to that problem. In effect this is building up a histogram. In this case, the histogram is lying on its side, but that does not matter. The problems with the most ticks are obviously the most frequently occurring and most urgent problems. Such a flip-chart histogram has the great advantages of being easy to use, visible for all, and up-to-date.

A special form of histogram, with similarities to the flip-chart procedure, is **the measles chart**. Here, defects or problems are simply plotted on an engineering drawing, blueprint or map at the location where the problem occurs. The accumulation of marks on the drawing gives an excellent impression of where the problems lie. It avoids numerical or written description and may lead to the rapid identification of related problems. A symmetry of the defects may indicate a process problem, but a lack of symmetry may indicate a maintenance or wear problem. There are extensions of this technique: times can be written in; or different symbols used for different operators. Measles charts are widely used outside of manufacturing. Traffic police and engineers use them to pinpoint accident black spots, and for example, a theme park could use them to track litter problems, complaints, and areas where children tend to get lost. The histogram and measles chart are shown in Figure 10.

The histogram helps identify likely causes. The next stage requires some experimentation to find out how that cause can be eliminated. The next set of tools, **run diagrams**, is appropriate.



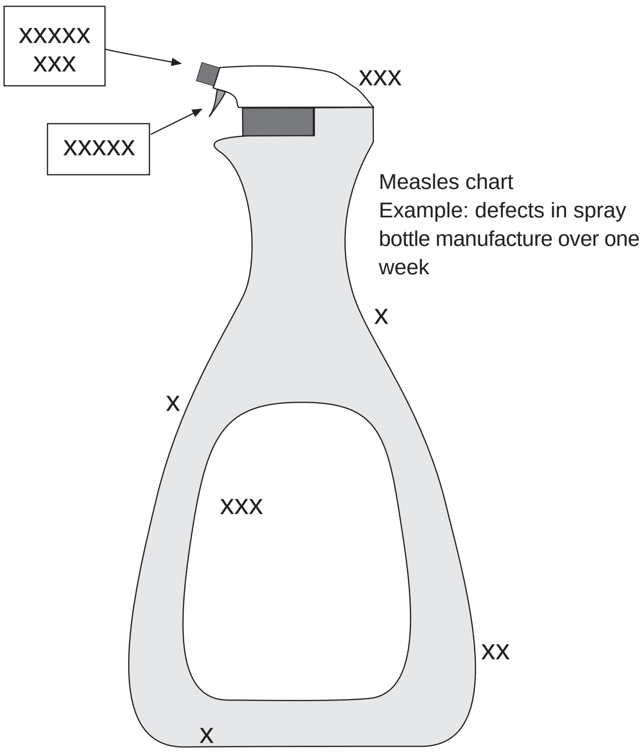


Figure 10: The histogram and measles chart

4.5 Run diagrams

Run diagrams are used to explore relationships between events and time, and between problems and causes. They are used for basic experimentation, to find out when and how problems arise and how problems can be rectified. Despite sounding rather scientific, they are often simple but very effective, and certainly within the capability of most operators and front-line personnel.

The run diagram is simply a graph of the number of events plotted against time. For example, a record can be kept of the number of complaints over time. This may reveal that complaints occur at the beginning of the month or at a certain time of day. If defects produced on a machine are plotted against time, we may discover that most defects tend to occur when the machine has been used for some time (hot?) or just after the tea-break (carelessness?). A common use for a run chart is to detect slow trends, that is, a gradual increase or decrease. For this, the charts have to be maintained over a long period.

ACTIVITY 11

Consider the three run diagrams shown in Figure 11 below. They show weights taken from a breakfast cereal filling line. The vertical bars show the range (minimum to maximum) of weights taken from batches over the course of a few days. What do they suggest to you? What are possible reasons?

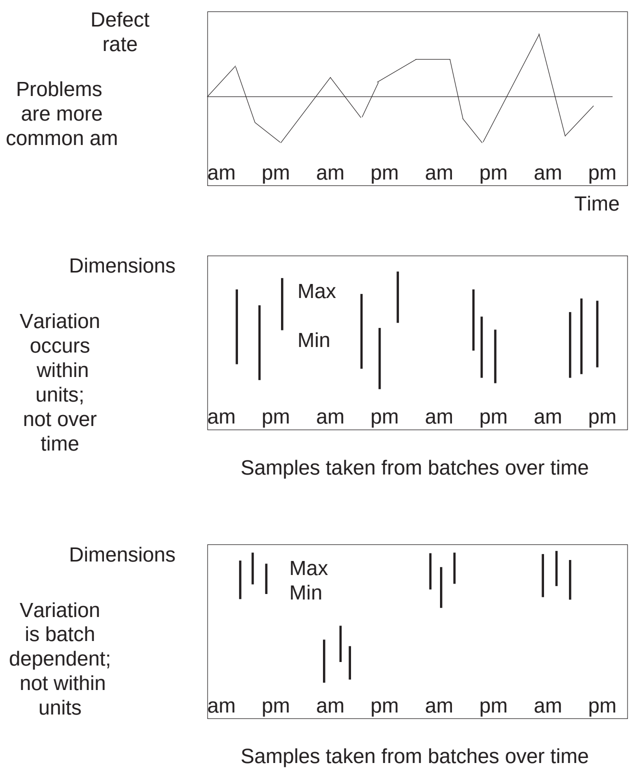


Figure 11: The run diagram

It is surprising the amount of information that we can glean from such a simple tool. In the first diagram, problems occur predominantly in the morning. So this is where to look: could the problem lie with the morning shift or with machines that run worse when cold? In the second and third diagrams, the length of bars represents the spread of a sample of readings. In the second diagram, there does not seem to be much difference by time of day, but there does seem to be quite large variation within the samples. This indicates process instability, perhaps due to wear-out or lack of training. In the third case, once again there is little difference between time of day and there is also only small variation within the samples. But here the problem lies with differences between batches so this could suggest differences between raw materials used or incorrect set-up. From these examples, we can see that run diagrams can be useful in pointing where to look and where not to look.

4.6 Correlation diagrams and stratification

The **correlation diagram** is used for more specific experimentation. Usually defect level, or some other measure of performance, is plotted on the vertical axis and the 'experimental variable' on the horizontal. An example would be rejects against temperature. Perhaps as temperature rises rejects fall, but then around a specific temperature rejects begin to increase again. This could either be found out by a specific experiment involving deliberately varying the temperature, or by simply counting rejects and taking the temperature from time to time in the normal course of operation.

Very often no relationship or correlation is found. So something else has to be tried, perhaps first temperature, then pressure, then temperature divided by pressure, and so on. In services, perhaps we are investigating customer wait time against number of servers, or customer response time against quantity of information displayed on a screen. Eventually, and with intelligent guesswork, good relationships can be found. This detective work can be a lot of fun, and front line people are often good at it because they appreciate the real factors that make a difference. Normally an attempt is made to hold other factors as constant as possible while one factor at a time is varied.

We can calculate the measure of correlation, called the **correlation coefficient** by formula. You will have met the formula, and associated tests, in your quantitative methods studies. The measure is also 'built in' to many scientific calculators. However, it is always preferable to plot the results on graph paper and to judge the relationship visually.

Often we use both run diagrams and correlation diagrams. First we use a run diagram for more general analysis and to see if time of day or month has an effect. Then we follow with a correlation study for the specifics. There are other possibilities as well. A common one is the matrix, where, for example, errors are recorded in a matrix which shows operator names along one axis and types of error or time of day along the other axis. This would reveal, perhaps, that different operators are good at different things or have different error-prone periods.

Stratification simply means splitting the data into groups and plotting the results on graphs. For example, defect data against time may appear to have no particular pattern, but when data for individual operators or machines is plotted the situation may suddenly clarify. Clearly there is often a large number of ways in which data can be separated out; by operator, machine, material, time, batch, product, customer, location are just a few. But once a team knows about stratification they are likely to make good suggestions about how it can be separated. Of course, this means that care has to be taken in the first place about how the data is collected. It is a learning process. Correlation and stratification are illustrated in Figure 12. Note that in diagram c there appears to be no correlation when the results from two machines are shown together. In diagram d by stratifying the results there is a correlation between defects and temperature for machine A.

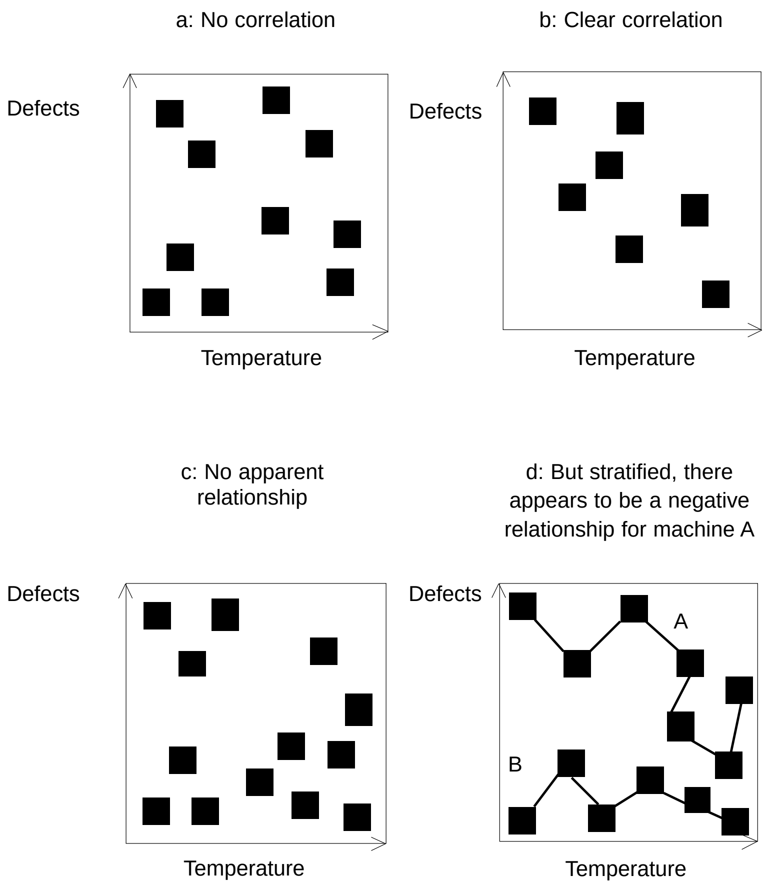


Figure 12: Correlation and stratification

Run diagrams, correlation diagrams and stratification have the effect of identifying what are termed ‘special causes’. These are the events or defects which cannot be explained by natural variation of the process. We deal with this topic in *Section 5*.

4.7 Check sheets

The last of the seven tools is there to maintain the level of quality attained by the application of the previous tools. This is the straightforward yet effective tool of **check sheets**. A check sheet simply details the correct procedure. This correct procedure must be verified or audited at specific intervals.

There are several forms. ‘Aircraft-style’ checks would be carried out at the start of every shift or the start of each new batch, as an airline pilot would do before setting out. A process diagram, placed next to the machine or service counter, details what should be done and may advise what action to take in special circumstances. Whatever the form used, the philosophy is to have the correct procedures laid out and available at the workplace, not in some remote office. McDonald’s is a service organisation that makes extensive use of check sheets.

One special form of check sheet, used by Toyota, is a sheet containing perhaps 50 questions that ask operators if particular events are taking place, for example, ‘Do you have to reach to grasp a control?’ and ‘Do you have to take more than two paces to collect parts?’. If an affirmative answer is obtained, this indicates that there is potential for improvement, and the operator is challenged together with his or her group to suggest possible improvements. We discuss this further in the Unit 9, *Time Based Operations*.

ACTIVITY 12

The point about the seven tools is that they are a set. In an earlier activity you considered how to improve your business studies programme, or a class or course, using the Ishikawa diagram. Now extend this by considering how each of the other tools could be used for improvement. This may require some speculation.

There are a few possibilities. The process diagram could be used in its ‘moments of truth’ form to trace through your experiences. We could have an overall chart, and more detailed charts to do with a typical course, an exam period, accommodation, library, etc. Pareto could be used to highlight your complaints or concerns in some of these areas. Suggestions to alleviate the top-most concerns could then be brainstormed using Ishikawa. Run diagrams could trace assignments due, complaints, grades, books on loan, and others against time. Correlation diagrams could study the relationship between seminar attendance, course marks, and exam marks. A measles chart on where students and lecturers live might prove revealing. We might then ask what check sheets are now provided, and what should be provided.

Summary

This section discussed the seven tools of quality. The seven tools form a basic problem-solving and quality-improvement kit. Ishikawa put them together as a set to be used by quality circles, or for team problem solving. The aim was to make them accessible to enable everyone in the organisation to use them. The participation by everyone is at the heart of TQM.

SECTION 5

Statistical Process Control (SPC)

Introduction

Statistical process control (SPC) aims at achieving good quality during manufacture through prevention rather than detection. It is concerned with controlling the process, or machine, which makes the product. If the process is good, then the products will automatically be good. So the process or machine which makes the product is inspected rather than inspecting the product itself. This is really proactive management – inspecting and controlling the process before the event, rather than reactive management – inspecting the product after the event.

SPC is not, of course, the full answer to total quality. A poorly designed product can conform to all manufacturing requirements, but still fail to convince customers that it is a quality product. SPC is just one of the tools in the total quality toolkit, although it is a major tool.

Perhaps confusingly at first, the best way to find out what is happening to a process is to take measurements of the products that the process is producing. Of course you do not need to look at every product that is produced. Instead you take samples and use statistics to judge what is happening to the process. This is why it is called **statistical process control**. It may appear that we are inspecting a few of the products coming out of the process, but in fact it is the process that is being inspected and controlled.

SPC is undertaken through the use of charts on which the performance of the process is plotted. If the process starts to go wrong it can be stopped in good time before many or any defectives are made. We begin by examining the types and content of these SPC charts.

5.1 Variables charts

There are two main types of SPC chart: variables and attributes. A **variables chart** measures some characteristic that is variable along a scale, such as length or the number of scratches. It is something that can be measured. An **attribute chart** is used where there are only two possibilities: pass or fail, yes or no. With an attribute, a judgement is made rather than a measurement taken.

The main variables chart is the **average and range chart**, also known as the **x bar and R chart**. This is actually two charts, one tracks the average measurement of the sample taken, and the other the range of the sample, that is the maximum minus the minimum value. Both are necessary. For example, the average of a sample of five may be fine, but the range could be unacceptably wide. And the range could be small, but located in the wrong place; that is it has an undesirable average. So typically, from time to time throughout the day, the operator will take, say, the five most recent products produced and set them aside. This is a **sample**. The particular product dimension is measured and the average and range values of the sample calculated. These two results are plotted on the chart, usually by the process operator. The chart indicates if the process is acceptable. If it is acceptable work continues. If not, work stops to investigate. This is SPC in practice.

Refer to Figure 13. Note the rotated normal distribution shown next to the average chart indicating the expectation that samples will be normally distributed and that the upper and lower control limits correspond to plus and minus three standard deviations. Notice that both the average and the range charts have an upper and a lower 'control limit'. These limits are the bounds beyond which unacceptable performance is indicated.

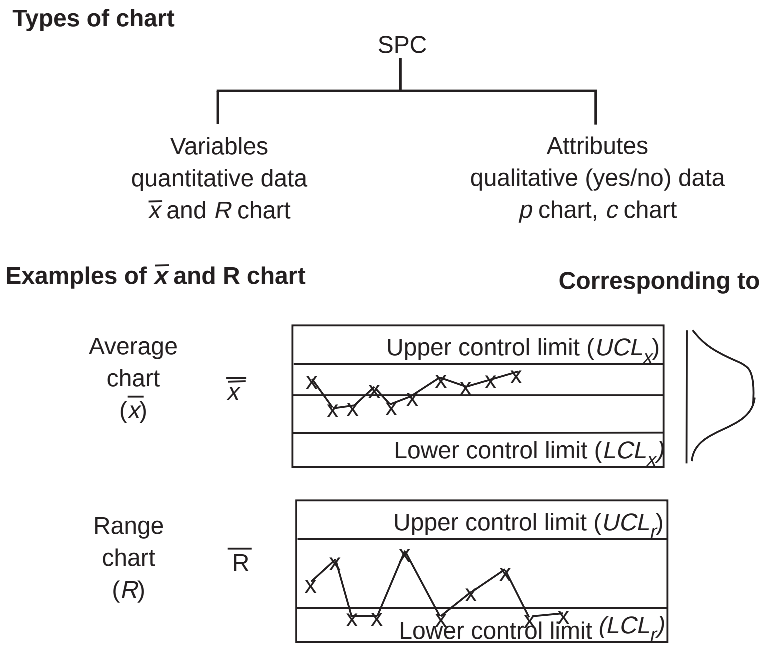


Figure 13: Statistical process control charts

Natural variation of the process

This brings us to the concept of **natural variation**; you met this earlier in our discussions on Deming. Every process has natural variation. In other words, it is impossible to make any product with absolute consistency. The inconsistency will be caused by chance variations, however small, in, perhaps, the material, tool wear, positioning of the piece, speed of the machine, actions by the operator, and so on. These are called **common causes**. This variation can be measured and, using statistics, its spread can be predicted. It turns out that the spread follows the normal distribution, irrespective of the type of process. This is a consequence of the central limit theorem. Therefore if points are plotted which fall outside the distribution, then **special events** are occurring. The special events are assignable to unusual or unexpected changes or events, which may cause defects to be produced. This knowledge is very convenient for two reasons.

First, if the variation does not follow a normal distribution then we know that some special event is taking place. The special event may be an untrained operator, a change in the type of material, tool or bearing wear-out and so on. These special events can, with perseverance, be tracked down and the cause eliminated.

Second, the spread of a normal distribution can be measured by calculating the control limits. The formula is given in Figure 14. It turns out that within these limits which equal plus or minus three 'standard deviations' on either side of the process average value, lies virtually all of the natural variation. So if an operator takes a measurement and finds that it lies outside these control limits, then it is virtually certain that something has happened to the process. The process is then referred to as being **out of control**. The process should be stopped and the situation investigated.

Be careful to distinguish between: the **control limits** (which are a characteristic of the process and are set at plus and minus three standard deviations from the average), and the **tolerance limits** (also known as the specification limits) which are set by the designers or engineers. Ideally, of course, the control limits should lie within the tolerance limits, and a designer should take into account the normal variation of the process when designing a product.

SETTING UP THE CONTROL CHART

A chart should ideally be set up for each process, that is for each machine, making a particular type of product. (Pre-printed SPC charts are available from some quality societies or in books, and these make data entry and chart plotting very easy.) When setting up a chart it is important that there is consistency, so you should take samples over a representative period of time. You will need to decide on a sample size and the number of samples. Typical numbers are a sample size of 5 and at least 25 samples. For each sample calculate the average ('mean') and the range. Refer to Figure 14. Then calculate the average of the averages, and the average of the ranges. Now you will need to look up the control limit factors for the sample size you have used. If you have used a sample size of 5, the factors are given in the Figure 14. Now use the formulas in Figure 14 to calculate the control limits. When these are drawn in you can begin to use the charts for control purposes. You will have to decide what is a reasonable interval for samples to be taken. Generally, the higher the 'Cpk' value, the less frequent does the sampling have to be. We discuss Cpk, or capability ratios, later.

$\bar{x}$ and $\bar{R}$ charts

Assume samples of the size 3 are taken
the readings are x^1, x^2, x^3

$$\bar{x} = \frac{x^1 + x^2 + x^3}{3}, \quad R = \text{largest } x - \text{smallest } x$$

These two values are plotted on the charts
To set up the chart, take 20 (minimum) random samples, each of sample size (say) 3
Calculate $\bar{x}$ and R as above, then

$$\bar{\bar{x}} = \frac{\bar{x}^1 + \bar{x}^2 + \bar{x}^3 + ... + \bar{x}^{20}}{20} \qquad \bar{R} = \frac{R^1 + R^2 + ... + R^{20}}{20}$$

These give the average (x and R) lines on the chart
Then calculate the control limits using the formulas

$UCLx = \bar{X} + A^2 \times \bar{R}$ $\qquad UCLr = D^4 \times \bar{R}$

$LCLx = \bar{X} - A^2 \times \bar{R}$ $\qquad LCLr = D^3 \times \bar{R}$

where the values A^2, D^3, D^4 depend on the sample size

Sample size	**A^2**	**D^3**	**D^4**
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

Figure 14: Calculations for mean and range charts

CHART INTERPRETATION

There are other criteria, apart from falling outside of the control limits, that indicate an out of control condition. These other criteria can be identified by operators, or automatically where SPC data is entered by computer, so that early action can be taken. Let us consider the logic. With natural variation occurring you would expect measurements to be spread more or less evenly on either side of the average value. To be more precise, with the standard deviation known, you would expect a certain proportion of measurements to fall within plus and minus one, two, and three standard deviations of the average value. If this does not occur, again there is an indication of trouble. As an example, the probability of a measurement falling above the average is, of course, 50%. The probability of two successive measures above the mean is 25% (.5 × .5). And the probability of three successive measures above the mean is 12.5% (.5 × .5 × .5). Four successive measures above is 6.25%, and so on. If we get to seven successive measures above the average the probability is less than 1%, and we could reasonably conclude that something strange (a special event) has taken place. The other criteria are linked with the probabilities of successive measurements falling beyond a particular number of standard deviations.

The interpretation of process control charts is a skill that can be developed. Particular chart patterns are indicative of particular problems that may be developing. Some indications of the possibilities are given in Figure 15.

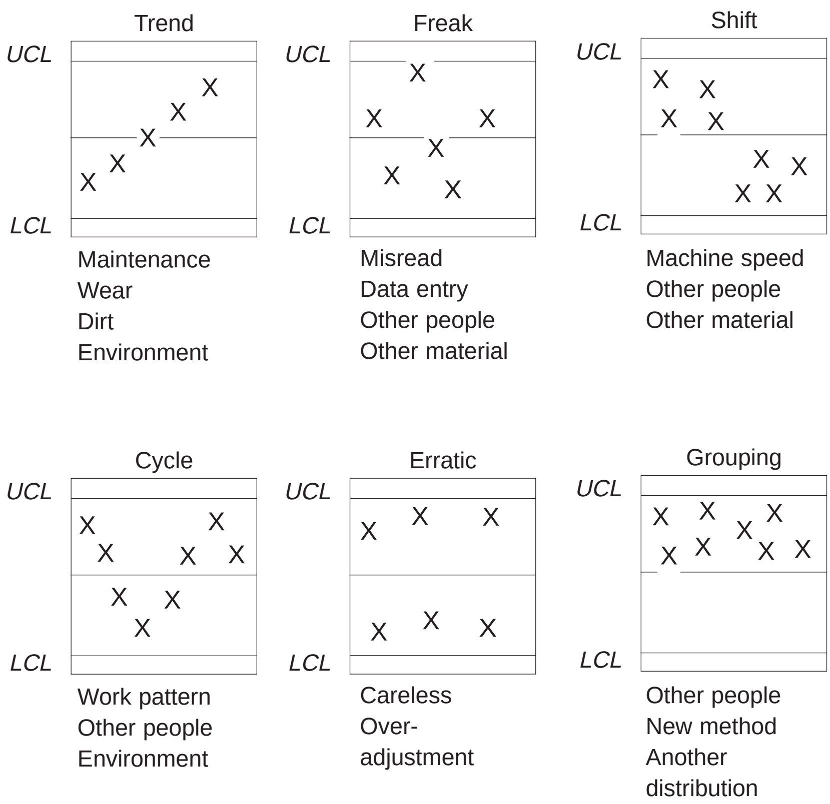


Figure 15: SPC chart interpretation

5.2 Attribute charts

It is not always possible to measure variables. Some defects, such as scratches, tears, and holes are either there or they are not. The products either pass inspection or they do not. There are two basic types of **attribute chart**: ***p* charts and *c* charts**. *p* charts are used where there are batches of product and the percentage that are defective can be determined. *c* charts are used where there are a number of possible types of defect associated with a particular product, for instance the number of scratches or stains or dents on a table.

With attributes only one chart is plotted, not two, as with the average and range chart. But the basic concepts of controlling variation, of taking samples, of setting up the charts, and of interpreting them, remain. Only the formulas are different. Formulas for *p* and *c* charts are given below.

$$\bar{p} = \frac{\text{number of defectives in all samples}}{\text{total inspected in all samples}}$$

$$UCL_p = \bar{p} + \sqrt{\frac{\bar{p}(1-\bar{p})}{\text{n}}}$$

$$LCL_p = \bar{p} - \sqrt{\frac{\bar{p}(1-\bar{p})}{n}}, \text{or zero whichever is greater}$$

c Charts

$$\bar{c} = \frac{\text{number of defectives in all samples}}{\text{number of units sampled}}$$

$$UCL_c = \bar{c} + 3\sqrt{\bar{c}}$$

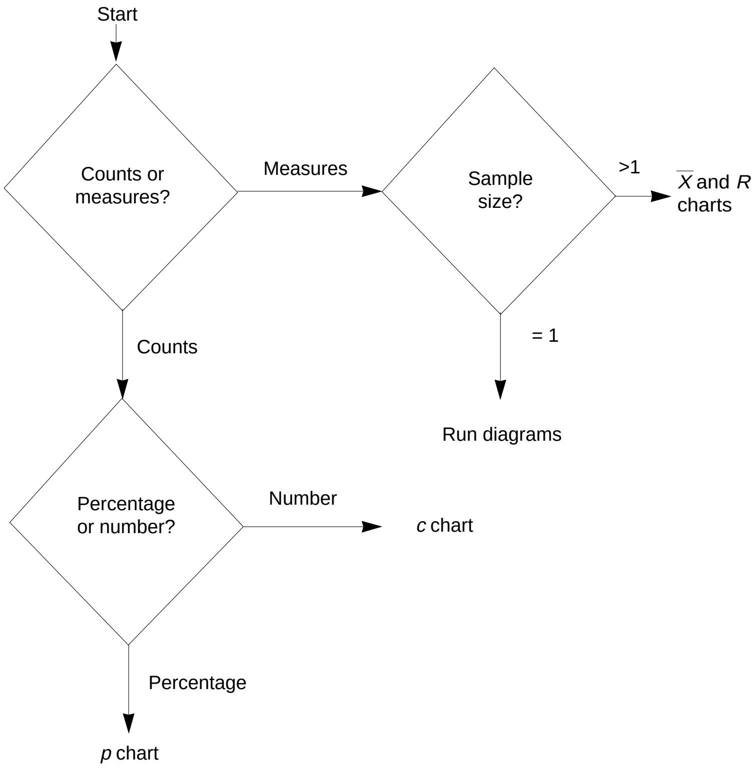
$$LCL_c = \bar{c} - 3\sqrt{\bar{c}}$$

ACTIVITY 13

For each of the following examples, select the appropriate control chart:

1 time to run a computer exercise
2 number of paint defects on a wall
3 diameter of a wheel
4 bags of cement used to pave 100 square metres
5 time spent in the queue at a bank
6 proportion of fridges sold requiring work under guarantee
7 number of complaints received in a hotel
8 proportion of students attending lectures
9 time to reply to an enquiry
10 number of enquiries per period

The following flow chart is a guide for your answers:



5.3 Process capability

Being ‘in control’ indicates that measurements taken from items coming out of the process follow an expected pattern (the normal distribution). But being ‘in control’ does not necessarily mean that the process is making good quality products. The process may be producing consistent products with small variation all of which are below the specification (i.e. consistently bad). So there is another requirement. This is referred to as **process capability**.

Process capability refers to the match between the location of the upper and lower process control limits (*UCL* and *LCL*) and the specification limits *USL* and *LSL* (also known as tolerance limits *UTL* and *LTL*). The location of the process control limits is due to the natural variation of the process that makes the product. The specifications of the product, on the other hand, are given by the designer of the product. These are two distinctly separate issues, but they must relate in order to produce quality products.

It is important that we don’t measure process capability before the process is in control. In other words, if there are assignable causes and special events to be sorted out, this must be done first. These assignable causes are by their nature unpredictable, and have an unpredictable effect on the process control measures. This is illustrated in Figure 16.

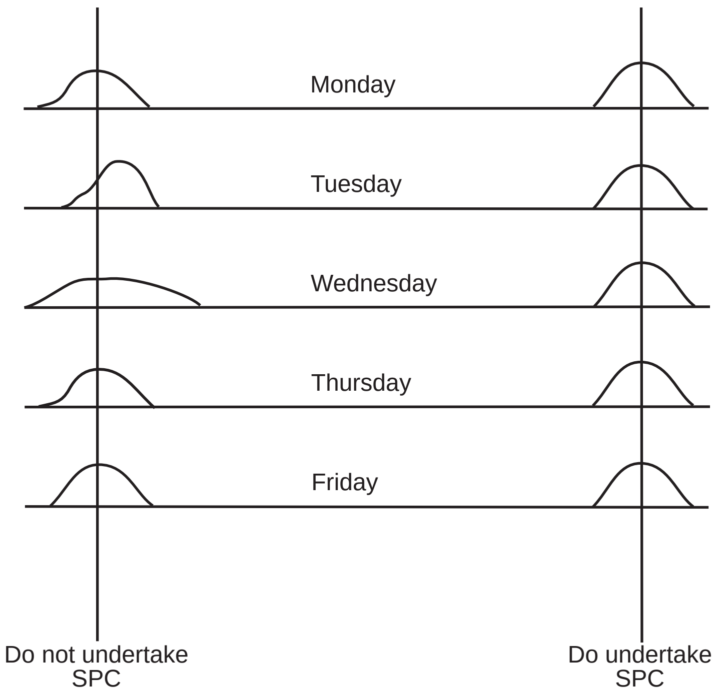


Figure 16: Process capability study

Process capability is measured by two ratios: 'Cp' and 'Cpk'. The Cp measure simply compares the specification (or tolerance) spread with the process spread. Clearly if the natural spread of the process is wider than the spread of the specifications, the Cp ratio is less than 1, then defectives are certainly going to occur. Defectives will 'seep out'; this is a way to remember the ratio names. But we need to also be concerned with where the process spread is located in relation to the specification limits. We could have a small process spread located outside of the specification limits, even though the Cp value is acceptable. So Cpk is needed.

Cpk is the smaller of two ratios:

$$\frac{\text{(upper specification limit – process average value)}}{\text{half the process spread}}$$

or

$$\frac{\text{(process average value – lower specification limit)}}{\text{half the process spread.}}$$

Half the process spread is, of course, equal to the upper control limit minus the lower control limit. Refer to Figure 17 below.

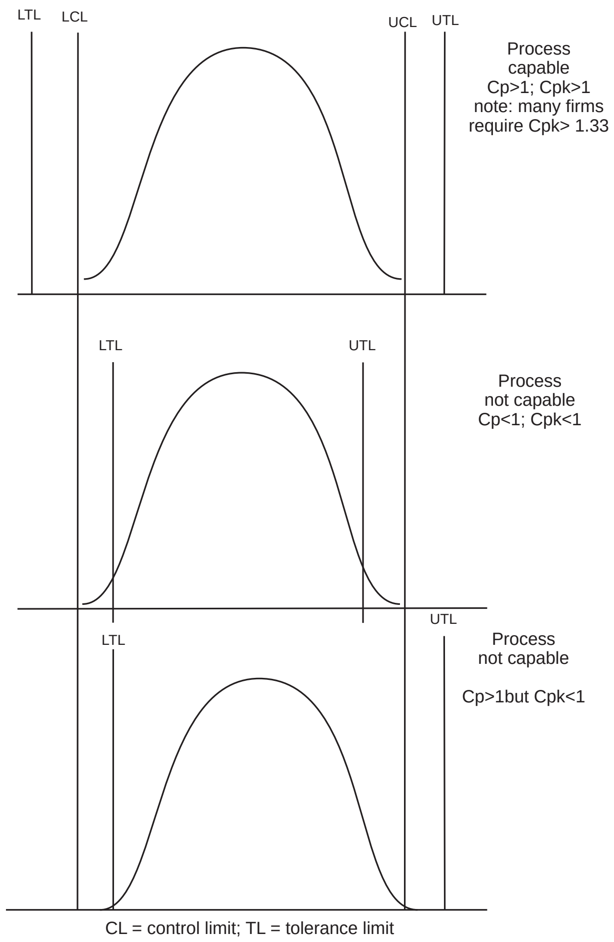


Figure 17: Process capability diagrams

In practice, many companies, such as Ford, insist on a Cpk value of at least 1.33 before the process is regarded as ‘capable’. So ‘quality capable’ means that the process or machine is both ‘in control’ and has a Cpk value of at least 1.33. As the Cpk value goes above 1.33, the likelihood of defects declines so the need to take more frequent samples decreases. It is always a good idea to seek to improve Cpk values even if the value of 1.33 has been reached. This can be done by many means including improved maintenance, better tool wear monitoring, closer working with suppliers, and improved training.

5.4 Six Sigma

Six sigma is a concept and aim developed by the Motorola Company but now adopted by many others. Motorola defined it as: ‘a measure of goodness – the capability of a process to produce perfect work’. The six sigma concept is about the aim of making all processes in a chain highly capable; that is achieving a capability index of at least two. Six sigma is the number of standard deviations from the average setting of a process to the tolerance limit. In statistical terms, this translates as 3.4 defects per million opportunities for error. At Motorola this concept has been extended to every function in the company, where everyone is considered to be both a supplier and a customer. For such levels of quality, both design and manufacturing must play a role.

'Sigma' is the symbol that is used for the standard deviation of the normal distribution (σ). In statistical process control, when samples are taken from a process the readings are expected to stay within plus or minus three standard deviations of the mean. If a sample is taken which plots outside of these limits the process is said to be 'out of control'. It should then be stopped and investigated. There is still a small chance that an in-control reading will be taken outside of these limits. If however the tolerance limits are set by the designers at plus or minus six sigma, then it is highly likely that a deviating process will be stopped well before defects are made. Six sigma aims to set tolerance limits at six standard deviations from the mean, whereas the normally expected deviation of the process is three standard deviations. This gives a capability index of two.

To give you an idea of six sigma standards of performance, we estimate is that it would be equivalent to only two spelling mistakes in a business studies class of 30 students in all written assignments and examinations over a period of a year.

When Motorola announced its six sigma programme, such levels of process capability were rare. Most product manufacturing chains were found to have quality levels at five or even four sigma (which is still a good standard not achieved today by many companies). Expressing the company goal as six sigma indicated a clear aim. It also acts as a guide to priorities, because those processes with the lowest sigma ratings could be targeted first and all new products (for example, Motorola's Keynote pager) would have six sigma as the target quality level.

Motorola has attacked the six sigma objective through a variety of means, but team involvement and design of experiments have been particularly important.

5.5 Alternatives to SPC

Traditional SPC is widely, but not universally, applicable in manufacturing. In this section, we will consider two techniques that may be used either as alternatives or supplementary to SPC.

PRE-CONTROL

SPC is more suited to longer production runs where a large number of samples can be taken over time. Unfortunately this is not the case with many JIT systems. Also, particularly with JIT, it is important to verify as quickly as possible if a changeover has been undertaken correctly and the process is capable of producing good quality parts. One possibility is to use **pre-control**, originally developed by consultants Rath and Strong.

The procedure is as follows:

1 Divide the tolerance (or specification) band (i.e. the area between the upper and lower tolerance limits) into four equal bands. The middle two bands are the green zone (and should be coloured green on a chart). The two outer areas are called the yellow zone. Beyond the tolerance limits is the red band.

2 Following changeover (to check capability): measure five consecutive units.
If all five are in the green zone, the process is in control. Production can start.
If even one is in the red zone, the process is not in control. Production must not start. Reset the process.
If one is in the yellow zone, a ‘special cause’ may be present. Take another sample of five. Better still, investigate.
If two consecutive readings fall in the yellow zone, adjust the process and restart the measurement process.

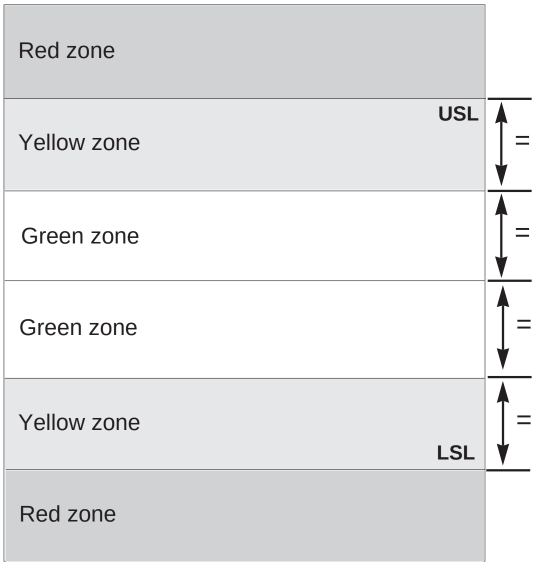
3 During production: take samples of two consecutive units.
If even one unit falls in the red zone, stop production and investigate. Return to Step 2.
If both units fall in the yellow zone, stop production and investigate. Return to Step 2.
If one unit falls in the yellow zone and one in the green, continue.
If both units fall in the green, continue.

4 Sample six pairs between set-ups. (e.g. for an hour-long batch, sample approximately every 10 minutes).

The method is obviously very simple. Pre-control charts can be printed ahead of time and no statistical training is necessary. Implementation is immediate. However, critics have pointed out that pre-control is based on tolerance limits, not on process variation as is the case with SPC. As such the method relies on these tolerances being carefully set during design. Some statisticians have pointed out that a sample size of two may simply be inadequate. Nevertheless, the technique is statistically based and is likely to be reliable under many circumstances. Bhote (1991), who has been a strong advocate of pre-control, has pointed out some weaknesses in SPC, and claims that SPC is very antiquated. Bhote claims that pre-control has overtaken SPC in popularity in Japan. Pre-control is illustrated in Figure 18.

FAILSAFING OR ‘POKAYOKE’

Pokayoke, or **failsafing**, is about adding devices to machines and processes in order that defects are simply not made. Although we could argue that failsafing has been used for a long time, it was the late Shigeo Shingo that popularised the concept. ‘Pokayoke’ is a Japanese adaptation for ‘foolproofing’ or, rather,‘mistake proofing’. Shingo believed that today, in an era of defects measured in parts per



For process capability, 5 successive units must be in the green zone. For production, take samples of 2 units (dividing inter-setup time by 6)
If 2 units in green zone, continue
If 1 unit in green and 1 in yellow, continue
If 2 units in same yellow zone, stop and adjust
If 2 units in opposite yellow zones, stop
If 1 unit in a red zone , stop

,

Figure 18: Pre-control zones

million, statistical quality control and inspection is no longer appropriate. Hence a pokayoke device aims to:

- carry out 100% automatic inspection, done by the process or the next process
- stop the process, or give a warning, if a defective is found.

Although Shingo's classic textbook *Zero Quality Control* (1986) gives details of scores of pokayoke devices, most of the devices themselves have to be developed by the ingenuity of in-plant personnel. Essentially, after an actual or potential quality problem is identified, a device must be invented that checks every part for the defect. This is often done by a limit switch detector or by a physical barrier. An example of the former is a switch that is tripped when a part is added to a packing case. Unless the switch is tripped the conveyor carrying the case simply stops. An example of a mechanical device would be one that prevents a part with an excessive dimension slipping through. When such a part is found it is channelled off, thereby tripping a switch which stops the machine or gives a warning. Another variation of pokayoke is the 'constant number' type. Here an automatic counter prevents progress to the next stage unless the exact number of steps have been taken or parts have been added.

Pokayoke systems should be operated on two levels. At the first level, defectives are simply prevented from proceeding. At the second level, where such stoppages or warnings recur, these should be recorded and the underlying cause of the problem identified.

ACTIVITY 14

Take an everyday process such as making tea or getting ready to go out. Which activities can be failsafed and how?

In doing this it is useful to begin with a process chart to detail all the steps involved. Then it is up to your imagination. Part of tea making might already be failsafed by an automatic kettle. You may also use tea bags, sugar sachets and milk catering packs, all to ensure exact quantities. You could use an alarm to notify when the exact length of time required for the tea to brew has been reached, and so on.

There is, of course, no limit to the number or location of pokayoke devices that can be employed. While manufacturing examples abound, service applications are certainly possible, ranging from cooking times in a fast food restaurant to warning systems for goods which are past the ‘sell-by’ date. Chase and Stewart (1994) have studied failsafing in service industry, with an approach beginning by identifying possible failure points, and then going on to failsafe them.

It is now the experience of many organisations that once the concept is understood by employees and a few examples developed, a large number of innovations are possible from employees, not necessarily confined to engineers and technicians, who relish the challenge of invention. Pokayoke comes down to education, support for innovation, and reward for enterprise.

Summary

This section has examined SPC, a powerful family of techniques for preventing defects. Today many manufacturers, and some retailers, demand that their suppliers have implemented SPC.

SPC involves setting up a chart and monitoring the process to detect if a shift has taken place. If it has, the process should be stopped. Whether it is stopped before defects are made is determined largely by the capability index. Many companies today are striving to improve their process capability.

A recent innovation relating to SPC is pre-control, based on tolerance limits rather than process variation. Shingo has argued that SPC is not good enough where parts per million defect levels are being aimed at, and recommends the use of failsafing or pokayoke in these situations. Pokayoke is yet another alternative with wide and growing applications in both manufacturing and service industries.

SECTION 6

Some Improvement Techniques

Introduction

Today it is not good enough merely to control quality or even to prevent defects from occurring. Continuous improvement is a necessity. In this section we will consider five of the most useful concepts for continuous improvement.

6.1 Cost of quality

Cost of quality (CoQ) aims at the financial quantification of all activities involved in the prevention and rectification of defects. The idea is that if the locations and magnitudes of quality related costs are measured and brought to the attention of management, this will be a powerful force for directed improvement. Cost of quality analysis may range from one-off estimates to a complete parallel accounting system. Traditionally, quality is measured by a series of ratios. The problem is that these are seldom comprehensive and lack common units. Ratios should be supplemented by costs, which should be publicised throughout the organisation. CoQ can provide specific cost justification data for a management considering the question of quality 'hype' against quality benefit.

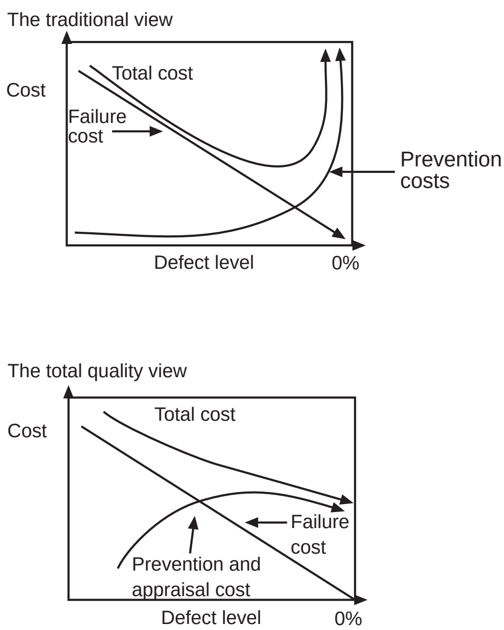


Figure 19: The cost of quality: traditional and total quality views

The conventional quality costing categories are:

- **prevention costs**: the costs of measures to prevent defects from taking place. This would include training, pokayoke, and capability studies and improvement (see SPC).
- **appraisal costs**: costs incurred in the detection of defects. This would include testing and inspection.
- **internal failure costs**: all failure costs incurred by internal customers. The costs incurred to rectify defects and failures internally, before the product or service reaches an external customer. This includes costs of scrap, rework, and all internal activities incurred through 'not getting it right first time'.
- **external failure costs**: all failure costs incurred by external customers. The costs incurred to rectify products and services after they have reached external customers, including returns, warranty claims, complaints, field repair, and perhaps lost custom.

As you saw earlier, Crosby (1979) groups the first two as POC (price of conformance) and the second two as PONC (price of non-conformance). For simplicity we can refer to the first two as **prevention costs** and the second two as **failure costs**.

Traditionally, prevention and failure costs have been seen as a trade-off. This is shown in the top diagram in Figure 19. Total costs are the sum of failure costs and prevention costs. Failure costs are thought to decline steadily, perhaps linearly, as quality improves. But as the defect level decreases, particularly as it nears 0% or perfect quality, prevention costs begin to rise very steeply, perhaps exponentially. The result is that there is an 'optimal' quality level, where total costs are minimised, which is below perfect quality (or above 0% defects). This trade-off thinking is now considered to be dangerous; it means that perfect quality is not only not the aim but actually undesirable. It becomes the excuse for not seeking to 'get it right first time'.

The total quality view is different. This is shown in the bottom diagram in Figure 19. Here, while failure costs continue to decline steadily, prevention costs tend to level out, at least above a certain level. The belief is that with 'total quality' everyone participates, quality becomes the natural way of life and not an 'extra'. Prevention requires initial but not continuing investment, and as a result costs stabilise. Total costs continue to decline all the way to the level of zero defects, so that the optimal is reached with perfect quality.

ACTIVITY 15

Do you believe that costs can actually decline with near perfect quality?

Students and quality professionals often have difficulties with this concept. Quality in this context must be defined as performance to specification or fitness for purpose. It probably does not apply to Kano's delighters. It is more likely to be true with product quality than service quality. But, as Crosby points out, if you disagree with the concept, how many babies is it acceptable to let die, and how many faults is it acceptable to send out on a new car?

The diagrams in Figure 19 are conceptual and have seldom been proved or disproved in practice. One point in favour of the total quality view is that the costs of failure are really unknown in terms of lost reputation and future custom. Therefore, if anything, failure costs are understated and may at least match the prevention costs.

The real point is that cost of quality analysis does set out to quantify what poor quality actually costs. The results, in many organisations that have implemented CoQ, are often **shock treatment**. The cost of not getting it right first time is typically in the range of 20% to 25% of turnover. So the savings that can be achieved by improving quality are very large, and the associated investment often more cost effective than the costs of increasing turnover, including marketing and capacity acquisition.

CoQ pinpoints the sources of quality costs. Specific budgets can then be set and controlled. Juran, the early pioneer of cost of quality, sees CoQ as an essential feature of his 'trilogy'. Quality becomes a closely managed function, using money rather than having quality as something that is desirable but really of low priority.

Some more advanced CoQ systems now incorporate cross-coding, so that some of the costs that are booked into the normal costing system are cross-linked to appropriate CoQ categories. This is not an exact science, and many of the problems that are found in cost accounting, such as the appropriate allocation of overheads, also found in CoQ. But exactness is not the issue; it is the trends, approximate magnitude, and locations that are important. When setting up these parallel costing systems it is useful to go further than just prevention and failure costs by identifying the source of the defect; operator error, equipment problem, material problem, specification problem, procedural problem, supplier problem or communication problem.

Many organisations do not yet undertake CoQ on a regular ongoing basis. Instead they rely on specific CoQ assessment studies. Here detailed questioning is the norm, usually making use of the process diagram, Pareto analysis, Ishikawa diagram, and histogram.

CoQ can be seen as closely related to the 'Seven Wastes' we discuss in Unit 9. The real aim is not merely to keep on reducing the costs of (poor) quality but to go on reducing the costs of all wastes. Defects are but one of the seven wastes. Some companies have now begun to cost wastes, either directly or through new cost accounting systems such as **activity based costing** (ABC).

6.2 Benchmarking

The Benchmarking Centre defines **benchmarking** as: 'the continuous, systematic search for, and implementation of, best practices which lead to superior performance'. In essence, it aims to compare a range of performance criteria with what the best in the business is achieving. It is a guide to necessary present performance and to future requirements if the organisation is to be 'world class'. It is about knowing yourself and really knowing the competition: where they are weak, where they are strong, and where they are going. To an extent, benchmarking is an alternative to 'cost plus' budgeting, and to productivity targeting by simply 'matching inflation'. It is outward looking rather than inward looking. It is concerned with tracking performance, not just taking snapshots. Think of the on-going Deming cycle. And, like several other techniques discussed here, it is equally applicable to products and to services.

Of course, benchmarking has always existed. People and organisations have always compared themselves to others. But it was the Xerox Corporation that appears to have pioneered **competitive benchmarking**. It was the systematic and comprehensive way in which Xerox set about making benchmarking a competitive weapon that has brought this technique into prominence. Robert Camp of Xerox is responsible for much of the thinking, and has written the definitive book (1989).

Types of benchmarking include:

- **internal** (where one branch is compared with others)
- **competitive** (as per Xerox, comparing with the toughest competitors)
- **functional** (where similar processes are compared with non-competitors)
- **generic** (where basic processes found in any business, such as human resource practices, are compared).

Benchmarking can be seen not just as a technique on its own, but as one of a mutually reinforcing family. The insights from benchmarking are useful if not necessary for quality function deployment. For value management it can help identify what is technically possible. Benchmarks help bridge the credibility gap. It identifies which Garvin's dimensions of quality that a competitor is competing on. And systematic measurement is part of any quality improvement process, such as the Deming cycle or the Juran trilogy.

We begin with the understanding that a single measure of performance is rarely adequate. Just as several instruments are necessary to monitor and control the performance of a car or plane, so it is with any organisation. Now recognise that to be competitive in quality and productivity, steady inward-looking progress may not be enough. But of course we do not go out to benchmark everything possible. It must be a directed search.

WHAT TO MEASURE

Robert Camp states that benchmarking is 'first a goal setting process'. You have to know what to benchmark, and, as with much of quality management, this brings you right back to the customer. Identify your customers, present and future. Now you can begin to assess their needs and the core processes. These are the areas where the organisation absolutely needs to perform well, and where unique advantages can be obtained. Garvin's dimensions are useful as an aid. The areas can be assembled by a team using brainstorming or the Ishikawa diagram.

There may be a particular interest in targeting areas that are known to be important, such as costs or complaints or geographical areas. Staff policies, salaries, and personnel policies on training, recruitment, and the use of people at work may be relevant. There may be some standard productivity or quality measures which are prevalent in the industry, such as cars per employee per year in the car industry. However, beware of being too specific on what should be measured. The idea is to concentrate on processes first and measures of performance second. You now know what you wish to benchmark, your next step is to identify who to benchmark.

It is a good idea to think through the information collection procedure, in particular who will be responsible and where it will be centred. The latter has to be clearly communicated so that if information is obtained from or by an unexpected source, it will still go to the right place. It will often be necessary to dedicate people, part time or short term, to information collection.

WHO TO MEASURE

The aim of competitive benchmarking is to find the 'industry-best' performance, and where appropriate the 'world-best' performance. The toughest competitors now and in future are often known or easy to shortlist, so a search can be more focused. But do not close your mind to the possibility of world class performance from a new or unexpected source. Benchmarking is an on-going process.

HOW TO MEASURE

We assume that internal benchmark information is relatively easy to obtain. Now comes the external information. There is a huge number of potential sources of benchmark information. But it must be ethically collected and secured; benchmarking is not stealing, nor passing on potentially valuable information obtained from one source to another. For partnership benchmarking, you have to be prepared to give and take; not just take. For competitive benchmarking some possibilities are: a library database search, commercial press-cutting databases, specialist industry reviews in newspapers or journals, specialist surveys, for example by *The Economist Intelligence Unit*, trade magazines, conference papers and proceedings, market research, special surveys, factory visits and evening meetings of relevant societies, annual financial reports and published accounts, trade and sales literature, quotations from the companies themselves, management consultants and academics.

Many benchmarking exercises will involve actual use of competitor products, including one-way viewing through mirrors of customer usage, and full technical disassembly.

USING BENCHMARKS

Benchmarking is not static. It aims at projecting future trends. When the internal and external benchmarks are assembled, analysts can begin to assess the critical question of whether the 'gap' between our own and competitor performance is widening or narrowing. This leads to the establishment of areas for priority action. Competitive benchmarking can become a management philosophy in itself, the aim is to remain or achieve 'industry-best' position in the particular niches identified as important. As soon as one set of improvements has been implemented, it all begins again. It's the Deming cycle.

6.3 Design of experiments

Design of experiments (DoE) is a family of techniques which enable a quality professional to identify rapidly the most important variables in new product design or process improvement. DoE has a long history, going back to Sir Ronald Fisher in 1930, but popularised and refined by Taguchi, Box, and, more recently, by Dorian Shainin (see Bhote, 1991). DoE has until recently been the province of professional statisticians, but the effect of the work of the above named people, has been to open up DoE (somewhat) to non-statisticians.

Let us say that we suspect a number of variables (say temperature, pressure, metal thickness, length of time processed etc.) has an influence on the quality level of a product. Traditionally these would be explored one variable at a time whilst maintaining all the other variables constant. Where there are several variables, say 13, each of which has three possible settings or ‘levels’, this becomes totally impractical as over 1.5 million trials would be needed. The optimal combination could be missed, especially if there are significant ‘interactions’ between variables, for example, drink alone or drugs alone may be survivable, but in combination they could be fatal.

The DoE answer to this problem is to use an ‘orthogonal array’, combined with Analysis of Variance, (ANOVA: a straightforward statistical technique that you may have covered in your quantitative methods studies) to identify the correct combinations. In our example, in fact, only 27 trials would be necessary. This procedure was popularised by Taguchi who took it out of statistical specialisation to become a procedure that many engineers could use. Taguchi orthogonal tables are available in books such as that by Peace (1993).

A simple version of Taguchi works like this. Consider that you are investigating the flow of liquid through a membrane. The goal is to maximise the flow. First, identify the relevant factors; this may be done by brainstorming or experience. Say there are three: thickness, viscosity, and temperature. Each factor can have two ‘levels’, for example, thick/thin, low/high. Four trials would be necessary and the orthogonal array would be as shown in Figure 20. Notice that between any two columns each combination of levels occurs the same number of times. Undertake the trials, measuring flow each time. Analysis of variance is now used to calculate the percentage contribution of each factor. This identifies the critical factor(s) to watch. In some cases it is necessary to undertake further analysis to examine the interactions between factors.

There is no doubt that DoE is essential to achieving world-class levels of quality in manufacturing, such as the six sigma programme. For improvement, DoE is an order of magnitude more powerful than the basic seven tools.

	Thickness	Viscosity	Temperature
1	Thick	Low	Low
2	Thick	High	Medium
3	Thin	Low	Medium
4	Thin	High	Low

Figure 20: An orthogonal array for flow through a membrane involving 3 factors, each with 2 possible levels, 4 trials would be involved, as shown

SHAININ TECHNIQUES

Despite considerable support, not all companies have achieved success through the Taguchi approach. It is still quite complex for the non-statistician. More recently, Dorian Shainin has further refined and simplified DoE. His methods involve even more 'engineering judgement' than those of Taguchi, and are not accepted by all purists. An additional problem is that the Shainin methods have in general not been written up to the extent of Taguchi's approach, and are also subject to copyright. Nevertheless, the Shainin techniques deserve considerably more attention than they have been given.

The Shainin approach to DoE uses a series of methods to identify what is termed the 'red X' (the critical factor, or top problem) or the 'pink X' (a likely or important factor). The three basic methods are:

- **the multi-vari chart** (a more sophisticated form of run diagram)
- **components search** (a four-stage procedure used where there are interchangeable components, which involves identifying good and bad products, disassembling them and reassembling from components taken from good and bad products, then retesting)
- **paired comparisons** (used when there are no components, which involves carefully observing and noting all differences between several pairs of products, one good and one bad in each pair, to give a strong clue as to the problem).

Quite often these methods will reveal the red X directly. If not, then, having identified the pink Xs, we move onto 'variables search' and 'full factorial' analysis. These are similar to the orthogonal array and ANOVA approach, but have been modified by Shainin.

A more complex example would be to compare two university courses taken by the same students, but having very different average marks. We could list many of the attributes: lecturer, textbook, amount of quantitative material, lecture times, tutorials, examination, coursework, etc. side by side and make a qualitative comparison of differences. This would help identify the 'pink Xs', being the reasons for the discrepancy in marks.

ACTIVITY 16

A very simple, perhaps over-simple, demonstration of the components search method involves taking two ball-point pens, one of which has no ink remaining, and is thus 'defective'. If you know which is the 'defective' one, you can make a list of all the visible differences, one of which will be that there is no ink. This is then a 'pink X'. Another demonstration involves identifying the good and defective pens, and marking each component as 'possible good' and 'possible bad'. Then disassemble them, interchange the two parts and reassemble. Once again test and note possible goods and possible bads. There will only be one part, the empty ink carrier, that is twice identified as bad.

Finally, the **B versus C** tool is a simple but effective 'paired comparison' method to determine if a better (or B) process is truly better than a current (or C) process, given a level of risk of being wrong. As an example, consider the case of three random samples taken from a current C process and three random samples taken from a possibly better B process. If the results are arranged in order from best to worst, and if the three best are all from the B process, then B stands a good chance of really being better. But if, for example, the two best readings are from B but the third best is from C, then there is a greater risk in concluding that B is really better. The B versus C tool extends this type of analysis to the case where there is known variation in the current process. This is really a refinement of a statistical test for the difference between two means, but requiring far less data. Such a test has wide application in quality management: from comparing two processes or methods, to comparing customer opinions about two products or services.

DoE fits in well with quality function deployment (QFD), which we deal with in the next section. In QFD, a set of 'technical specifications' (the columns in a QFD matrix) are set against the customer requirements (the rows in a QFD matrix). DoE is a powerful way to test which of the technical specifications has the most influence or is most sensitive.

6.4 Quality Function Deployment

Quality function deployment (QFD) is a tool used to aid the product design and development process. Customer needs are identified and systematically compared with the technical or operating features of the product. The process brings out the relative importance of customer requirements which, when set against the technical features of the product, leads to the identification of the most important or sensitive technical characteristics. These are the technical characteristics which need development or attention. Although the word 'product' is used in our descriptions which follow, QFD is equally applicable in services. Technical characteristics then become the service characteristics.

Perhaps a chief advantage of QFD is that it is carried out by a multi-disciplinary team who are all concerned with the particular product. QFD is then the vehicle for these specialists to attack a problem together. QFD is, therefore, not only concerned with quality but with the simultaneous objectives of reducing overall development time, meeting customer requirements, reducing costs, and producing a product or service which fits together and works well the first time. The mechanics of QFD are not rigid and can easily be adapted to local innovation.

QFD is also referred to as the **house of quality**. This is because of the way the matrices in QFD fit together to form a house-shaped diagram. A full QFD exercise may make use of several house of quality diagrams, forming a sequence which gradually translates customer requirements into specific manufacturing steps and detailed manufacturing process requirements. The most simple QFD exercise would use only one house of quality diagram which seeks to take customer requirements and to translate them into specific technical requirements.

In addition, a QFD exercise may spin off (or 'deploy') a whole hierarchy of house of quality exercises. This would happen where a new product is being considered. The first exercise would consider the product as a whole but subsequent exercises may involve consideration of individual components. For instance, a complete new car could be considered at the top level but subsequent exercises may be concerned with the engine, body shell, doors, instrumentation, brakes, and so on. Thereafter the detail would be deployed into manufacturing and production.

House of quality diagram

We now explain the essential composition of the basic house of quality diagram. Refer to Figure 21.

Central (or relationship) matrix (CM)

The central matrix lies at the heart of the house of quality diagram. This is where the 'what is required' is matched with the 'how to do it'. Each customer requirement (the what) is systematically compared with each technical characteristic or design feature (the how). The nature of the relationship is noted in the matrix by an appropriate symbol. The team can devise their own symbols; for instance, numbers may indicate the relative strength of the relationship or simply ticks may suffice. The relationships may be positive, neutral or negative. This matching exercise is carried out by the team based on their experience and judgement. The idea is to clearly identify all means by which the 'whats' can be achieved by the 'hows'. It will also check if all 'whats' can in fact be achieved (insufficient technical characteristics?), and if some technical characteristics are not apparently doing anything (redundancy?).

Customer requirements (CR)

The usual starting point for QFD is the identification of customer requirements or the 'voice of the customer'. These are entered into the rows to the left of the central matrix. Information on customer needs may be obtained from a variety of sources and this may be a major exercise in itself. Customers may be present or future, internal or external, primary or secondary. All the conventional tools of marketing research are relevant, as well as techniques such as complaint analysis

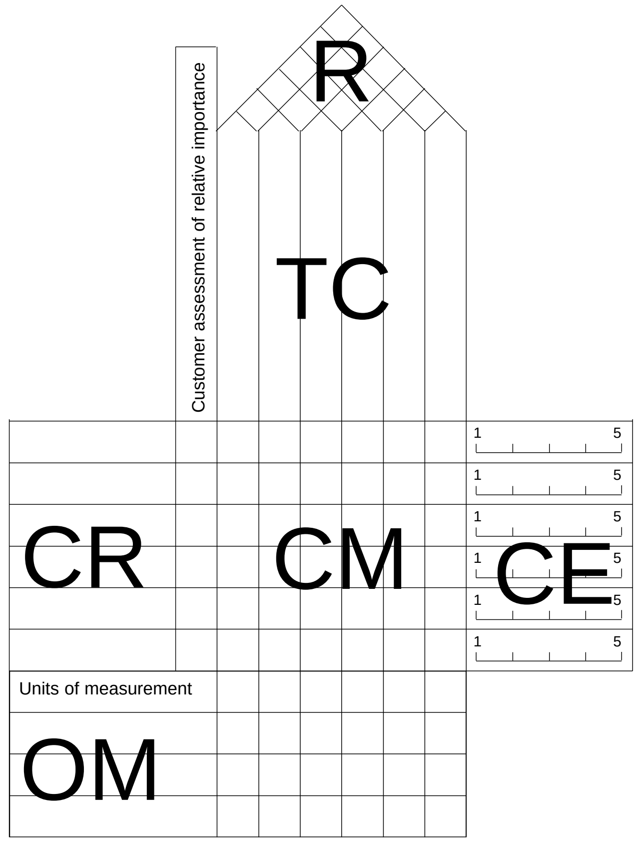


Figure 21: Quality function development: house of quality

and focus groups. Customers may include owners, users, and maintainers, all of whom have separate requirements. After collection comes the problem of how to assemble the information before entering it into the column. It helps to think in terms of a hierarchy; on the primary level are the broad customer requirements, secondary requirements add the detail.

Marketing would have responsibility for assembling much of the customer information, but the team puts it together. Marketing may begin by circulating the results of surveys and by a briefing. Thereafter the team should brainstorm out the customer requirements, but not the technical features as short phrases.

In a real study, the number of apparent customer requirements may be very large. There is the temptation to shorten the list by grouping. This may be reasonable, but an important requirement is to preserve the 'voice of the customer'. The team must not try to 'second guess' or to assume that they know best what is needed.

RANKINGS OR RELATIVE IMPORTANCE OF CUSTOMER REQUIREMENTS

When the customer requirements are assembled onto the matrix on the left of the house diagram, weightings are added to indicate the importance of each requirement. Weightings are established by market research or focus groups, or failing these the team may determine rankings by a technique such as **pairwise comparison**. Each requirement is compared with each other. The most important of the two requirements gains a point, and all scores are added up to determine final rankings. The rankings may be listed in a column immediately to the right of the relationship matrix.

Competitive evaluation of customer requirements (CE)

Each customer requirement may then be examined in terms of customer perceptions. For each customer requirement, a group of customers may be asked to state how they perceive the present performance of the company's product as against those of competitor products. The aim of this part of the exercise is to clearly identify the SWOT (strengths, weaknesses, opportunities, threats) of competitor products against your own. The competitive evaluation is placed in a row to the right of the customer requirement rankings.

Technical characteristics and associated rankings (TC)

Customer requirements, weightings and competitive evaluations are displayed from left to right across the house. The corresponding technical characteristics (or design features), rankings, and competitive evaluations are displayed from top to bottom across the house. Immediately above the central matrix are listed the technical characteristics of the product. These characteristics are stated in terms that are likely to have an impact on the customer requirements.

Immediately below the relationship matrix appears one or more rows for rankings such as cost or technical difficulty or development time. The choice of these is dependent on the product. These will enable the team to judge the efficiency of various technical solutions. The prime row uses the customer weightings and central matrix to derive the relative technical characteristic rankings.

Next below the relationship matrix comes one or more rows for competitive evaluation. Here, where possible, 'hard' data is used to compare the actual physical or engineering characteristics of your product against those of competitors. To the right of the relationship matrix we can judge relative customer perceptions, and below, the relative technical performance.

The bottom row of the house, which is also the 'bottom line' of the QFD process, are the target technical characteristics. These are expressed in physical terms and are decided upon after team discussion of the complete house contents, as we describe below. The target characteristics are, for some, the final output of the exercise, but many would agree that it is the whole process of information assembly, ranking, and team discussion that goes into QFD which is the real benefit, so that the real output is improved inter-functional understanding.

Roof of the house (R)

The roof of the house is the technical interaction matrix. The diagonal format allows each technical characteristic to be viewed against each other one. This simply reflects any technical trade-offs that may exist. For example, with the hamburger case (see Figure 22) , bun size may have to be compatible with beef size. These have a positive relationship; increasing the bun size increases the beef size. These interactions are made explicit, using the technical knowledge and experience of the team.

USING THE HOUSE AS A DECISION TOOL

After assembly of the customer requirements, customer rankings, competitive data, technical characteristics, and technical competitive measures, work on the house begins by completing the main relationship matrix and the technical relationship matrix. The full team should be involved because this is a major learning stage.

In the central matrix, customer requirements are compared with technical characteristics. The extent to which each customer requirement is matched by each technical characteristic is judged. Go through the matrix, cell by cell. Using the hamburger example in Figure 22, ask, for example: to what extent does the meat in a hamburger meet the requirements for nutrition? The answer will be high (write in 9 points), medium (write in 3 points), low (write in 1 point), or not at all (write in zero). In some cases a negative is possible (write in minus 3). Then, for each cell, multiply the point score by the weight for that row (the customer requirement ranking). Write this figure in the top right-hand of the cell. When complete, add up the top right-hand figures for each column. This gives a weighting which reflects the ability of each technical requirement to meet each customer specification.

Matrix Analysis

Example: design of a hamburger to customer preferences

Begin with a focus group to determine customer requirements and relative weightings. Then perform the analysis in a QFD matrix.

Customer requirements	**Customer preference weighting**	**Features**			
		Beef	**Bun**	**Lettuce**	**Ketchup**
Moisture	1	0 0	0 0	1 1	9 9
Flavour	3	9 27	0 0	0 0	3 9
Nutrition	3	9 27	3 9	0 0	0 0
Visual appeal	5	9 45	1 5	1 5	1 5
Value for money	5	9 45	1 5	0 0	1 5

	Beef	Bun	Lettuce	Ketchup
Weighted scores	144	19	6	28

Conclusion: Concentrate attention on beef and ketchup

Figure 22: Ranking matrix: hamburger example

When all cells have been completed, the matrix is examined. A blank row indicates that a customer requirement is not met. A blank column indicates a redundant technical feature. The main matrix shows the required technical characteristics that will need design attention. The costs of these can be seen with reference to the base rows. This may have the effect of shifting priorities if costs are important. Then the technical trade-offs are examined. Often there will be more than one technical way to impact a particular customer requirement, and this is clear from rows in the matrix. And it may also be that one technical alternative has a negative influence on another customer requirement. This is found out by using the roof matrix. Eventually, through a process of team discussion, a team consensus will emerge. This may take some time, but experience shows that time and cost is repaid many times over as the actual design, engineering and manufacturing steps proceed.

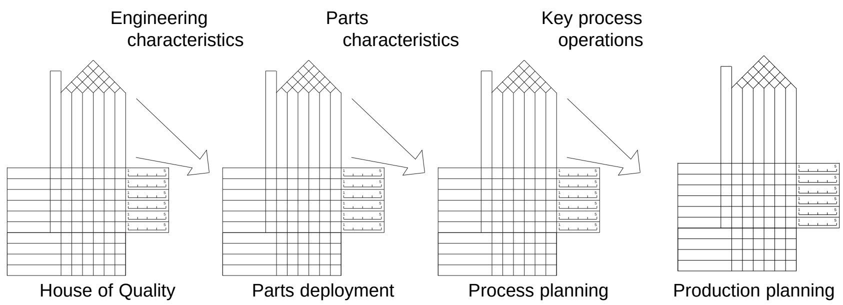


Figure 23:Deployment

The bottom line is now the target values of technical characteristics. This set can now go into the next house diagram (Figure 23). This time the target technical characteristics become the 'customer requirements' or 'whats', and the new vertical columns (or 'hows') are, perhaps, the technologies, the assemblies, the materials, or the layouts. And so the process 'deploys' until the team feels that sufficient detail has been considered to cover all co-ordination considerations in the process of bringing the product to market.

QFD may be used in several stages in order to 'deploy' customer requirements all the way to the final manufacturing or procedural stages. Here the outcome of one QFD matrix (for example the technical specifications), becomes the input into the next matrix which may aim to look at process specifications to make the product (Figure 23).

ACTIVITY 17

Use QFD to analyse your local library service. To do this properly you will have to:

- survey customer requirements, including ranking them
- list the technical characteristics (i.e. the services offered)
- undertake benchmarking or comparisons with other libraries
- complete the central matrix and roof
- identify areas of strength and weakness
- make some recommendations.

6.5 Kaizen

Kaizen is the Japanese name for continuous improvement. As such it is a vital part of total quality. It brings together several of the tools and techniques described in this unit and a few others. Kaizen was made popular in the West by Maasaki Imai (1986). According to Imai, Kaizen comprises several elements. Kaizen is both a philosophy and a set of tools.

PHILOSOPHY OF KAIZEN

Quality begins with the customer. But customers' views are continuously changing and standards are rising, so continuous improvement is required. Kaizen is dedicated to continuous improvement, in small increments, at all levels. Everyone has a role, from top management to shop floor employees. Top management must allocate the resources and establish the strategy, systems, procedures and organisational structures necessary for Kaizen to work. Middle managers are responsible for implementing Kaizen. They must monitor performance of the continuous improvement programme, and ensure that employees are educated in the use of the necessary tools. Supervisors are responsible for applying Kaizen. They must maintain the rate of suggestions, coach, and improve communications at the workplace. And shop-floor employees must make suggestions, learn new jobs, use the tools, and generally participate in continuous improvement activities individually and in teams. Imai's book has several examples of how this philosophy works its way down the organisational hierarchy in Japanese companies.

Imai believes that without active attention, the gains made will simply deteriorate. But Imai goes further. Unlike Juran, who emphasises 'holding the gains', Kaizen involves building on the gains by continuing experimentation and innovation.

According to Imai there are several guiding principles that include :

- questioning the rules (standards are necessary but work rules are there to be broken and must be broken with time)

- developing resourcefulness (it is a management priority to develop the resourcefulness and participation of everyone)
- get to the root cause (don't solve problems superficially)
- eliminate the whole task (question whether a task is necessary; in this respect Kaizen is similar to BPR, that we discuss in Unit 9)
- reduce or change activities (be aware of opportunities to combine tasks).

Tools of Kaizen

Kaizen incorporates several tools but the most well known are the **5 Ss**, the **5 M Checklist**, and the **5 Whys**.

The **5 Whys** is a simple but effective technique developed at Toyota and strongly associated with JIT manufacturing. It involves asking 'why?' over and over again, typically five times, so as to get to the 'root cause' of the problem. This avoids 'solving' the problem at the superficial level.

The **5 Ss** are five Japanese words beginning with S covering aspects of housekeeping. Many Japanese believe that this is the foundation for quality and productivity. Some British companies taken over by Japanese companies have experience of this fundamental belief. When Sumitomo took over Dunlop, apparently the first six months were spent on these five Ss. The 5 Ss correspond to:

- cleanliness (operators/staff must be responsible for keeping their own equipment clean).
- orderliness (put equipment away in the right place, in the right condition when not needed)
- tidiness (a place for everything and everything in its place)
- organisation (removing unneeded items, laying out the workplace, tools, equipment, and inventory)
- discipline (doing all this every day, not periodically).

Nissan has an audit procedure to check on these aspects. We will meet these 5 Ss again when we discuss total productive maintenance later in this unit.

The **5 M Checklist** is intended to ensure that all five factors: men (people), machine, material, method, and measurement, are considered in any process improvement or problem solution. The 5 Ms are often incorporated in constructing cause and effect diagrams as the basic fishbone framework.

Summary

In this section we have reviewed a selection of more advanced quality improvement techniques: cost of quality, benchmarking, design of experiments (DoE), quality function deployment (QFD) or the house of quality, and kaizen. QFD is a technique that integrates several others. All of these techniques provide an essential background to our next section.

SECTION 7

Reliability and Maintenance

Introduction

Reliability is a concept very closely associated with quality. You will recall that reliability is one of Garvin's **dimensions of quality**, and for many people, reliability figures strongly in any set of desirable product characteristics, for example, remember the *Top Gear* survey we discussed in Section 1.

Maintenance, in turn, is closely associated with reliability. Often without good maintenance procedures there will only be poor reliability. Reliability and maintenance are vast subjects in themselves and often involve high levels of statistics. In this brief section, the aim is to introduce you to the topics rather than to make you a reliability and maintenance expert. Like many other areas of operations management, maintenance has undergone a revolution over the past decades with the influence of Japanese methods. Total productive maintenance (TPM) philosophically has much in common with TQM.

7.1 Reliability

Reliability is defined as 'the probability of a product performing its specified function under prescribed conditions without failure for a specified period of time'. (*APICS Dictionary*, 1995). The word is also in common use in relation to a duration of time without failure.

In reliability theory, the 'bath-tub' curve is well known, and probably fits with your own experience. It is shown below in Figure 24.

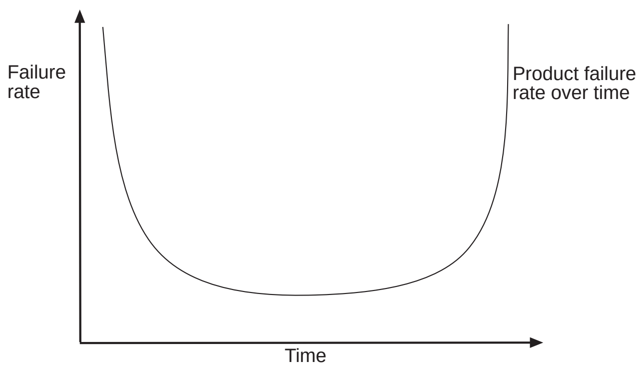


Figure 24: The 'bath-tub' curve of reliability theory

Notice that the axes are failure rate against time, not failures against time. Infant mortality or **burn-in** failures are often the result of defects undetected during manufacture. It is common for many types of electronic equipment, particularly where high reliability is required, to be subjected to a 'burn-in' test period before leaving the factory. The system is run through a number of cycles often subject to increased temperature. The idea is to make any defective products fail, before they reach the customer and are therefore much more expensive to repair.

Random failures are a function of product design. Finally, **wear-out** failures are a function of design and, of course, wear and age.

Although the bath-tub curve is common, this is not the only mode of failure.

RELIABILITY STATISTICS

We will not say much about this, but a brief insight is useful. The exponential distribution, shown in Figure 25, is by far the most commonly-used reliability distribution.

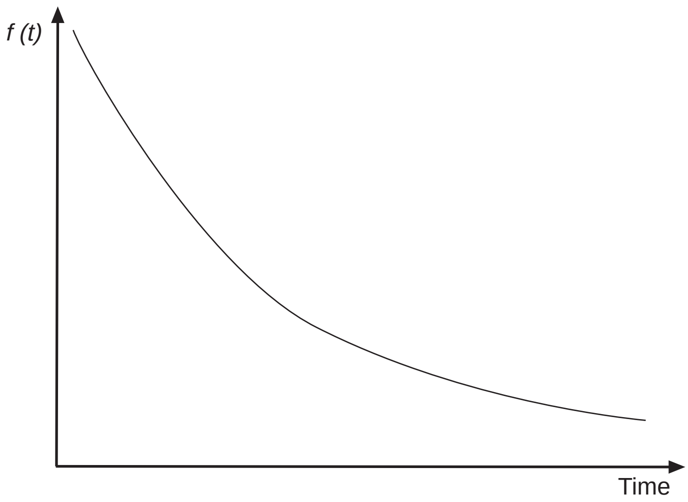


Figure 25: Reliability statistics – exponential distribution

The probability density function of the exponential distribution is

$f(t) = \lambda e^{-\lambda t}$ where

λ = failure rate

and the Reliability is $Rt = e^{-\lambda t}$

This is fortunate, because the exponential distribution has some special features, which are :

- mean and standard deviation are equal; thus it is relatively easy to obtain. This is known as the **mean time between failures** or **MTBF**, an important figure in reliability calculations.
- approximately 63% of the values fall below the mean, which means that there is a 37% chance of survival beyond the MTBF.

ACTIVITY 18

A photocopier has a MTBF of 50 hours. What is the probability that it will work perfectly for 2 days, or 16 hours?

The failure rate is 1/50 = 0.02 per hour, so:

$e^{-\lambda t} = e^{-(0.02)(16)} = 0.73$ or 73%

SYSTEM RELIABILITY

Many products or systems have hundreds or thousands of components. The whole system fails if one component fails (a common problem, but fortunately becoming less common with PCs), then this is known as a **series system** (Figure 26). The reliability of such a system is the product of the sub-system or component reliabilities. If there are three components with reliabilities, for say 1,000 hours of operating life, of 0.98, 0.95, and 0.99, then the system reliability is:

$$0.98 \times 0.95 \times 0.99 = 0.9216 \text{ or } 92.16\%$$

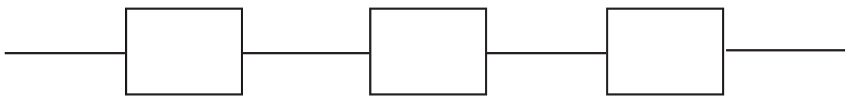


Figure 26: A series system

ACTIVITY 19

Work out the system reliability for 100 series components each with a reliability of 0.995, or 99.5%. Low isn't it ?

Sometimes sub-systems are arranged in parallel for reliability reasons (Figure 27). This happens with, for example, 'hot back-up' computer systems. Here, the system fails only if both sub-systems fail.

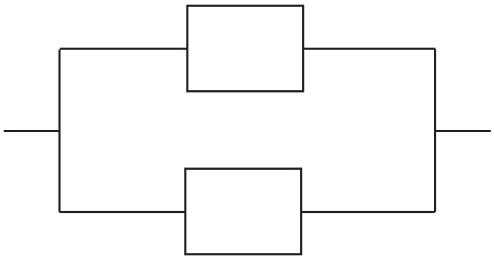


Figure 27: A parallel system

Here the relevant formula, for two components, is:

$$R(s) = R_1 + R_2 - R_1 \times R_2$$

so, for two components, each having a reliability of 0.95, R(s) = 0.9975.

7.2 Maintenance

Here we will concentrate only on total productive maintenance (TPM). The term productive is used because we wish to gain productivity, not just concentrate on maintenance. TPM, like TQM, has been one of the great ventures of the past 10 years. It has much in common with TQM, namely the involvement of all the maintenance task, not just the specialists. Like TQM, TPM relies on team involvement. TPM is very relevant to JIT manufacturing, but its principles are not confined to manufacturing.

TPM begins with the idea of **six big losses**. These are

- breakdown losses
- set-up and adjustment losses (delaying the start of work)
- idling and minor stoppages (due to necessary minor adjustments)
- reduced speed losses (unable to run at full speed)
- start-up losses (pre-production breakdowns)
- quality defects (as a result of imperfect equipment).

ACTIVITY 20

Apply these six big losses to your car, when you are just about to set off for an important appointment. What could you do about them?

Breakdown is obvious. Set-up losses might involve seat and seatbelt adjustment, or delays when you have forgotten to put fuel in. Idling and minor stoppages might involve a headlight or brake-pad failure. Reduced speed may be caused by cumulative imperfect maintenance or poor tuning. Start-up losses may be due to a flat battery, or having to scrape ice off the windscreen. Quality defects are probably not applicable here, but of course would be in manufacturing or service. What could you do? You could call your local garage, or an emergency repair service if you are a member; or you could take greater care, and check beforehand. This is what TPM does: it makes operators and staff aware of the losses and puts them, as far as possible, in charge of their own processes. Like TQM, TPM is a do-it-yourself (DIY) methodology: 'ownership' of the machine or process is fundamental.

The role of the maintenance experts is to teach the DIY activities, being responsible only for the more complex tasks, including maintenance information systems. This is a feedback loop. As staff take over more maintenance tasks themselves, so the maintenance staff have more time to train, track, and improve.

To do this, there are the five Ss, which should guide all staff, as we listed earlier:

- cleanliness (operators/staff must be responsible for keeping their own equipment clean).
- orderliness (put away in the right place, in the right condition when not needed)
- tidiness (a place for everything and everything in its place)
- organisation (removing unneeded items, laying out the workplace, tools, equipment, and inventory)
- discipline (doing all this every day, not periodically).

And finally, the five pillars of TPM are then :

- adopt improvement activities aimed at the six big losses
- improve existing planned and predictive maintenance
- establish a level of self-maintenance and cleaning carried out by the operators (using the five Ss)
- improve the skills of operators and maintenance staff
- initiate prevention techniques.

The associated techniques of TPM are numerous, and some can only be mentioned here. They include aircraft-style checks (a start-of-shift checklist used by all, like that used by pilots), condition monitoring (where, for example, oil and vibration is monitored to give early warning of problems), full use of senses (humans are very sensitive to changes in vibration and sound, so get the operators to report when they detect a change), and maintenance information systems (to keep track of faults and costs). Many of the problem-solving techniques we discussed under quality are highly relevant to TPM also.

ACTIVITY 21

Many lecturers and presenters rely on maintenance staff for the good operation of overhead projectors, and then complain when things go wrong. This is not TPM! What might you do if TPM was considered part of the job? Brainstorm out some ideas, preferably in a group. (The idea for this exercise comes from Tom Willcox & Peter Willmott, 1994.)

You will probably come up with quite a few sensible actions, including keeping spare bulbs handy, getting training on how to change bulbs, cleaning the glass afterwards, and checking and testing before the lecture starts. You would be familiar with the manual. Then you might record the approximate length of time that the bulb has been switched on, to allow timely replacement, and you might monitor the temperature with a thermometer, even carry out studies as to the maximum length of time to switch on for. By knowing the costs of components, you might recommend scheduled maintenance or replacement, etc. All very different, but all easy, and all possible.

Summary

In this brief section, we have learned something of the meaning of reliability and looked at the basic formulas used for prediction and management. We have looked at the effects of placing components in series and parallel. Finally, we looked at total productive maintenance (TPM), observing the similarities with TQM as both emphasise involvement and empowerment of staff.

Unit Review Activity

Read the article ‘Getting the numbers right’, Resource Item 6.2. Identify the approaches BT uses to promote TQM in the company. What are the benefits to the customer?

Unit Summary

In this unit we looked at quality – an area that has leapt to the top of many senior management agendas over the past decade. First we looked at the meaning of the word ‘quality’. There are several dimensions, such as reliability, performance, conformance and perspectives, such as macro and micro. Quality is a changing target. Quality must begin with the external customer, but internal customers are also important.

The views of some of the quality 'gurus' such as Deming, Juran and Crosby were examined. These people have had a considerable influence, not only on product and service quality, but also on management in general.

We looked at TQM, noting that it involves all functions, all people, all products, and all processes from design to delivery. We looked at a well-known standard, ISO 9000, and at various quality awards, which form a useful checklist for the support infrastructure for quality. Prevention, rather than detection, was seen to be a consistent theme. A 'cost of quality' exercise makes this explicit by tracking the costs of failure and the costs of prevention and detection.

We examined a small selection of tools and techniques for quality. Many of these tools have applicability well beyond that of simply improving a product. An example is statistical process control, which can also be used in areas such as forecasting, inventory control and cost accounting. Finally, in a brief section, we looked at reliability, an area closely linked to quality.

Acknowledgement
Portions of this unit, both text and figures, were taken from John Bicheno, *The Quality 50*, PICSIE Books, Buckingham, 1994. Permission to copy is acknowledged.

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Recommended Reading

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