TEXTBOOK NO. 7005④

An Introduction to Quality Control

TEXTBOOK

Mitutoyo

CONTENTS

PREFACE

The concept of quality control was first introduced by Bell's Dr. W. A. Shewhart in 1926. Dr. W. Edward Deming of the U.S. brought the idea to Japan around 1948 and it became well known in the industrial fields along with the Deming Award.

There is no need to explain how important quality control is to a person related directly or indirectly to production for in that field there are few actions carried out without keeping quality control (QC for short) in mind. People working in manufacturing plants are well acquainted with the quality control terminology, but sales people and those who work outside the plant may find it difficult and awkward to use and understand Greek symbols and complicated-looking mathematical formulas. Quality control is just as important for the sales department as it is for the production department.

The object of this textbook is to correct the misunderstanding that quality control is difficult, and to get everybody acquainted with quality control so that they can apply the principles to their own work.

1. WHAT IS QUALITY CONTROL?

Quality control **is: — using everyday language —**
A method to make good products inexpensively and quickly for our customers so that they buy many products and are satisfied with their purchases.

To satisfy customers **means that:**
The customers can use the products safely and effectively, and the products should be evironmentally safe.

In addition, there should be no failures or after-sales service problems to worry our customers. The product must be designed not only for immediate appeal, but it should also be useful in the true sense of the word. The product must be superior in functionality and performance to similar products of other companies.

A good product **is:**
A product of high quality. Quality includes the following three factors. All three must be superior in a good product.

- Design quality
- Workmanship
- Service quality

Taking a color TV set as an example, the design quality can be gauged as follows:

- Color quality
- Sound quality
- Ease of operation
- Reliability

Workmanship can be measured by comparing two color TV sets of the same model:

- Differences in color and sound quality
- A flaw or scratch
- Defects (e.g. a knob came off.)

(In other words, workmanship determines the degree of dispersion in the quality of each product.)

The service quality is defined as the quality of after-sales service, which includes the following considerations:

- Availability of spare parts
- Accessibility to service

It is essential to take the above points into consideration when we talk about the quality of our products.

2. TOTAL QUALITY CONTROL

From the company's point of view, quality control is regarded as the managing technique required to produce "good products." If we are to make high-quality products for our customers, quickly and inexpensively, the entire company must cooperate and be fully committed to quality control. This kind of activity is called *total quality control* (TQC for short).

Total quality control can be expressed as "the cooperation of all departments in a company to make and sell a product as inexpensively and quickly as possible, to the satisfaction of the customers." In short, the motto "for the customers" should be the common goal throughout the company.

3. STATISTICAL QUALITY CONTROL

There is one thing that should always be kept in mind when implementing total quality control; "all actions taken must be based on facts." Never come to conclusions based on the one-sided opinions of a few people, or on your own prejudices. We must be determined to only make decisions grounded on facts and to take practical actions. In order to gain a thorough understanding of the facts to be studied, we must collect specific data that truly represents the facts and compile the data using a method called statistical analysis. The statistical method applied to quality control is called *statistical quality control* (abbreviated SQC).

4. STATISTICAL QUALITY CONTROL TOOLS

Some of the most powerful SQC tools used on production lines are cause-effect diagrams, Pareto diagrams, graphs, check sheets, histograms, scatter diagrams, and control charts. Each of these seven SQC tools can be described as follows:

1) Cause-effect diagrams

The cause-effect diagram is a systematic, fish-skeleton like diagram representing the relationship between the characteristics (results) in question and causes that influence those characteristics (**Fig. 1**).
The cause-effect diagram is an effective tool for improving process control. The following is an example of a cause-effect diagram for safety-related procedures (**Fig. 2**).
The processes referred to in this text apply not only to the machining stage, but also includes all aspects of the manufacturing process, such as machinery, material, work standards, and workers' skill, etc. that affect the final quality of the product.

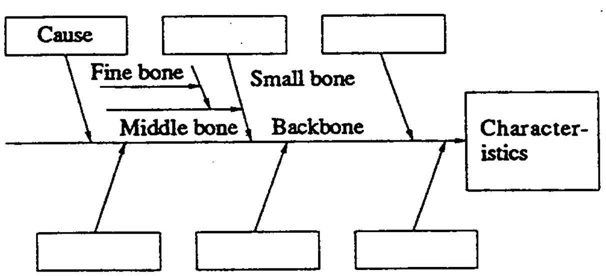


Fig. 1 (See Fig. 2)

2) Pareto diagram

The Pareto diagram is a graph where rejected parts, defects, claims, or failures are classified according to their causes in the order of their importance or influence on the problem studied. This information is then used to construct a bar graph and an cumulative line graph.
The Pareto diagram is a useful tool to observe the individual causes of a problem according to the overall impact or effect the individual cause actually has on the problem, and to decide on the most effective way to correct the problem (**Fig. 3**).

a) Classification according to the number of rejects

Defect	Number of rejects	Cumulative number of rejects
Defective chrome plating	421	421
Flaw	262	683
Defective stain finish	150	833
Stain	93	926
Peeling	51	977
Improper washing	40	1017
Others	65	1082

b) Classification according to the money lost

Defect	Loss (¥)	Cumulative loss (¥)
Flaw	196,500	196,500
Defective stain finish	72,000	268,500
Stain	44,640	313,140
Peeling	24,480	337,620
Defective chrome plating	21,050	358,670
Improper washing	1,200	359,870
Others	5,525	365,395

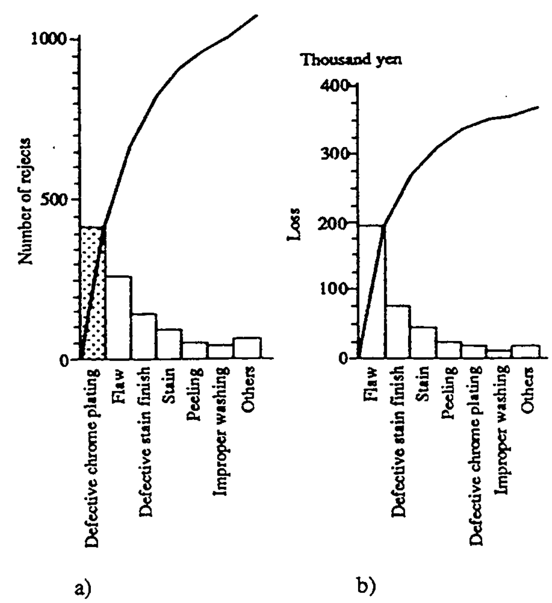


Fig. 3 Analysis of surface finish defects

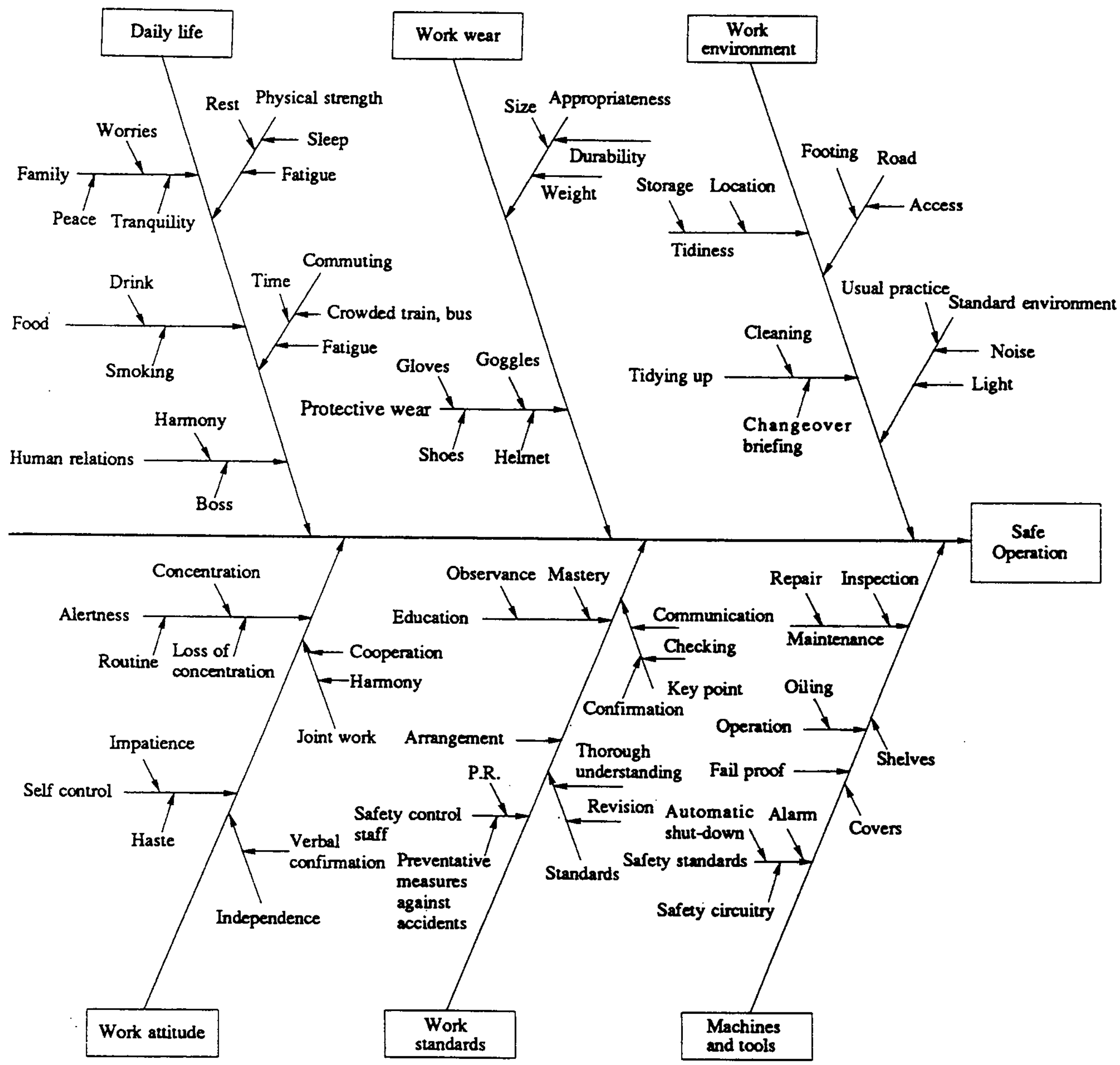


Fig. 2 Cause-effect diagram for "safe operations"

Considerations:

The defective chrome plating was the primary cause in the Pareto diagram classified by the number of rejects, but the 5th in the Pareto diagram based on money lost. If importance is placed on defects that cause the larger losses, that problem must be given first priority for process improvements. Thus, the Pareto diagram is very effective when deciding on the target of improvements and to check on the effect of those improvements.

3) Graph

The following are ten benefits of graphs in the field of quality control.

(1) A visual image instead of numerals — far more effective when observing differences in size or change over time.

(2) An entire relationship can be grasped at a glance because the quantity is represented by long and short bars or the direction of a line.

(3) An alternative to reading — graphs require less effort than reading.

(4) Eye-catching — figures and pictures will attract attention and arouse interest.
(5) Easy to understand — there is no need to read or calculate.
(6) Quick to grasp the facts — graphs also help make objective observations.
(7) Graphs can be drawn easily — even elementary school children can draw bar graphs and line graphs.
(8) Give good comparisons — comparisons with other results can be achieved without difficulty.
(9) International — there is no language barrier.
(10) Appealing — the emphasis can be strongly focused.

Because graphs have the above advantages and are easy to draw, they are used for a wide variety of purposes; graphs for explanation, analysis, controlling, planning, calculation, and so forth.

4) Check sheet

(1) What is a check sheet?

Data must be collected in order to draw Pareto diagrams on the causes of product failure or to produce histograms (described later) for checking part dimensions against the specifications. However, it is quite a burden in a busy work area to collect data. Even after the data is collected, it is often troublesome to organize, and occasionally find yourself too late for the results to be used effectively anyway.

Check sheets are forms designed to allow easy collec tion and arrangement of data. Just 'check' the chec sheet, and all necessary information is collected in a well-organized manner, without the worry of over-looking important facts or figures.

(2) Types of check sheets

Check sheets can be divided into two types; recording forms and checking forms. The following are examples of some of the typical uses of check sheets.

① Checking defects (**Figs. 4**)
② Checking defect causes (**Fig. 5**)
③ Checking the distribution of a process
④ Checking defect locations
⑤ Inspection and confirmation (**Fig. 6**)

Vehicle No.		Date of inspection	
Color		Inspector	
Remarks		Sprayer	

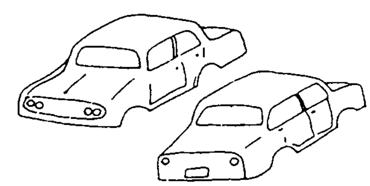


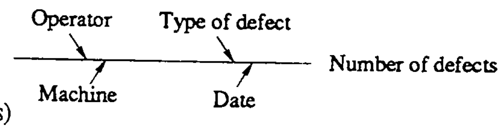
Fig. 4A Check sheet for the spray finish of an automobi body

Reworked item	Mar. 2	3	4	5	6	9	10	11	12	13	Total
Miniature lamp replaced	//	/	///	///		𝍸	𝍸 //	𝍸 //	////	𝍸 /	38
Screws tightened	/	///	//		//			𝍸	/	//	16
Panel position adjusted	/	𝍸 /	//	/		///	/	//	////	////	24
Missing items supplied			/	/				/			3
Cleaned	𝍸 //	//	/	////	/	///	𝍸	///	𝍸 /	////	36
Others	/	/			///		//	//	///		12
Total	12	13	9	9	6	11	15	20	18	16	129

Fig. 4B Reworked item check sheet

(1) Method

Data : Number of rejects
Classifications : Operator (A, B)
Machine (No. 1, 2, 3, 4)
Type of defect
(dimensions, flaw, material, others)
Date (month, day)



(2) Classification by the operator, machine, type of defect and date

Operator	A							
Machine	No. 1				No. 2			
Date \ Type of defect	Dimensions	Flaw	Material	Others	Dimensions	Flaw	Material	Others
Month-Day	/		//				/	
• •		/	/				/	
• •								

Operator	B							
Machine	No. 3				No. 4			
Date \ Type of defect	Dimensions	Flaw	Material	Others	Dimensions	Flaw	Material	Others
Month-Day			/					
• •		/	/			/		/
• •								

(Note)
1. Add columns when recording the number of products per machine and the total number of rejects as well.
2. The check sheet format can be changed as necessary. For example, exchange the items between the column and row headings to make a wide check sheet.

(3) Classification by the Operator, machine and date, with the defect checked using different marks according to the defect type

Marks for defects: ○ Dimensions, Δ Material, • Flaw, x Others

Operator	A		B	
Date \ Machine	No. 1	No. 2	No. 3	No. 4
Month - Day	○ Δ Δ	Δ	Δ	
• •	• Δ	Δ	• Δ	• • x
• •				

Fig. 5 Check sheet for the number of defects from each

Area	Location	Motor capacity / Serial No.	Date of inspection	Weather	Temperature	Inspector

Section manager	Sub-section manager	Group leader	Person in charge

Equipment	Inspection item	No.	Descriptions	Check	Remarks
Distribution board	Circuit breaker	1	Is the switching mechanism in good condition?		
		2	Are the terminals securely connected?		
		3	Is the contact area between the blade and the support in good condition?		
	Knife switch	4	Is the circuit breaker correctly rated?		
		5	Is the handle insulated?		
	Selector switch	1	Is the knob pointing correctly?		
		2	Do the switches operate correctly?		
	Snap switch	3	Are the lock nuts tight ?		
		4	Are the contacts in good condition?		
	Meters	1	Is the ammeter in good condition?		
		2	How much current?	A	
		3	How much voltage?	V	
		4	Are there any broken pilot lamps?		
	Buzzer	1	Does the buzzer beep?		
	3-phase relay	2	Does the switch operate without excessive free-play?		
	Reed switch	3	Are there any abnormal sounds or smells?		
		4	Does it operate with a 3E phase missing? 60%	sec.	
		5	Does it operate with a 3E phase missing? 80%	sec.	
	Meters	6	Does it operate with a 3E phase missing? 100%	sec.	
		7	Does the solenoid chatter ?		
		8	Are the contacts in good condition?		

Fig. 6 Check sheet for distribution board inspection

5) Frequency distribution and histograms

(1) Variation

The quality of a product is not always the same, even when the product is manufactured using the same material, equipment and process, by the same worker, and following the same work standard. The differences in quality are called *variation.*

(2) Distribution

When quality characteristics are measured in terms of length, weight, time, or temperature, the frequency of occurrence usually follows a general pattern where the frequency decreases the further it gets away from the central value. This pattern of variation, which is attributed to the process itself, is called *normal distribution* or *bell-shaped distribution* (**Fig. 7**). The concept of frequency distribution is useful for understanding the nature of the distribution of quality characteristics.

(3) Frequency distribution

Frequency distribution is an arrangement that shows the frequency of occurrence in ordered classes or categories into which data is grouped, and is represented in the form of a graph (histogram) or a table. Since frequency distribution represents data in a compact form, it gives a good overall picture of the entire distribution of the quality characteristics produced by the process.

(4) Frequency distribution table

The frequency distribution table is an arrangement of data obtained from a process, where the data is divided into about ten groups of the same interval by tallying the measurements that fall into each group (**Fig. 8**).

(5) Histogram

The most common form of graphic representation of a frequency distribution is the *histogram* (**Fig. 9**). A histogram is constructed by representing measurements or observations grouped on the horizontal scale and the class frequencies on the vertical scale of a sheet of graph paper, and drawing bars or rectangles whose bases equal the class intervals and whose heights are determined by the corresponding class frequencies.

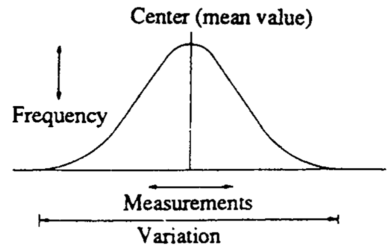


Fig. 7 Frequency distribution

No.	Class	Central value	Frequency marks	Frequency
1	8.05 ~ 8.35	8.2	/	1
2	8.35 ~ 8.65	8.5	///	3
3	8.65 ~ 8.95	8.8	~~////~~ ///	8
4	8.95 ~ 9.25	9.1	~~////~~ ~~////~~ ~~////~~ /	16
5	9.25 ~ 9.55	9.4	~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~ ///	28
6	9.55 ~ 9.85	9.7	~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~ /	36
7	9.85 ~10.15	10.0	~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~ ///	38
8	10.15 ~ 10.45	10.3	~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~ ////	34
9	10.45 ~ 10.75	10.6	~~////~~ ~~////~~ ~~////~~ ~~////~~ ~~////~~	25
10	10.75 ~ 11.05	10.9	~~////~~ ~~////~~ ~~////~~ ///	18
11	11.05 ~ 11.35	11.2	~~////~~ //	7
12	11.35 ~11.65	11.5	////	4
13	11.65 ~ 11.95	11.8	//	2
Total				220

Fig. 8 Frequency distribution table (diameter of rods)

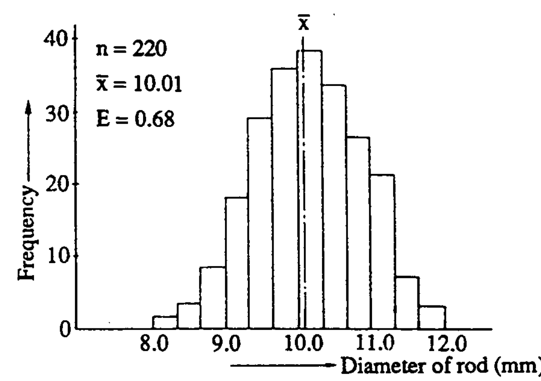


Fig. 9 Histogram

(6) How to read a histogram

When observing a histogram, try to find the overall pattern of the graph, taking into account the fact that there may be a certain degree of irregularity. In most cases, you will notice a fairly regular and symmetrical pattern. Drawing a smooth curve along the tops of the bars will help you to grasp the inherent characteristics of the distribution. Check the following points.

1. Where is the center of distribution?
2. How is the data distributed?
3. Is the distribution biased to the left or right?
4. Is the data spread evenly along the horizontal scale or concentrated in one area?
5. Is there any class that does not have any data?
6. Is any remote data found?
7. Is there more than one peak?
8. Does the left or right side of the distribution form a cliff?
9. Divide the distribution into groups if necessary. Is there any special pattern found by doing so?
10. Is out-of-tolerance data found?
11. Does the center of the distribution fall on the center of tolerance limits?
12. Does the distribution fit within the tolerance limits with sufficient margins?
13. Do the 3σ (σ: standard deviation) limits fall on the appropriate positions?

For normal distributions having the general bell shape, most data (about 99.73%) falls within a range of plus and minus three standard deviations (σ). **Fig. 10** is an example of a histogram.

(7) The histogram and specifications

A comparison between a histogram and the specifications gives a good indication of whether the process capability (see page 12) satisfies the technical requirements. It also helps find problems with the current process and to review the manufacturing method. Consider the following points when studying the relationship between the distribution pattern of a histogram and the specifications or target values.

1. Does the center of distribution fall on the center of tolerance limits?
2. Is the dispersion of the distribution too large, or abnormally small?
3. Is out-of-tolerance data found?
4. Does the distribution fit within the tolerance limits with sufficient margins?

Fig. 11 shows some examples of the above considerations.

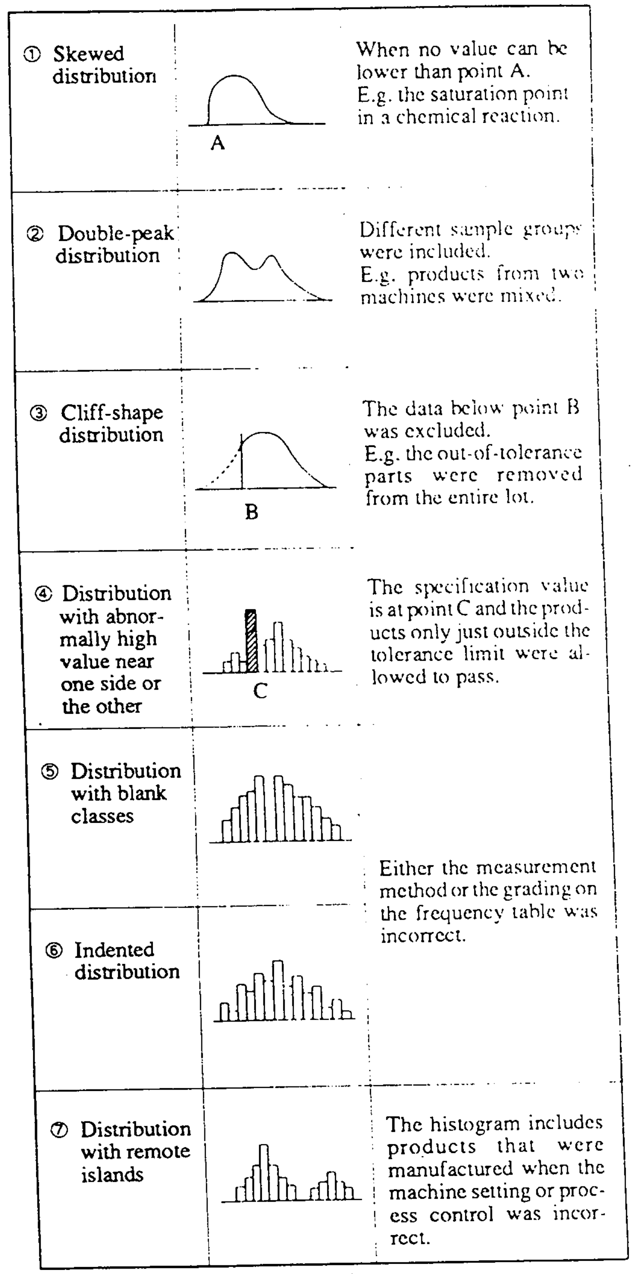


Fig. 10 Various types of histograms

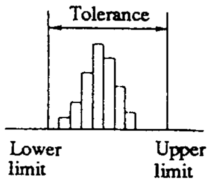
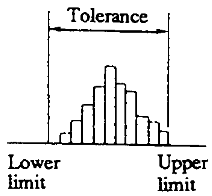
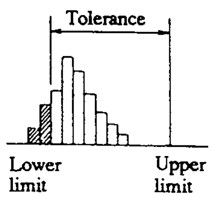
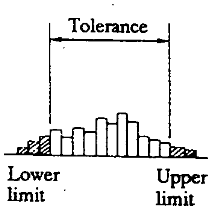
① 	The specification is satisfied. This is the optimum condition, where rejects will not be produced by a slight change in the condition of the process.
② 	The distribution is biased. Although there are no rejects at the moment, a slight change in the condition of the process may produce rejects.
③ 	The center is shifted. There are some out-of-tolerance articles, but all the products will lie within the tolerance range by adjusting the process to a slightly higher target value.
④ 	The dispersion range is too wide. The process must be improved to make the dispersion range narrower.

Fig. 11 Distribution patterns of histograms and the tolerances

6) Correlation and scatter diagrams

The scatter diagram is a graphic representation of the correlation of a pair of qualitative or quantitative variables, where the data is plotted as dots on graph paper (**Figs. 12** and **13**).
The scatter diagram is a useful tool for studying the correlation between two data variables. An investigation of the correlation between the cause and the effect is the most popular application, but this method can also be used to study the correlation between one cause and another, or one effect and another. The correlation can be either positive or negative, or there may be no correlation.

- Positive correlation
  Variable B (y) increases as variable A (x) increases.
- Negative correlation
  Variable B (y) decreases as variable A (x) increases.
  An example of a positive correlation is shown in **Fig. 13.**

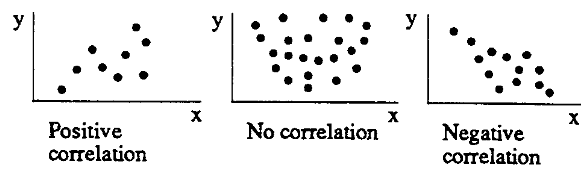


Fig. 12 Scatter diagrams

Data sheet

No.	x	y	No.	x	y
1	0.80	8.0	19	1.45	13.0
2	0.40	3.0	20	1.25	6.0
3	1.00	10.5	21	0.70	6.5
4	0.65	4.5	22	1.35	12.5
5	0.50	5.0	23	0.95	7.0
6	0.90	7.5	24	1.75	13.5
7	1.30	10.0	25	0.60	11.5
17	1.40	11.0	35	0.55	8.0
18	1.90	14.5	36	1.20	9.5

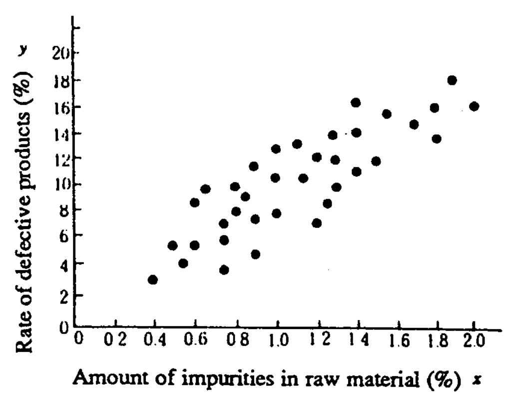


Fig. 13 Scatter diagram

7) Control chart

In order to produce high-quality products, it is necessary to always check that the work being carried out in the process meets the specified standard, that there are no products whose quality is outside the tolerance limits, or that there is no possibility of products going out of tolerance in the future. However, it is impossible to continually monitor every product, so control charts (**Fig. 14**) are used as a practical way to control product quality at a low cost.

The control chart graphically shows the central tendency and quality characteristic dispersion to find out whether there is any abnormality in the process and to detect a change in operating conditions.

There are two kinds of dispersion in quality characteristics:

(1) Unavoidable dispersion ... due to machine capability, etc.

(2) Unusual dispersion ... due to tool wear, etc.

Process control charts utilize control limits as reference lines for judgment. They are:

Upper Control Limit (UCL)

Lower Control Limit (LCL)

The control limit lines should not be determined based on the specifications or standards, but decided according to the past records of the manufacturing process in question. If the dispersion of the products is between these control limits, it is normally regarded as unavoidable dispersion.

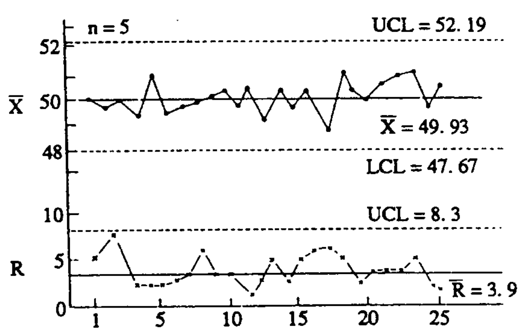


Fig. 14 $\overline{X}$-R control chart

Data types for various control charts

- Measurable values

  $\overline{X}$-R control chart (for the mean and the range) (**Fig. 14**)

  $\widetilde{X}$-R control chart (for the median and the range)

  X-Rs control chart (for the difference between two adjacent values)

  X control chart (for independent data)

- Countable values

  P control chart (for the fraction rejected)

  Pn control chart (for the number of rejects)

  C control chart (for the number of nonconformities)

  u control chart (for the number of nonconformities per unit)

5. HOW TO USE SQC TOOLS

SQC tools can be effectively used to control and improve production methods and environments. The following approach shows the basic sequence for solving workshop problems:

Study the present situation —> Analyze —> Implement and check the corrective measures —> Standardize and control the process

Apply the SQC tools to each stage of the above, as follows:

(1) Studying the present situation
Where is the problem? ····· Pareto diagram
What is the present situation? ····· histogram, check sheet, scatter diagram, graph (control chart)
What is the relationship between the cause and the result? ····· cause-effect diagram

(2) Analyzing the situation
Classify the data. ····· histogram, graph (control chart), scatter diagram
What is the correlation? ····· scatter diagram
What is the change over time? ····· graph (control chart), check sheet, Pareto diagram

(3) Implementing and checking the corrective measures
Were the corrective measures effective? ····· graph (control chart), check sheet, Pareto diagram

(4) Standardizing and controlling the process
Did the process stabilize? ····· graph (control chart), check sheet

CONCLUSION - THE FUTURE SHOP FLOOR

As technology improved, vacuum tubes were replaced by transistors, then by ICs, by LSI-ICs, and now by VLSI-ICs. The capacity of a small chip that can be held by two fingers is equivalent to hundreds or thousands of vacuum tubes. Our world has thus changed and developed so rapidly in the past and today it is changing even more rapidly.

To stay in line with these changes, it is important for the manufacturing industry to take advantage of these advances in technology to further improve the quality and reliability of their products. On the other hand, it is the responsibility of each employee to keep informed on the latest developments in his or her area and to be willing to learn new skills and methods of improving their efficiency so that they can face the challenge of new machinery and equipment with confidence, and use the equipment to manufacture a superior product "as quickly and as inexpensively as possible."

APPENDIX

STATISTICAL PROCESS CONTROL AND ITS TERMINOLOGY

Statistical process control (SPC) has a similar meaning to statistical quality control (SQC) described in Section 3. However, statistical process control places more emphasis on the prediction and prevention of defective products, by controlling the process using control charts and other means. The quality control movement has experienced a recent resurgence of interest in the U.S. with SPC spreading across the country as the method that best suited to the computer age, and looks likely to become the mainstream of contemporary quality control. The wide spread use of digital measuring devices and the development of computer technology has also encouraged industrial circles throughout Japan to employ SPC as a powerful tool to improve quality.

The following are some statistical process control terms that must be understood before advancing your studies from the basics of quality control to statistical quality control and process control.

1) Mean

The value obtained by adding a set of numerical data and dividing the sum by the number of data items. The symbol is $\bar{X}$ (X bar).

$$\bar{X} = \frac{X_1 + X_2 + \cdots + X_n}{n} \rightarrow \bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} = \frac{\text{Sum of numerical data}}{\text{Number of data items}}$$

The mean is used as a yardstick to indicate the center of the distribution. The following are some related terms.

Median $\tilde{X}$ (X tilde) :
Center value

Midrange M_r :
(Minimum value + Maximum value) / 2

Mode :
The value which occurs with the highest frequency

Note that these parameters (including the mean) do not give any indication as to the dispersion or variation of the data.

2) Sum of the squares

The sum of the squared deviation from the mean of each measurement, denoted by symbol S (uppercase). The degree of dispersion can be indicated by the difference of each individual value X_i from the mean $\bar{X}$. This difference $(X_i - \bar{X})$ is called the *deviation*. Let us note here that unless the X_i's are all equal, some of the deviations will be positive, some will be negative and they will cancel one another so that the sum of the deviations, and consequently also their mean, are always zero. For this reason, the dispersion cannot be evaluated by the average sum of the deviation. In order to eliminate the effect of the signs, a measure of variations is defined in terms of the absolute values by squaring each deviation from the mean. Generally, when there are n samples $(X_1, X_2, \cdots X_n)$, the sum of the squares S is calculated as follows:

$$S = (X_1 - \bar{X})^2 + (X_2 - \bar{X})^2 + \cdots + (X_n - \bar{X})^2$$
$$= \sum_{i=1}^{n} (X_i - \bar{X})^2$$

In practical applications, however, the sum of the squares is often calculated by using a dummy average X_0 and a multiplier h that makes $h \times (X_i - X_0)$ an integer.

3) Sample variance

The sum of the squares divided by the sample size less one (n−1), used as a measure of variation. The symbol is V. The sample variance is sometimes referred to as the *unbiased variance*. The use of n − 1 rather than n is to compensate for the bias created by measuring deviations from the sample average rather than from the unknown universal average. The n − 1 is called the *degrees of freedom*, and is normally represented by the symbol ø.

$$V = \frac{S}{ø} = \frac{S}{n-1} = \frac{\text{Sum of the squares}}{\text{Degrees of freedom}}$$

Although the sum of the squares is an indication of variation, the value changes depending on the sample size (n). Even if the dispersion is the same, the square sum becomes larger as the number of samples increases. Since this is not useful when comparing dispersion between different sizes of samples, the square sum is divided by the degrees of freedom (n–1), to eliminate the influence of the number of samples.

4) Sample standard deviation

The square root of variance V, denoted by symbol s (lowercase).

$$s = \sqrt{V} = \sqrt{\frac{S}{n-1}}$$

As the sample variance V is commonly used to express the squared deviation, so the sample standard deviation, obtained as the square root of the sample variance, is generally used to express the degree of variation in place of the population standard deviation s (where the sum of the squares is divided by the sample size or population n).

5) Range

The range, denoted by the symbol R, is the maximum value minus minimum value of a set of data ($X_1, X_2, ... X_n$).

$$R = Xmax - Xmin$$

The range is the simplest measure to express the variation, because it is calculated just by subtraction. However, the maximum and minimum values alone are used, so more data is disregarded as the number of data items increases, and the range can no longer be considered an appropriate measure to express the variation.

6) Process capability

Process capability can be defined as the capability of a process to produce a specific quality of product. The term refers to the upper limit of quality that a process can accomplish taking into the account the 4M's (material, machine, method, and man); these factors have the most influence on the quality of the product. In other words, the process capability is the capability of a process when the process is standardized to its best operating conditions and any causes of error removed.

7) Process capability index (Cp)

The process capability index Cp is the most commonly used measure of the process capability. The process capability index is determined by the following formulas:

(a) For two-sided specification

$$Cp = \frac{Su - S_L}{6\,s} = \frac{\text{Tolerance range(upper limit – lower limit)}}{\text{6 x Sample standard deviation}}$$

(b) For one-sided specification

$$Cp = \frac{\bar{X} - S_L}{3\,s} \quad \text{or}$$

$$\frac{Su - \bar{X}}{3\,s} = \frac{\text{Range from mean to upper or lower limit}}{\text{3 x Sample standard deviation}}$$

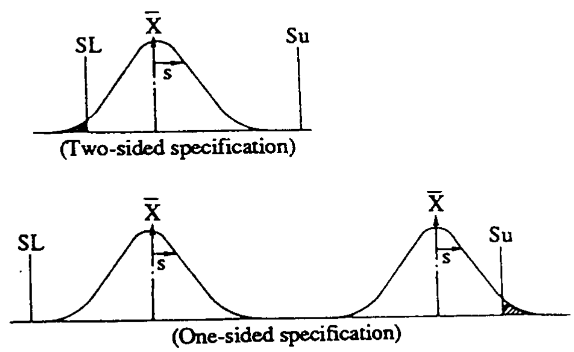


Fig. 15

8) Using the process capability index to evaluat the process capability

The process capability is considered satisfactoı when the following two conditions are satisfied.

① The process is well controlled and stable. (Judge also by control charts, etc.)

② The process capability index Cp is higher than tl required value.

It is known that when a process produces articl having a normal distribution, 99.73% of the data included inside the range ±3s from the mean.

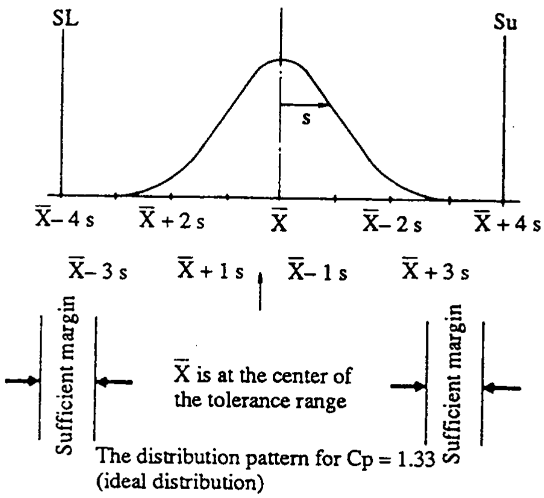


Fig. 16

If the tolerance range is ±4s from the mean, the distribution will have wider margins, which is considered to be an ideal condition. Therefore, the criteria of the process capability is given by the following value.

$$Cp = \frac{8\,s}{6\,s} = 1.33$$

$Cp \geqq 1.67$

The process capability is more than adequate.

* There is no need to worry even if the dispersion of the product becomes somewhat larger. The only improvements could be simplifying the process control procedures and reducing production costs.

$1.67 > Cp \geqq 1.33$

The process capability is sufficient.

* Maintain this condition.

$1.33 > Cp \geqq 1.00$

The process capability is barely acceptable, though not insufficient.

* Rejects may be produced as the Cp approaches 1.0 so take the actions as necessary.

$1.00 > Cp \geqq 0.67$

The process capability is insufficient.

* Rejects are being produced and the process must be improved. Perform a 100% inspection.

$0.67 > Cp$

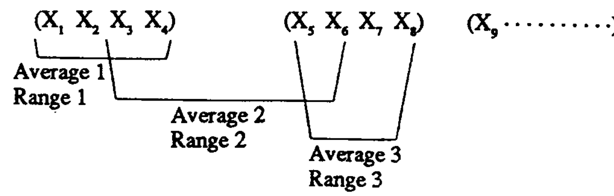
The process capability is far from satisfactory.

* Study the cause, and take corrective actions immediately.

An index called CPK, which expresses the bias of the distribution, is sometimes used to evaluate the process capability.

9) Moving averages and Moving ranges

In some processes, especially in continuous manufacturing processes found in chemical plants, methods using moving averages (i.e., averages of consecutive measurements) and moving ranges are more appropriate when drawing control charts rather than calculating the $\bar{X}$ and R of each sample subgroup. One typical method is shown below, where the moving average and moving range are calculated as the average and range including the preceding subgroup to 'smooth' data fluctuations in each subgroup and emphasize any trends.



10) Machine capability

The machine capability can be defined as the capability of a machine to produce a specific quality of product. Since a process usually involves more than one machine, it can be said that the process capability is the cumulative results of the capabilities of the machines used in the process. As described above, $\pm 3\sigma$ is used as the range of dispersion to calculate the process capability index. However, for the capability of an entire process consisting of several machines to fall within the required range, stricter tolerance control over the dispersion produced by each machine is necessary. For this reason, $\pm 4\sigma$ is used as the range of dispersion to determine the machine capability.

11) Probability paper

Graph paper called probability paper is useful when making predictions whether a set of data forms a particular kind of distribution. The probability paper for normal distribution is designed so that a sample of data from a normally distributed population plots a straight line. The cumulative frequency of the data grouped by value is plotted on probability paper, whose vertical axis has the probability scale for normal distribution while the horizontal axis has a linear scale. When the points plotted on the probability paper approximately form a straight line, the data is normally distributed.

The following are the steps taken to plot data on probability paper and to check whether the data is normally distributed.

(1) Collect about 100 pieces of data.
(2) Divide the range into about 10 groups, and create the frequency distribution table.
(3) Calculate the cumulative frequency and percentage of the cumulative frequency for each value.

$$\text{Percentage of cumulative frequency} = \frac{\text{Cumulative frequency}}{\text{Number of data}} \times 100\ (\%)$$

(4) Assign the upper value of each group to the horizontal axis and the percentage of cumulative frequency to the vertical axis of the probability paper, and then plot the data against these axes.
(5) Check if the plotted points form a straight line (normal distribution).

• When the data plotted on the probability paper follows the normal distribution, the average $\overline{X}$ and sample standard deviation s can be obtained from the plotted data.

① How to find the mean
Draw a line along the plotted points. The mean $\overline{X}$ is given as the X axis intercept of this line and the 50% line on the vertical axis (marked →).

② How to find the standard deviation
Read the X axis values at the intersecting points of the line plotted on the probability paper and the 50% and 15.9% lines on the Y axis (marked →). The difference between the two values is the standard deviation.

12) Estimated lot percentage defective (Pz)

The percentage of defects in a lot, estimated from the $\overline{X}$ and σ of a random sample. This value can be calculated using the formula for normal distribution, but can be found easily on a table (called *the table for estimating the lot percent defective*) by calculating the following two quality indexes (denoted as Z).

Upper quality index $ZUSL = \frac{Su - \overline{X}}{\sigma}$

Lower quality index $ZLSL = \frac{\overline{X} - S_L}{\sigma}$

Find and sum up the upper and lower percentage of defects from the table.

13) Others

① Distortion, skewness

The distribution pattern obtained from any set of data varies more or less from the normal distribution. The shape parameter β, which reflects the pattern of the curve, is the most useful parameter to determine any deviation from the normal distribution. The expression $\sqrt{\beta_1}$ is used to indicate the distortion and skewness of the frequency distribution. The distribution is more symmetrical and closer to the normal distribution as this value approaches 0.

② Kurtosis

This parameter is used to determine the extent to which a frequency distribution is concentrated about the mean, i.e., whether it has an abnormal peak height or skirt width compared to the normal distribution. The kurtosis is expressed as β_2, and the distribution is considered to be closest to the normal distribution as this value approaches 3.

③ Sample size

The number of articles inspected in a single sampling. About four to five pieces are required for each inspection for creating an $\overline{X}$-R chart and other control charts.

④ Subgroup

When creating an $\overline{X}$-R control chart or set of types of control chart, a number of sampling are taken, and each set of samples is called the subgroup. At least 30 subgroups are required for these purposes.

⑤ Subgroup size

The number of articles in a single subgroup.

Note)

For a better understanding of this appendix, please refer to the M-SPC textbook.

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