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IS 15431 (2003): Seven Basic Tools for Quality Management
[MSD 3: Statistical Methods for Quality and Reliability]



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Bhartrhari—Nitiśatakam

“Knowledge is such a treasure which cannot be stolen”

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भारतीय मानक
गुणता प्रबन्ध के लिए सात मूल उपकरण

Indian Standard

SEVEN BASIC TOOLS FOR QUALITY MANAGEMENT

ICS 03.120.30

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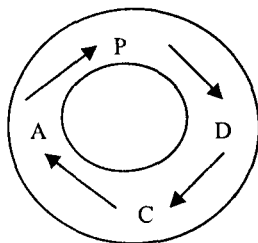
FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Statistical Methods for Quality and Reliability Sectional Committee, had been approved by the Management and Systems Division Council.

In the backdrop of globalization of market economy, quality at a competitive price has become the most important consideration in customer's selection of a product or service. Quality, in fact, has become the key factor in all types of industries — manufacturing, process, service and software. To ensure fullest possible satisfaction of the customer, the manufacturer or the service provider has to have a total approach for achieving a twin goal: on the one hand, to ensure quality of products/services through market survey on customers needs and expectations, translating these into various features and characteristics with defined acceptability criteria, fulfilling these at all stages of manufacture by adopting quality control and quality improvement techniques, proper marketing and ensuring prompt and adequate after-sales service; on the other, reduction of cost due to scrap, rework, return, warranty claims etc, which affect quality.

To achieve the twin goal, a system has to be introduced which takes care of not only correction of quality deficiencies as and when they occur but also their prevention through planned efforts for continuous improvement in quality, waste elimination, maintenance and calibration of equipment's, education and training of staff, etc.

In solving a quality problem, Deming's Plan-Do-Check-Act (PDCA) cycle is worth following. At the 'Plan' stage, one has to select the problem to be solved, schedule the activities, understand the current situation, set the target, analyze the problem and plan counter measures. At the 'Do' stage, one has to implement the plan. At the 'Check' stage, results achieved are to be checked to see if plans were executed as expected, and objectives were achieved as planned. At the 'Act' stage, if the objectives are not met, one has to analyze the results further and plan counter measures; if objectives are met one has to formalize and standardize measures adopted. At this stage, the whole exercise is to be reviewed and measures for further improvements are to be planned.



For understanding and solving a quality problem towards achieving the above twin goal, the essential approach is to study the pattern of variation in the pertinent area and properly measure this variation. Several simple and basic tools are available for systematically studying the pattern of variation in solving a quality problem, and thereby ultimately achieving quality improvement and cost reduction. These tools are:

- a) Cause and effect diagram
- b) Check sheet
- c) Pareto diagram
- d) Histogram
- e) Stratification
- f) Run chart
- g) Scatter diagram

The above seven tools, are essentially simple seven tools of Statistical Process Control (SPC). These tools are simple to learn irrespective of the background of the learners, easy to apply, inexpensive, and yet produce abundant returns. Any sincere effort in an industry to solve a quality problem, and thereby quality improvement and cost reduction must start with introduction of training in and use of these tools.

The composition of the Committee responsible for the formulation of this standard is given in Annex A.

Indian Standard

SEVEN BASIC TOOLS FOR QUALITY MANAGEMENT

1 SCOPE

This standard describes the following seven basic tools for quality management:

- a) Cause and effect diagram
- b) Check sheet
- c) Pareto diagram
- d) Histogram
- e) Stratification
- f) Run chart
- g) Scatter diagram

The above tools have been illustrated with the examples for better understanding.

2 REFERENCES

The following standards contain provisions, which through reference in this text constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

<i>IS No.</i>	<i>Title</i>
397 (Part 1) : 2003	Method for statistical quality control during production : Part 1 Control charts for variables (<i>second revision</i>)
7300 : 2003	Methods of regression and correlation (<i>second revision</i>)
12801:1989	Pareto diagram and cause and effect diagram

3 TERMINOLOGY

3.1 Cause and Effect Diagram — Cause and effect diagram lists out in a classified and systematic manner all the variables, which are responsible for a problem or condition. It provides a method of exploring, identifying, classifying, organizing and displaying potential causes of a problem to discover its root causes, with a view to solving the problem at hand, and achieving improvement in quality in the long run.

NOTE — This tool was developed by Dr K. Ishikawa in Japan. This is also known as Ishikawa Diagram or Fish-bone Diagram (because of its shape).

3.2 Check Sheet — A check sheet is a template for systematic and easy way of recording the data from

historical sources or observations for understanding the status, analysis, monitoring and for decision-making. Check sheets are for counting and accumulating data so that patterns and trends can be clearly detected and shown.

3.3 Pareto Diagram — A pareto diagram is a simple graphical technique for ranking items from the most frequent to the least frequent. This diagram displays in decreasing order, the relative contribution of each item to the total effect. The relative contribution may be based on the number of occurrences, the cost associated with each item, or other measures of impact on the effect. Bars are used to show the relative contribution of each item. A cumulative frequency line is used to show the cumulative contribution of items.

3.4 Histogram — A histogram may be defined as a graphical-cum-pictorial presentation of variation of a single parameter observed in a set of data emerging from any process. It consists of series of rectangles with the range of variate as base and height proportional to corresponding frequency.

3.5 Stratification — Stratification may be defined as the process of classifying data into groups such that data within groups are as much homogenous as possible, while data between groups are possibly heterogeneous, so that intra-stratum variation is low, but inter-strata variation is high.

3.6 Run Chart — Run chart is a graphical presentation of data with time-scale on horizontal axis. It is a simple means of displaying trends, cycles, shifts etc, in a variable within observation points over a specified time-period.

3.7 Scatter Diagram — In the present context — for every quality parameter of interest, there is need to assess the nature and/or degree of impact on output of resulting 'quality parameter' as reflected in the observed changes caused by corresponding variations in the 'input parameter'. The former is called dependent variable and the latter independent variable. Attempts are made to get the behaviour of dependent variable in desired range by monitoring the independent variable in appropriately determined limits as indicated by the nature of relationship between the two. The dependent variable is plotted along y-axis and the independent along x-axis. Such a diagram is called a scatter diagram.

4 CAUSE AND EFFECT DIAGRAM

4.1 General

A cause and effect diagram is a diagrammatic representation of the relationship between a given effect (a quality problem, for example, variation in a quality characteristics), shown as the backbone, and its potential secondary and tertiary causes shown as the bones and sub-bones, grouped under major categories and sub-categories, respectively, so that the diagram looks like the skeleton of a fish. The diagram is often constructed by groups, but it may be constructed by individuals possessing appropriate process knowledge and experience.

4.2 Scope

It is a mapping technique for problems in areas like rejection/rework, warranty complaints, accidents, productivity and administration. A cause and effect diagram is used for analyzing and communicating cause-effect relationships in any of the above areas, and thereby facilitating solution of the problem by tracing the route: symptoms-causes-solution.

4.3 Steps for Construction

4.3.1 Define the effect (problem) that is to be diagnosed and solved clearly and concisely. Draw a broad arrow (the backbone) from the left to the right and indicate the problem on the right-hand side.

4.3.2 Organize a brainstorming session involving everyone connected with the problem (for example, production operators, supervisors, engineers, and others who can contribute in identifying the causes). For the success of a brainstorming session, it has to be ensured that all participants are encouraged to suggest ideas. All suggested causes and opinions, however, mundane, should be noted/listed without criticism.

NOTE — Brainstorming is a common method for a team to creatively and efficiently generate high volume of ideas on any topic by creating a process that is free of criticism and judgement.

4.3.3 Identify the major categories of possible causes from the 'Brainstormed' list of potential causes of any effect into several relevant classes which may include:

- a) Men,
- b) Machines,
- c) Materials,
- d) Methods,
- e) Measurement,
- f) Environment, and
- g) Data and information systems.

4.3.4 Begin to construct the diagram, defining the effect in a box on the right-hand side and positioning major categories as feeders to the Effect box (see Fig. 1).

4.3.5 For each main cause, define and list any sub cause (level 2) that may contribute to the problems against the small arrows coming out from main causes (see Fig. 2). This process of sub-division is carried on until all causes listed are accommodated. A well-developed diagram will have no branches of less than two levels, and many with three or more levels.

4.3.6 Once constructed, the diagram can become a living tool with further refinements being introduced as new knowledge and experience are gained.

4.4 Types of Cause and Effect Diagrams

4.4.1 Most widely used types of cause and effect diagrams are given below.

4.4.1.1 Dispersion analysis type

It is constructed by placing individual causes within each major cause category and asking 'Why does this cause happen?' for each item.

4.4.1.2 Process classification type

It sequentially lists all the steps in a process. The same cause category arrows as in the dispersion analysis type branch off line between each process step. The same questions are then applied to each cause category as in the dispersion analysis type diagram.

4.4.1.3 Cause enumeration type

It is almost identical to the dispersion analysis type. The only real difference rests in the fact that cause enumeration first organizes all the possible causes in list form and then places them in the major cause categories.

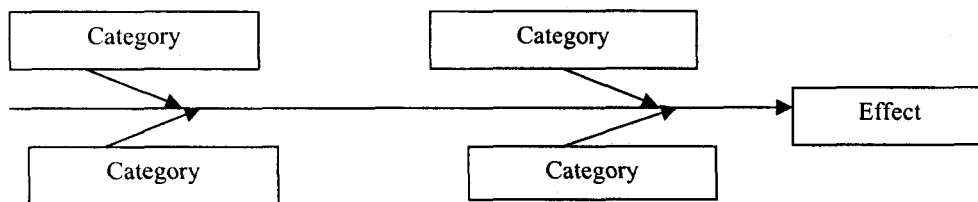


FIG. 1 BASIC STRUCTURE OF CAUSE AND EFFECT DIAGRAM

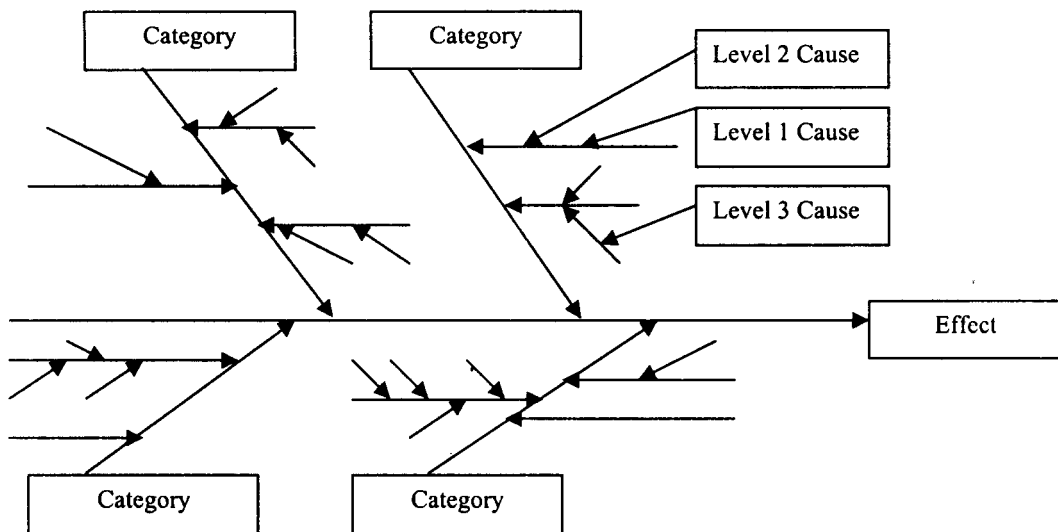


FIG. 2 DEVELOPMENT OF CAUSE AND EFFECT DIAGRAM

4.5 Uses

4.5.1 Cause and effect diagrams are most useful in group problem solving situations. In themselves they do not provide any solutions. However, the process by which they are constructed is enlightening and promotes better understanding of the problem by all concerned. Even people who do not yet know a great deal about their jobs can learn a lot from making a cause and effect diagram or merely studying a completed one.

4.5.2 Straying from the topics and repetition of complaints and grievances is avoided since a cause and effect diagram serves as a focus for the discussion. This is because every one knows the topic and the discussions so far advanced. The conclusion on actions to be taken may also be reached faster.

4.5.3 A cause and effect diagram shows the level of ability of the group responsible for drawing it.

4.5.4 The cause and effect diagram permits viewing the variables in perspective and in relation to each other with resulting improvement through planning.

4.5.5 The use of cause and effect diagrams helps to unify and systematize the thoughts of the team.

4.6 Example

An example of cause and effect diagram to find reasons for 'Poor Quality Photocopying' is given in Fig. 3.

5 CHECK SHEET

5.1 General

A good quality control programme aims primarily at

prevention of non-conformities. It requires generation of data on output parameter(s) and the corresponding input parameters. The data thus generated are used to assess whether what is being done is as required or planned. Therefore the purpose for which the data are being collected must be clear. If the data collected are inaccurate, even, the best statistical tool employed for their analysis will only result in drawing wrong conclusions.

5.2 Scope

Check sheets can be used in various areas like customer complaints, lost production time, machine failures, appearance rejects, leakages, non-conformities, accidents and clerical errors.

5.3 Steps for Construction

Steps for construction of a check sheet may be enumerated as follows:

- a) Agree on the definitions of the events or conditions being observed.
- b) Clarify the purpose for collection of data.
- c) Determine the time period for collection of data.
- d) Decide on variety of information that must be collected.
- e) Stratify the information as much as possible. It can be done area-wise, zone-wise, shift-wise, machine-wise, supplier-wise, operator-wise etc.
- f) Design the proper format that will facilitate the collection of needed data (clear, complete and easy to use).

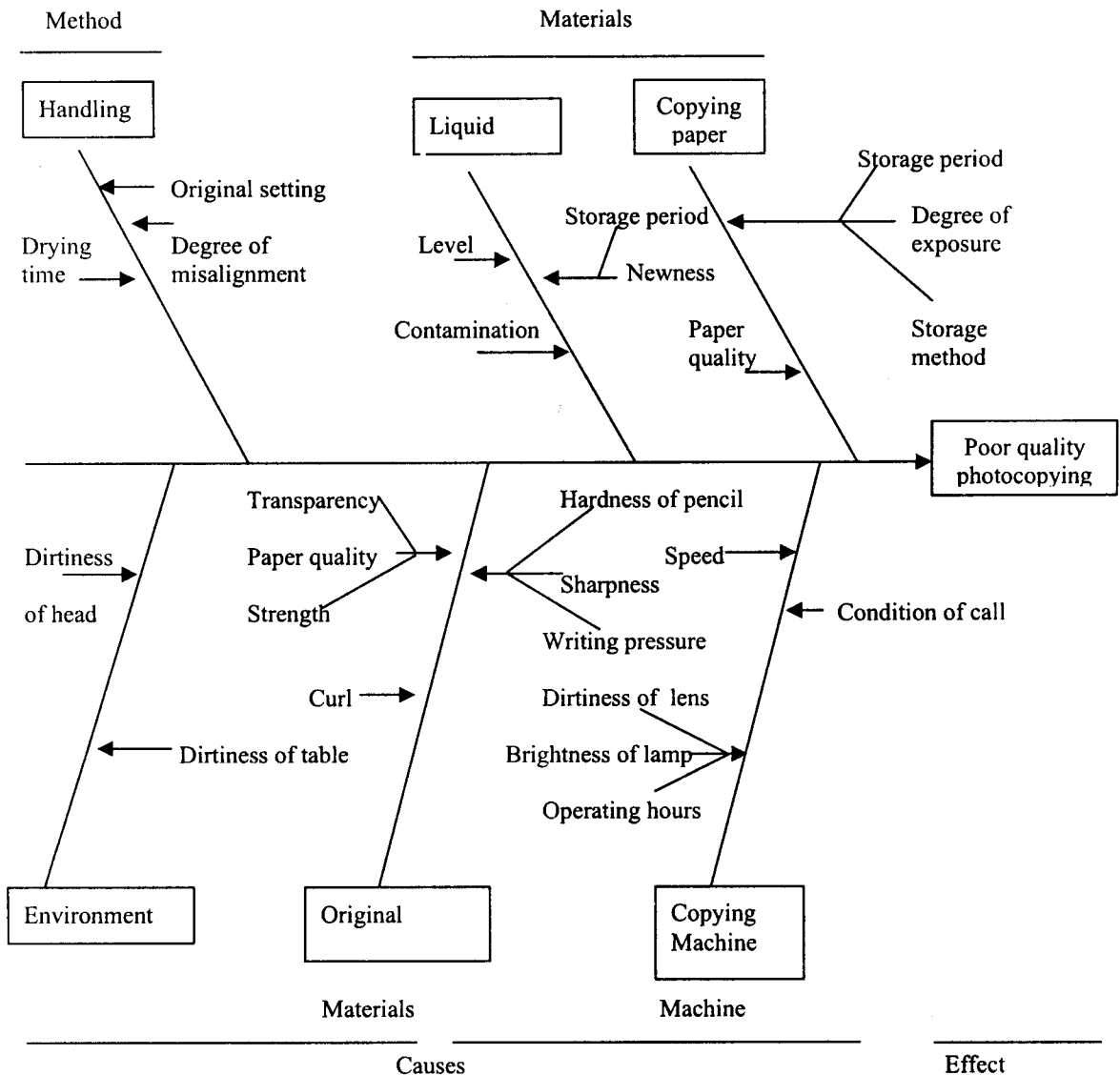


FIG. 3 EXAMPLE OF CAUSE AND EFFECT DIAGRAM FOR POOR QUALITY PHOTOCOPYING

- g) Record the data on the check sheet so designed. Collect the data consistently and accurately. Above all act on the data as quickly as possible.

5.4 Types of Check Sheets

The various types of check sheets normally used are as follows:

- a) Production process distribution check sheet, for recording data on physical measurement of quality characteristics.
- b) Non-conforming cause-wise check sheet, for recording frequencies of various causes of non-conformity.
- c) Non-conformity location check sheet, for identifying arrears of occurrence of a

particular non-conformity, for example, bubbles in an item made of glass.

- d) Check sheet for tracing sources of causes of non-conformity, for example, according to man, machine days, shift, etc.
- e) Check up confirmation check sheet, for example, those used for quality audit.

5.5 Uses

5.5.1 The two general uses of check sheets for data collection are for process control and problem analysis. It makes the patterns in the data obvious quickly.

5.5.2 Use in Process Control

Every work process has a number of indicators on how the process is performing. All types of check sheets can be used to collect information on key indicators.

Collection and later analysis of this information is an important part of monitoring a process.

5.5.3 Use in Problem Analysis

Check sheets can be used to answer who, what, where, when, why and how many times while determining the root cause of a problem during trouble shooting. Also check sheets are utilized to verify that a problem has been solved when a root cause has been eliminated.

5.6 Examples

Two examples of Check Sheets are given in Table 1 and Table 2.

6 PARETO DIAGRAM

6.1 General

Pareto diagram is a method of prioritizing/identifying the most critical problems. It is usually used in conjunction with cause and effect diagram in order to determine which items contribute most to a particular effect. This technique is named after an Italian Economist, Vilfredo Pareto, who was the first to observe that in any country the lion's share (70-90 percent) of total national wealth was owned by a few (10-20 percent) rich people. Thereafter it has been observed in terms of quality that a large percentage of problems are because of a small percentage of items. Pareto diagram identifies these 'vital few' items (from 'trivial many') so as to first take action on them first.

6.2 Scope

The tool may be used in areas like rejection, delivery, rework, complaints, accidents, administration, costing, efficiency, conservation of materials and energy.

6.3 Steps for Construction

6.3.1 The Pareto diagram may be 'cause-wise', such as, different operators, different machines, raw material, etc, or they may be 'effect-wise' such as number of non-conformities, non-conforming items, faults, complaints, repairs, accidents, default in payments, delay and loss expenses. Often a Pareto diagram of 'Effect' is constructed first, then a cause-and-effect diagram is used to find from the principal effect(s) the probable causes, which is again studied with another Pareto diagram for identifying the vital items.

6.3.2 The steps for construction of a Pareto diagram may be enumerated as follows:

- a) Decide on how the data should be classified, for example, shift-wise, according to types of non-conformity, etc.
- b) Select the items to be analyzed.
- c) Prepare a suitable check-sheet for collection of data, selecting the unit of measurement for analysis.
- d) Choose the time period for collection of data. Try to keep the time period the same for all related Pareto diagrams to facilitate comparison in future.
- e) For each cause effect, obtain the frequency of occurrences.
- f) Draw horizontal and vertical axis on a graph paper.
- g) Divide horizontal axis into equal segments, one for each cause/effect. Scale the vertical axis in such a way that the top of the axis represents a number equal to the sum of the frequencies for all the causes/effects.

Table 1 Non-conforming Cause-Wise Check Sheet
(Clause 5.6)

Product:		Date:
Manufacturing stage: Final inspection		Factory:
Type of non-conformity: Scar, incomplete, mis-shapen		Section:
Total No. inspected: 2530		Inspector's name:
		Lot No.
		Order No.
Type	Tally Marks	Sub-Total
Surface scar	### ### ### ### ### ## //	32
Cracks	### ### ### ### //	23
Incomplete	### ### ### ### ### ### ### ### ### //	48
Mis-shapen	////	4
Others	### //	8
Total NCs:		115
Total Rejects	### ### ### ### ### ### ### ### ### ### ### ### ### ### //	86

Table 2 Check Sheet for Tracing Sources of Cause of Non-conformity

(Clause 5.6)

Equipment	Worker	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday	
		FN	AN	FN	AN	FN	AN	FN	AN	FN	AN	FN	AN
Machine 1	A	④ ④ θ ς	④ θ	④ ④ ④	④ θ θ	④ ④ ④ θ θ θ ς	④ ④ ④ ④ θ θ θ	④ ④ θ θ ς ς	④ θ θ	④ ④ ④	④	④	④ θ ς
	B	④	④ ④ ④ ④ ④ θ	④ ④ ④ ④ ④ θ θ	④ ④ θ θ	④ ④ ④ ④ ④ θ θ	④ ④ ④ ④ ④ ④ ④ ④ ④ θ	④ ④ ④ ④ ④ θ	④ ④ θ ς ς	④ θ ς	④ ④ ④ ④	④	④
Machine 2	C	④ ④ θ	④ θ	④	Σ	④ ④ ④ ④	④ ④	ς	μ	°	°	°	°
	D	θ	θ	ς	ς μ	θ	μ	μ μ°	ς ς	° θ	θ θ°		

④ : Surface Scratch, ς : Improper Shape, θ: Blow Hole, ° : Others, μ : Poor Finishing.

- h) Write the cause/effect with maximum frequency at the left hand side of the horizontal axis followed by second maximum frequency and so on. The 'others' group is to be plotted at the extreme right hand side irrespective of its frequency.
- j) For each cause/effect, draw a bar. The height of bar shows the frequency of occurrence. Keep width of bars the same and each one should be in contact with its adjacent bar.
- k) Plot a line graph for the cumulative percentages showing the portion of the total that cause/effect category represents.
- m) Construct another vertical axis on the right hand side of the graph and scale it from 0 to 100 percent. The termination of the cumulative line should be at the point marked 100 percent. This 100 percent point shall correspond to the sum of the frequencies for all the causes.
- n) Add suitable legend and write briefly the source of data and any other relevant information.
- p) Interpret the results. Generally the tallest bar indicates the biggest contributor to the overall problem. Ask: Which one has the most impact on the goals of the business and/or customers.

6.4 Uses

6.4.1 It has been observed that different people in any

organization try to make improvements individually without any definite basis for their efforts. This results in waste of lot of energy producing very few results. The Pareto diagram is an indispensable tool for knowing exactly where the collective efforts for improvement should be concentrated so as to have the maximum gains. It is more useful to reduce the tallest bar — the items for which quality problems occur most frequently by half, than to reduce a short bar to zero. To reduce the non-conforming items represented by short bar to zero, would require a tremendous effort since there are more or less inevitable non-conforming items occurring now and then.

6.4.2 Pareto diagram can be applied for improvement in all aspects. In an organization, apart from the improvement of quality, there are many other problems, like efficiency, conservation of materials and energies, reduction in costs, safety and others. Whatever be the problem, Pareto diagram is the first step for improvement.

6.4.3 Pareto diagram can also be used to confirm the impact of improvement. If effective measures have been taken, the order of the sources/causes on the horizontal axis will usually shift. Comparing the before and after improvement diagrams, if it is found that the first most important cause of the problem has dropped to second or may be third or fourth place on the horizontal axis and the first place has been taken by

the previous second biggest cause, this shows that effective measures have been taken and bigger the shift in the order the bigger the impact.

6.5 Remarks

6.5.1 When the vital few have been successfully contained on routine basis, it is time to repeat the Pareto diagram study. The causes which were not dominant hitherto, now become vital and need to be attended on priority. This journey continues. If at any stage one feels that 'zero non-conformity' has been achieved, the competition brings in new concept of quality (may be life, cost, reliability, new features) that once again shows prevalence of 'non-conformities' needing attention. Thus the journey continues.

6.5.2 Sometimes it so happens that monetary loss resulting from a particular type of non-conformity is many times more than the loss resulting from some

other type of non-conformity. In such a situation Pareto diagram should be based on proportion to the damage caused by non-conformities instead of usual proportion to the frequency of their occurrences.

6.6 Examples

6.6.1 Pareto Diagram for Rejection of Castings (See Table 3)

6.6.2 Pareto Diagrams for Process Non-conformities — Before and After Improvement (See Table 4)

6.6.2.1 On the basis of before improvement Pareto diagram on the left, the problem of improper rotation was selected for improvement. Comparing the before improvement and after improvement graphs it can be seen that improper rotation dropped to the second most important source of trouble, the first place being taken by the previous source, noise.

Table 3 Details of Rejection of Castings
(Clause 6.6.1)

Sl No.	Causes	Weight of Rejected Material (in kg)	Percent of Rejected Material	Cumulative Total in Percent
(1)	(2)	(3)	(4)	(5)
i)	Blow hole	32.3	30.2	30.2
ii)	Shrinkage	27.4	25.6	55.8
iii)	Sand inclusion	14.3	13.4	69.2
iv)	Shift	10.1	9.4	78.6
v)	Mis-run	6.2	5.8	84.4
vi)	Slag inclusion	4.4	4.1	88.5
vii)	Incorrect dimension	4.0	3.7	92.2
viii)	Cold shot	2.0	1.9	94.1
ix)	Damages	1.3	1.2	95.3
x)	Others	5.0	4.7	100.0
Total		107.0		

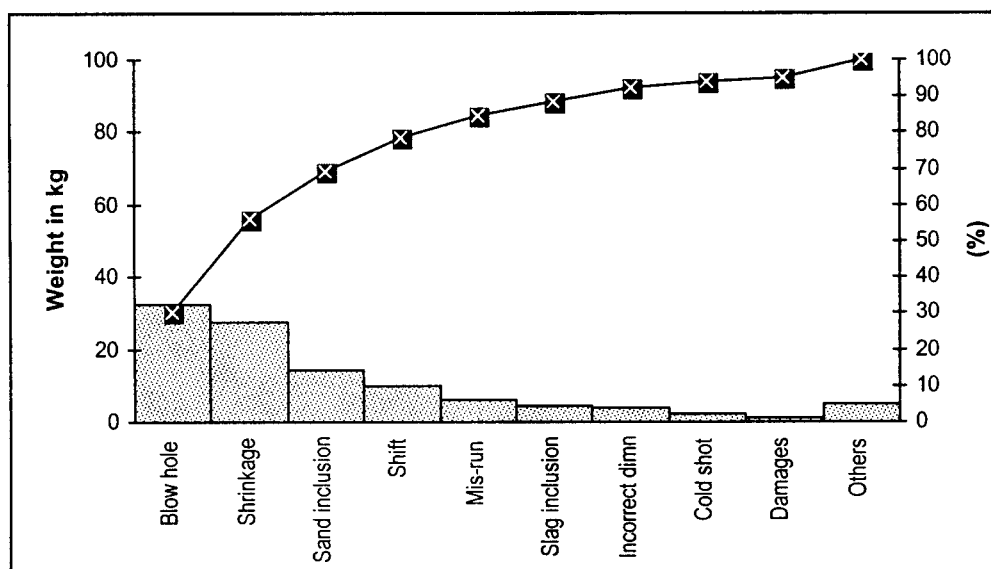


FIG. 4 PARETO DIAGRAM

Table 4 Process of Non-conformities
(Clause 6.6.2)

Data Before Improvement					Data After Improvement			
Sl No.	Causes	Non-conforming Cases	Percent Non-conforming Cases	Cum. Total in Percent	Causes	Non-conforming Cases	Percent Non-conforming Cases	Cum. Total in Percent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	Improper rotation	46	39.0	39.0	Noise	15	24.6	24.6
ii)	Noise	18	15.3	54.3	Improper rotation	12	19.7	44.3
iii)	Wobble	16	13.6	67.9	Pressure	11	18.0	62.3
iv)	Pressure	14	11.9	79.8	Wobble	8	13.1	75.4
v)	Leftover	11	9.3	89.1	Axis Caulking	7	11.5	86.9
vi)	Case Wobble	4	3.4	92.5	Case Wobble	3	4.9	91.8
vii)	Others	9	7.5	100.0	Others	5	8.2	100.0
Total		118	100.0		Total	61	100.0	

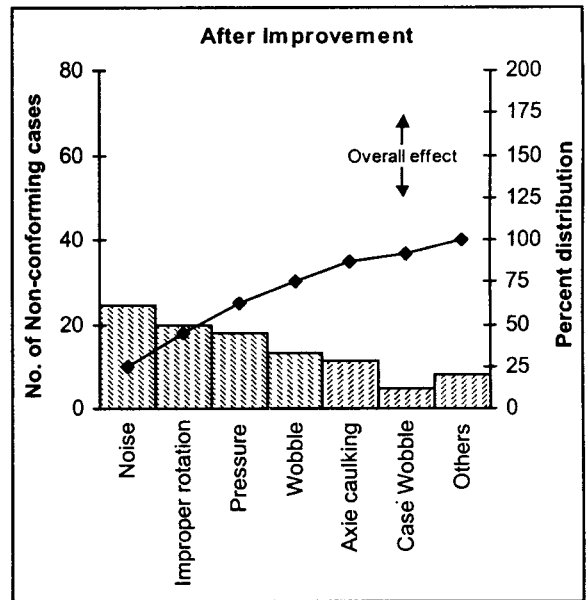
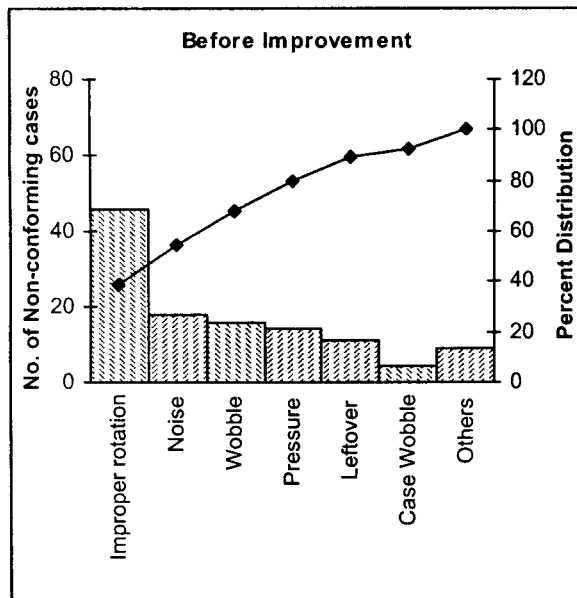


FIG. 5 PARETO DIAGRAM

7 HISTOGRAM

7.1 Scope

The tool can be used for assessing the current process state, analyzing process variation, checking effectiveness of an improvement, etc. The most important use of the tool is for summarizing data from a process that have been collected over a period of time.

7.2 Construction

The following steps are to be taken for constructing a histogram:

- a) The total number of observations (on the quality characteristics of interest) should not be less (preferably more) than 100 so that

frequency table may show any definite pattern.

- b) The class intervals should be of equal width for better graphical representation and easier computation of the mean, standard deviation, etc.
- c) Range (*R*) of the data is calculated (the difference of the maximum and the minimum values).
- d) The total number of class intervals (*k*) in a frequency table should be between 7 and 15. It is because if the number of class intervals is too less there would be considerable error in further calculations, and if the number is too large it would result in many class

intervals having zero or very less frequencies.

- e) Having known the Range (R) and that number of class intervals should be between 7 and 15, the class width (c) (the difference between the upper and the lower class limits of each class interval) is calculated by the following expression:

Number of class intervals (k) = Integral part of $[\text{Range } (R)/\text{Class width } (c)] + 1$

NOTE — Integral part means to take only integer value and ignore the fraction. It is not advisable to increase unnecessarily the number of class intervals so as to accommodate one or two extreme observations. Such observations can be classified conveniently by making first (last) class interval open and this class interval may be written as 'less (greater) than or equal to a certain value'.

- f) The first class interval is made by taking into consideration the minimum value in the data and the class width selected above, that is, the lower limit of the first class interval should be little less than the minimum value and the upper limit as the sum of the lower limit selected and the class width. For the second class interval, the lower limit is taken as the upper limit of the first class interval, and the class width is added to this to get the upper limit of this class interval. In this way the subsequent class intervals are also formed. The last class interval should contain the maximum value in the data.
- g) The class intervals should be defined in such a way that each observation belongs to one and only one class. This may be achieved by specifying class limits to one more decimal place than that obtained in the set of observations. Alternatively, some arbitrary rule can be fixed in advance with regard to the allocation of observations coinciding with the class limits. This rule shall be spelt out before summarization is undertaken and applied uniformly.
- h) It is desirable to choose the class intervals in such a way that the mid-point of the intervals is a convenient figure for calculation and plotting. Where there is a tendency for certain values (for example, multiples of 5 or 10) to occur much more frequently than the neighbouring values, the class intervals should be so arranged that these values occur at the middle of the corresponding intervals.
- j) Observations, which are to be grouped, should not be rounded off before grouping, since grouping is a form of rounding and

successive rounding is liable to lead to systematic errors.

- k) For each observation, as it occurs in the original data, a tally mark is put in the suitable class interval. For the sake of convenience the tally marks are grouped in groups of 5 each, the fifth tally mark being drawn across the other four. When every observation has been allotted to a class interval, the tally marks in each class interval are counted to get the frequency of that class interval.
- m) On a graph paper mark class boundaries on X -axis and frequencies on Y -axis.
- n) Make histogram and superimpose the specification limits.
- p) Record briefly the source of data and any other relevant information on the histogram.
- q) Interpret the histogram for centering, variation, shape and process capability.

7.3 Example

The data on thickness of 100 metal blocks is given in Table 5. The methodology for preparation of frequency table and histogram are given in Table 6 and Fig. 6 respectively.

Table 5 Thickness of Metal Blocks

All dimensions in millimetres.

3.48	3.50	3.42	3.43	3.52	3.49	3.44	3.50
3.50	3.52	3.47	3.48	3.46	3.50	3.56	3.38
3.47	3.49	3.45	3.44	3.50	3.49	3.46	3.46
3.44	3.50	3.45	3.44	3.48	3.46	3.52	3.46
3.32	3.40	3.52	3.34	3.46	3.43	3.30	3.46
3.59	3.47	3.38	3.52	3.45	3.48	3.31	3.46
3.46	3.51	3.48	3.50	3.68	3.60	3.46	3.52
3.56	3.50	3.52	3.46	3.48	3.46	3.52	3.56
3.46	3.45	3.46	3.54	3.54	3.48	3.49	3.41
3.34	3.44	3.47	3.47	3.41	3.48	3.54	3.47
3.56	3.48	3.41	3.55	3.48	3.59	3.40	3.48
3.52	3.41	3.46	3.56	3.37	3.52	3.48	3.63
3.54	3.50	3.48	3.45				

$$\text{Range } (R) = X_{\max} - X_{\min} = 3.68 - 3.30 = 0.38$$

$$\text{Number of Class Intervals } (k) = 10 \text{ (As per guidelines)}$$

$$\text{Class width } (c) = 0.38/10 = 0.038 \text{ (which is rounded off to 0.05 to make class division easier).}$$

7.4 Uses

7.4.1 A histogram by displaying the pattern of variation, usually communicates information about process behaviour and facilitates making decision as to where to focus improvement efforts.

7.4.2 It enables to calculate the mean and the standard deviation of the distribution easily.

Table 6 Frequency Table
(Clause 7.3)

Sl No.	Class Boundaries	Mid Values	Frequency Tally	Frequency
(1)	(2)	(3)	(4)	(5)
i)	3.275 – 3.325	3.30	///	3
ii)	3.325 – 3.375	3.35	///	3
iii)	3.375 – 3.425	3.40	###////	9
iv)	3.425 – 3.475	3.45	##################//	32
v)	3.475 – 3.525	3.50	########################//	38
vi)	3.525 – 3.575	3.55	######	10
vii)	3.575 – 3.625	3.60	///	3
viii)	3.625 – 3.675	3.65	/	1
	3.675 – 3.725	3.70	/	1

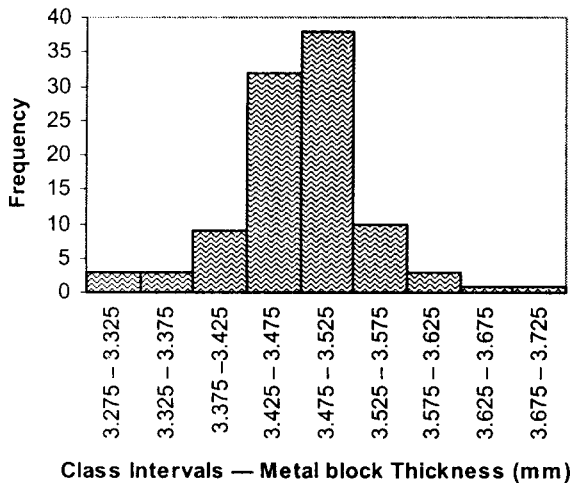


FIG. 6 HISTOGRAM

7.4.3 Identification of Problems by the Shape of the Distribution

7.4.3.1 After histogram is prepared, the mid-point of each class interval is connected by a smooth curve is drawn without following the unevenness of the histogram to get a frequency distribution curve. If the distribution is normal, this curve usually exhibits a bell-like form (see Fig. 7).

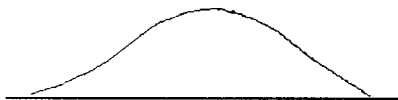


FIG. 7 FREQUENCY CURVE

7.4.3.2 In contrast, non-normal distribution curves such as in A-E of Fig. 8 are sometimes obtained. Attention shall be paid to the following points in the identification of problems on the basis of these histograms.

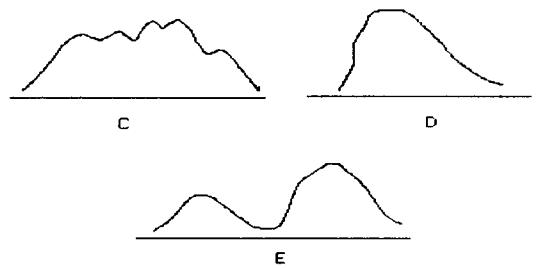
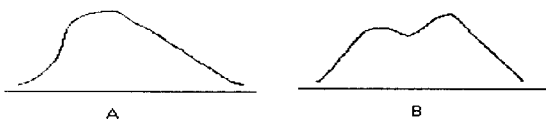


FIG. 8 NON-NORMAL DISTRIBUTION CURVES

Curve A: When there is no symmetry, the distribution as given in 'A' of Fig. 8 occurs. For example, in the distribution of particle size of granules produced by grinding, the number of large-size granules decreases rapidly while the small size granules exhibit a long-tailed distribution. This is because the number of large granules is small in the raw material and fine ones occur in a natural way even before the grinding operation.

Curve B: When different types of data are mixed, the distribution as given in 'B' of Fig. 8 arises. The shape suggests that stratification may be possible operator-wise, supplier-wise or instrument-wise.

Curve C: The distribution as given in 'C' of Fig. 8 often appears when measurements are taken by an inaccurate method or the class-width is not an integral multiple of the measuring unit or any other similar factor or cause depending upon the situation.

Curve D: The distribution as given in 'D' of Fig. 8 arises when measurements of only those items which meet the specifications are recorded or when the inspection department makes allowances for sub-standard articles to meet the required quantity. It also appears when the data below a certain level are removed intentionally or when saturation is reached in a chemical reaction because there are no data in the region beyond the saturation point.

Curve E: The distribution as given in 'E' of Fig. 8 is attributable to differences in quality of raw materials or process abnormalities.

7.4.4 Comparison with Specification and Target Values

7.4.4.1 When specification limits and target values are known, these shall be entered in the histogram and it shall be examined whether the actual data distribution is satisfactory. The mean should be as close to target as possible.

7.4.4.2 Comparison of the histogram with specification limits is explained by taking A-G in Fig. 9 as examples.

Histogram A: The distribution of data is within the specification limits with considerable margin on both sides. One of the measures is to make the tolerance

cost or increased productivity can be expected.

Histogram B: The distribution of data is within the specification limits, but the mean (μ) is shifted towards the lower specification limit. Therefore, slight decrease in the process average may result in off-specification items. When this type of distribution appears, steps shall be taken to increase the process mean.

Histogram C: The distribution of data is barely within the specification limits. Even a slight change of the mean (μ) may produce off-specification items. When this type of distribution appears, measures shall be taken to reduce the variability of the process or the appropriateness of the specification limits shall be reviewed.

appears, action shall be taken immediately. Taking into consideration the quality required by the user and the capability of the processes, the appropriateness of the specification limits shall be reviewed at first. If the quality required by the user and the process capability can be compromised when the specification range is widened to 8 times the standard deviation, revision of the specifications is one of the solutions. If the shape of the histogram is considerably flat with no distinct peak, or like B and C of Fig. 8, the causes shall be identified and removed.

Process improvement may be required if the tolerance can be reduced and the distribution is normal.

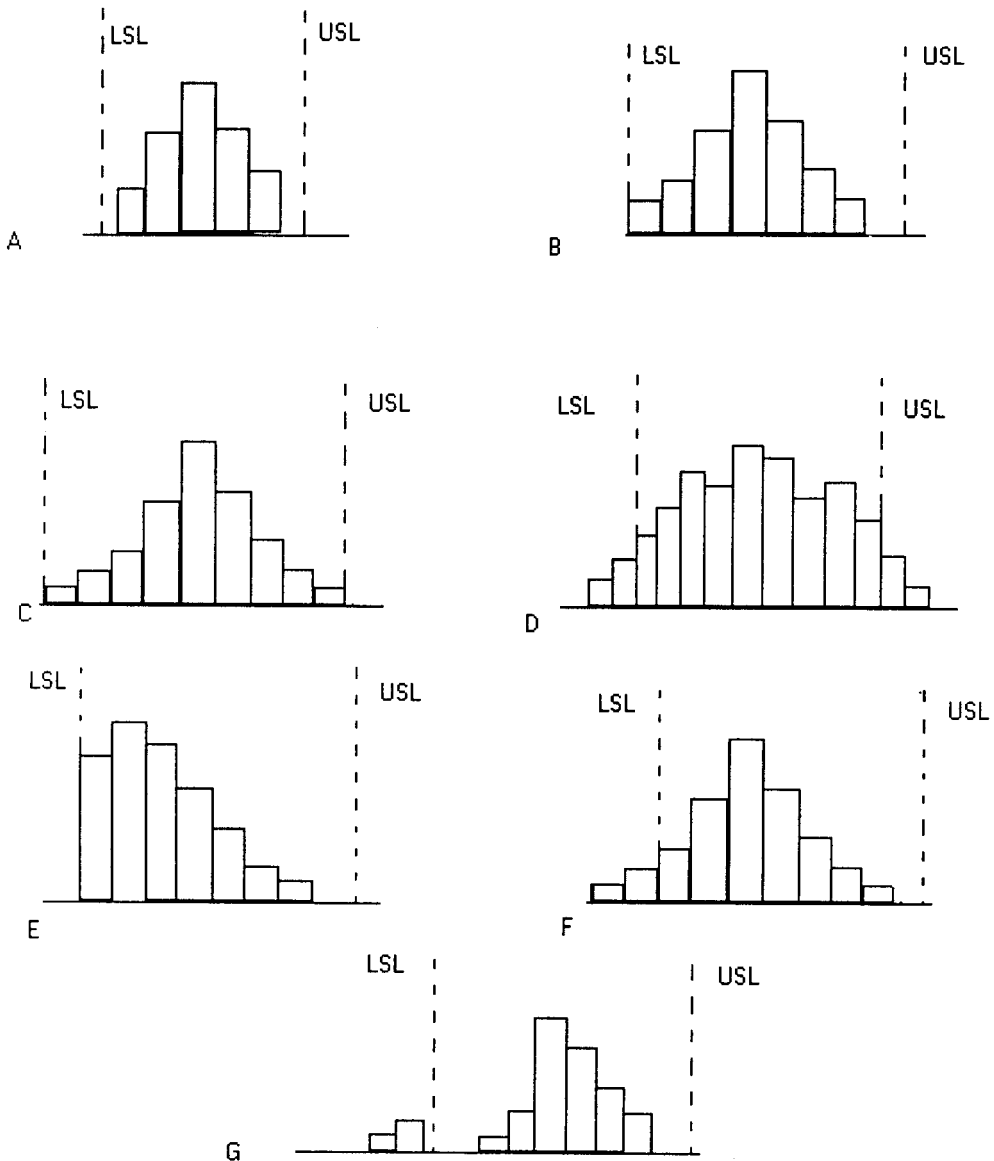


FIG. 9 VARIOUS HISTOGRAMS

Histogram E: The distribution of the data is barely within the specification limits, and the mean is shifted to the left. This type of distribution may be due to three causes:

- a) The items below the lower specification limit would not appear under certain manufacturing conditions.
- b) The items below the lower specification limit might have been eliminated by 100 percent inspection.
- c) Off-specification items might have been included intentionally within the specification limits. This may possibly occur when measurement is left to the manufacturing department and the rate of off-specification items is controlled strictly.

Action shall be taken to increase the mean to the centre of the specification range and reduce the variability of the distribution.

Histogram F: The range of the distribution is smaller than that of the specification limits, but data are distributed beyond the lower specification limit because the midpoint is deviated to the left. Action shall be taken to increase the mean.

Histogram G: Most of the observations are distributed within the specification limits and the target value is also at the midpoint of the specification range. But some observations lie beyond the lower specification limit. We have the distribution like E of Fig. 8. As this indicates non-normally, the cause shall be detected and removed.

8 STRATIFICATION

8.1 General

The idea behind stratification is to differentiate data, coming from different sources, as far as possible to facilitate tracing back of data indicating problems to their origins. Suppose a problem discovered in the output of a machine with four spindles, one of which is non-conforming items. Merging output from all the spindles together will help very little in identifying the proper source. However, stratification of data by spindles will uncover the problem easily.

8.2 Scope

Stratification of data is almost always a prerequisite for analysis of data for solving quality problems. Thus this exercise is undertaken while using the tools check-sheets, cause and effect diagram, Pareto diagram, control charts, scatter diagram, sampling, and the like.

8.3 Steps for Construction

The steps for construction of stratification may be enumerated as follows:

- a) Identify the quality problem to be analyzed from Pareto diagram.
- b) Draw a cause-effect diagram.
- c) Classify each quality characteristic by levels of one or more factors at a time depending on total amount of data and technological knowledge of their inter-dependence. Some common stratification factors for manufacturing applications are: time (day, week, month), shift, operators, machines (spindles, fixtures, pallets and stations), vendors, lots etc.
- d) Design check-sheets suitably for collection of data on quality characteristics with traceability to the corresponding operational level of each factor and its true generation.

8.4 Uses

The technique is simple, quick, cheap and yet powerful in solving almost all quality problems by identifying factors and their levels with favourable and unfavourable effects.

8.5 Examples

8.5.1 A sample of manufactured product was inspected for 6 different types of non-conformity coded as A, B, C, D, E and F. The distribution of non-conformities according to codes, for the entire output, and subsequently stratified by machines are given in Table 7.

Table 7 Distribution of Non-conformities According to Non-conformity Codes (Clause 8.5.1)

Sl No.	Non-conformity Code	Number of Non-conformities		
		Total Output	Output of Machine 1	Output of Machine 2
(1)	(2)	(3)	(4)	(5)
i)	A	125	98	27
ii)	B	55	12	43
iii)	C	40	35	5
iv)	D	34	3	31
v)	E	8	5	3
vi)	F	3	2	1
Total		265	155	110

8.5.2 The Pareto diagram for the total output indicates that codes A and B account for about 68 percent of the total non-conformities. However, to facilitate taking corrective actions, the stratified data by machines indicate that for machine 1 non-conformities of type A and C (about 86 percent), and for machine 2 non-conformities of Type B and D (about 67 percent) should be taken care of.

8.5.3 A good many case studies can be cited where stratification by men, machine, time, geographical

locations, vendors, process-stages and the like was immensely helpful in pinpointing the source of trouble.

8.6 Identification of Causes by Stratification

8.6.1 When the range of distribution is large and the rate of off-specification items is high, like D of Fig. 9, stratification may be used for the identification of causes. The cause that influences the most shall be identified and the histogram shall be prepared after stratification with respect to the identified cause. When stratification with respect to one cause is insufficient, it shall be repeated with others.

8.6.2 Example 1

There are two peaks in the histogram A in Fig. 10. Since this histogram is drawn on the basis of observations on the products manufactured by two machines, stratification by the first and second machine is carried out to obtain the two histograms B and C of Fig. 10.

Stratification reveals that the range of the distribution of the product manufactured by the first machine is more than that by the second machine and its mean is lower.

8.6.3 Example 2

The finishing accuracy of a metal roll 200 mm in diameter is specified to be under 10/1 000 mm, but

off-specification articles amounted to 8 percent. The first histogram in Fig. 11 shows the data of the products classified in the classes with the width of 1/1 000 mm. This histogram shows apparently that the mean is deviated to the left and the tail in extended gradually to the right.

The finishing of the roll was carried out by two operators, A and B. Accordingly, two independent frequency distribution tables were prepared individually for A and B and histogram after stratification were prepared as shown in the second histogram of Fig. 11.

In this histogram, the solid line indicates the data of A and the dotted line that of B. The number of observations for A is 41 and that for B is 109. These overlapping histograms show that the products manufactured by A are within the specified limits, but those by B are widely distributed and B is responsible for all the off-specification articles.

Action must be taken to improve the working accuracy of operator B. When the working practice of B was examined carefully, it was found that B did not attach a roll to the grinder properly. His accuracy improved to a large extent when he attached a roll in the same way as operator A.

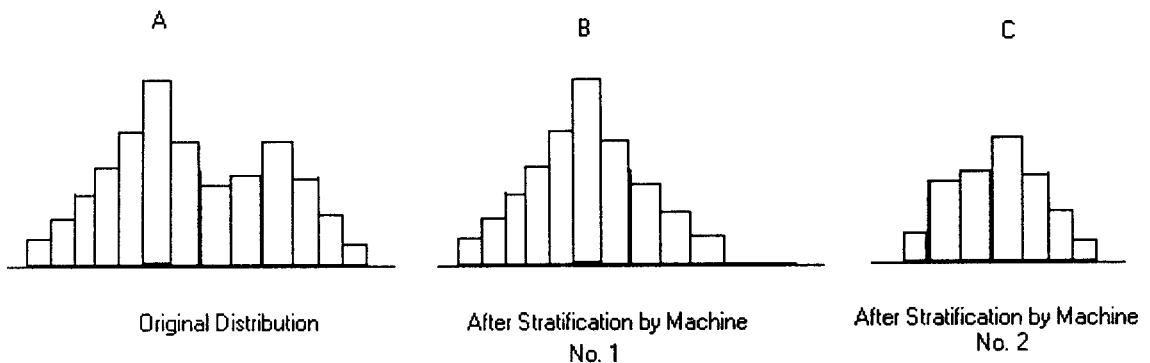


FIG. 10 HISTOGRAMS AFTER STRATIFICATION BY MACHINES

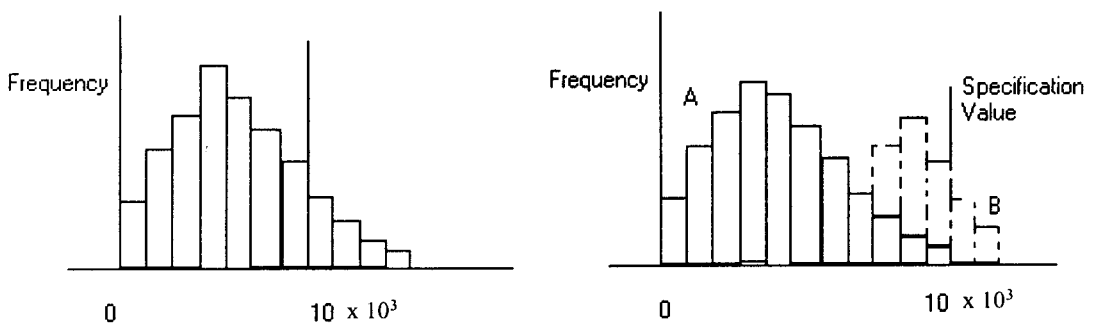


FIG. 11 STRATIFIED HISTOGRAMS OF FINISHING ACCURACY OF OUTSIDE DIAMETER OF ROLLS BETWEEN TWO OPERATIONS

9 RUN CHART

9.1 General

A special type of run chart extensively used in statistical process control is control chart. A control chart is a very useful diagnostic tool for assignable causes of variation in a process. Besides, it is used to evaluate process capability and to confirm whether process has improved after a corrective action has been taken.

The detailed procedures for construction including preliminary steps needed and interpretation of various types of control charts have been covered in IS 397 (Part 1).

9.2 Scope

9.2.1 Besides use as a control chart to understand the state (stable or unstable) of a process as indicated in 9.1, a run chart can be used to study the nature of change over time in any variable of interest to an industry, for example, production, consumption of energy, customer complaints, profit, machine downtime, scrap, productivity, and so on.

9.3 Steps for Construction

The steps for drawing a run chart may be enumerated as follows:

- a) Identify the variable to be plotted on the run-chart, with clearly defined unit of measurement.

- b) Decide on the time-points, or time-periods for which data are to be plotted.
- c) Scale the *x*-axis according to time-points or time-periods to be taken. Scale the *y*-axis according to the variable to be plotted. Show the zero-point on the *y*-axis, if necessary allowing a definite break.
- d) If measurement on a quality characteristic is to be plotted (control chart for individual items), it is helpful to indicate the target value as also the upper and the lower specification limits on the chart to facilitate assessment of the state of the process.
- e) Observe the variable over time and plot the corresponding points on the chart.
- f) Join the successive points by broken lines.
- g) Interpret the chart for trends (upward, downward, or more or less static), cycles, shift (in a quality characteristic, namely the target value and specifications) etc, after a sufficiently large number of points are plotted.

9.4 Examples

9.4.1 Example of a Run Chart Indicating Trend

An upward trend is apparent, indicating tool-wear over time (see Fig. 12).

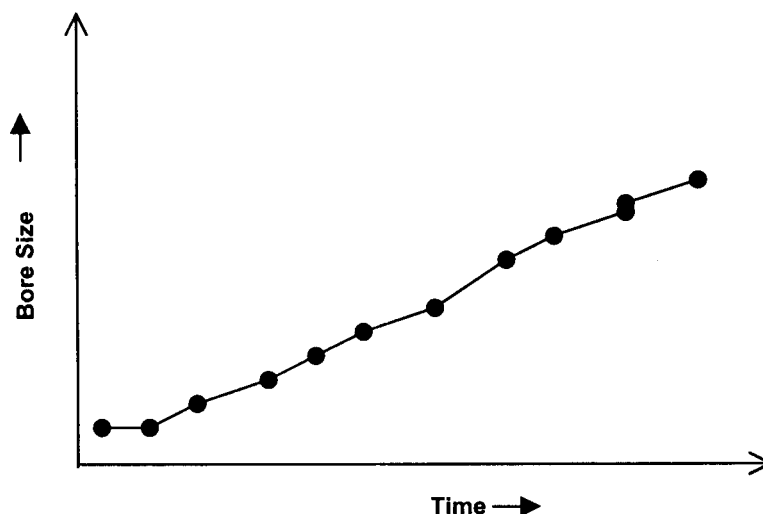


FIG. 12 RUN CHART INDICATING TREND

9.4.2 Example Showing Monthly Power Consumption (See Fig. 13)

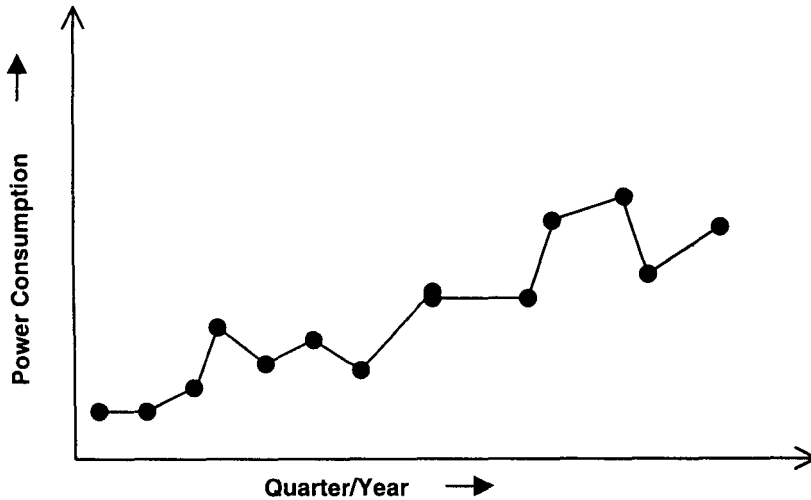


FIG. 13 RUN CHART INDICATING POWER CONSUMPTION

9.4.3 Example Showing Run Chart for Bore-Size of Fly Wheel (Individual Items) (See Fig. 14)

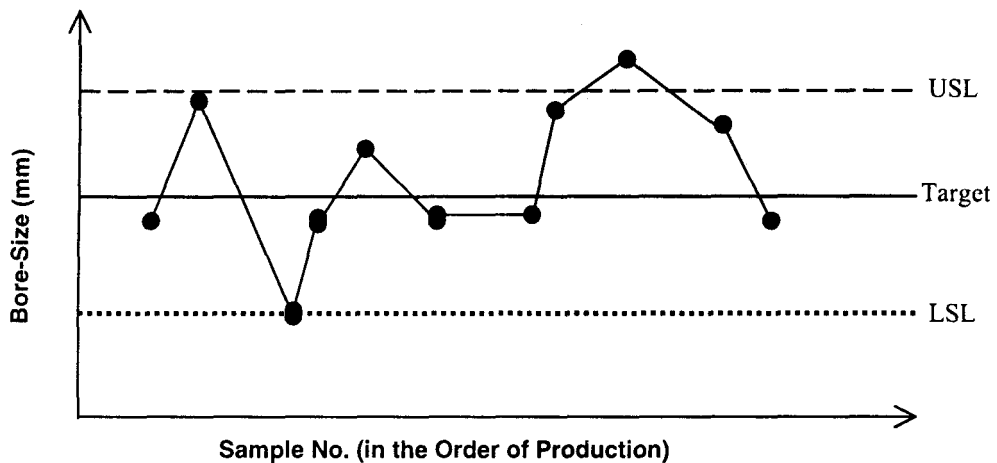


FIG. 14 RUN CHART FOR BORE SIZE OF FLY WHEEL

10 SCATTER DIAGRAM

10.1 General

The dictionary meaning of the word scatter is sprinkle, dissemination or dispersion. In the present context, for every quality parameter of interest, there is need to assess the nature and/or degree of impact on output of resulting 'quality parameter' as reflected in the observed changes caused by corresponding variations in the 'input parameter'. The former is called dependent variable and the latter independent variable. Attempts are made to get the behaviour of dependent variable in desired range by monitoring the independent variable in appropriately determined limits as indicated by the nature of relationship between the two. The dependent variable is plotted along

Y-axis and the independent along X-axis. Such a diagram is called a scatter diagram.

10.2 Scope

10.2.1 Scatter diagrams can be used to establish prima facie relationship between output variables reflecting quality and input variables, study rejection/rework problems, warranty problems etc.

10.2.2 After a prima facie case of linear or non-linear relationship between the variables under study is established, from the configuration of points on the scatter diagram, further analysis is taken up for quantifying the relationship by computing suitable numerical measures (correlation, coefficient for linear relationship, and correlation index for non-linear relationship), and for predicting the dependent variable

on the basis of the independent one by developing suitable regression equations.

10.2.3 Correlation and regression have been separately discussed in IS 7300.

10.3 Steps for Construction

The following steps are to be taken for drawing a scatter diagram:

- a) Decide on the dependent variable and the independent variable whose possible relationship is proposed to be studied through the scatter diagram. Also decide on the units of measurement for each variable.
- b) Scale the X-axis according to the independent variable (X) and the Y-axis according to the dependent variable (Y).
- c) Collect data (X, Y) the two variables for a sufficiently large number of items (about 50).
- d) Plot these points on the diagram.

10.4 Example

Scatter diagram between severed length (effect, output variable affecting quality) and conveyor speed (input variable) for the data given in Table 8 is shown in Fig. 15.

Table 8 Data on Conveyor Speed and Severed Length
(Clause 10.4)

Conveyor Speed cm/s	Severed Length mm	Conveyor Speed cm/s	Severed Length mm	Conveyor Speed cm/s	Severed Length mm
8.1	1 046	8.0	1 040	7.6	1 034
7.7	1 030	5.5	1 013	6.5	1 034
7.4	1 039	6.9	1 025	5.5	1 020
5.8	1 027	7.0	1 020	6.0	1 025
7.6	1 028	7.5	1 022	5.5	1 023
6.8	1 025	6.7	1 020	7.6	1 028
7.9	1 035	8.1	1 035	8.6	1 020
6.3	1 015	9.0	1 052	6.3	1 026
7.0	1 038	7.1	1 021	8.1	1 036
8.0	1 036	7.6	1 024	6.6	1 023
8.0	1 026	8.5	1 029	6.5	1 011
8.0	1 041	7.5	1 015	8.5	1 030
7.2	1 029	8.0	1 030	7.4	1 014
6.0	1 010	5.2	1 010	7.2	1 030
6.3	1 020	6.5	1 025	5.6	1 016
6.7	1 024	8.0	1 031	6.3	1 020
8.2	1 034	6.9	1 030		

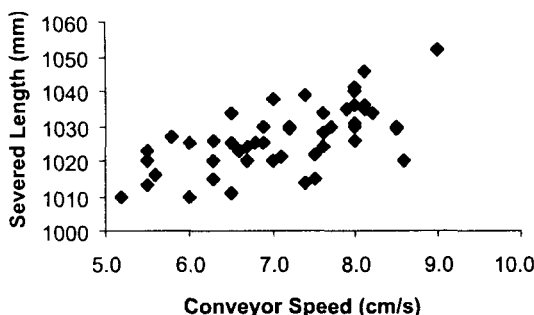


FIG. 15 SCATTER DIAGRAM

10.5 Interpretation

10.5.1 The configuration of the points on the scatter diagram will throw light on the nature of relationship between the variables under study.

10.5.1.1 Linear relationship

If the points on the scatter diagram lie more or less along a straight line, a perfect relationship between the variables is indicated (see Fig. 16).

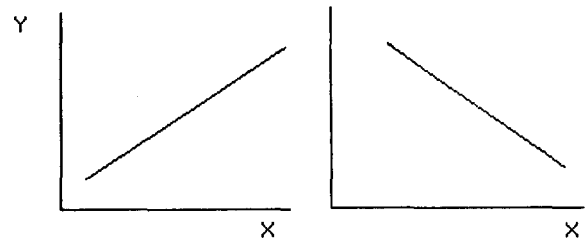


FIG. 16 LINEAR RELATIONSHIP

10.5.1.2 Positive correlation

If the line of scatter of the points has a positive slope (with an increase in the independent variable, the dependent variable also increases on the average), a positive correlation is said to exist between the two variables and these are said to be positively correlated (see Fig. 17).



FIG. 17 POSITIVE CORRELATION

10.5.1.3 Negative correlation

If the line of scatter has a negative slope (with an increase in the independent variable, the dependent variable decreases on an average, and vice versa), a negative correlation is said to exist between the variables, and these are said to be negatively correlated (see Fig. 18).

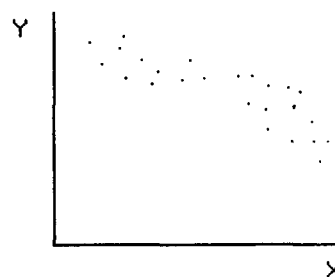


FIG. 18 NEGATIVE CORRELATION

10.5.1.4 No correlation

If the points do not betray the pattern of a straight line (with an increase in the independent variable, there is no change, on an average, in the dependent variable), there is said to be zero correlation between the variables, and these are said to be uncorrelated. Zero correlation only means there is no linear relationship between the variables. It is possible that there is some non-linear relationship (see Fig. 19).

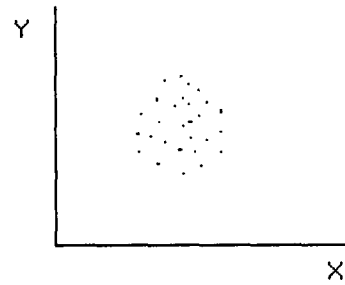


FIG. 19 NO CORRELATION

ANNEX A

(Foreword)

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GHAZIABAD. GUWAHATI. HYDERABAD. JAIPUR. KANPUR. LUCKNOW. NAGPUR.
NALAGARH. PATNA. PUNE. RAJKOT. THIRUVANANTHAPURAM. VISAKHAPATNAM.