APPENDIX V
QUALITY IMPROVEMENT TOOLS*

INTRODUCTION

Ishikawa's classic *Guide to Quality Control* (1972) is generally credited as the first training manual of problem-solving tools specifically presented for use in quality improvement. In the Japanese original, the book was a training reference for factory workers who were members of quality control (QC) circles. To the "seven tools" of that volume (flow diagrams, brainstorming, cause-effect diagrams, Pareto analysis, histograms, and scatter diagrams), we here add three more. Two are implied but not dealt with in detail in the Ishikawa work—data collection and graphs and charts. The third, box plots, is of more recent origin (Tukey 1977), but has proved itself a worthy complement or substitute for histograms under certain conditions. There are many other useful tools; this list is not exhaustive, nor could it or any list be so. But the list here is a useful starting place for quality improvement activity. Quality improvement teams that have mastered these tools are well prepared for most of the problems they are likely to face.

As presented by Juran Institute in the course *Quality Improvement Tools,* the tools are integrated with a structured quality improvement process (Figure V.1). Each tool is described and instructions for the tool's use are presented. In addition, the process steps in which the tool is used are identified. This information is captured in an application map in matrix form (Figure V.1), with each column corresponding to a tool, and each row corresponding to a process step. At each intersection is a symbol indicating the frequency of use of that tool at that process step (frequent, infrequent, and very rarely).

The process map is a valuable guide to problem-solving teams in these ways:

1. It reminds the team that there is a structured order to the problem-solving process and helps keep the team on track.
2. At a given step, if the team is at a loss what to do next, one of the frequently used tools may suggest the next action.
3. At a given step, using a tool indicated as rarely used is a signal to the team to reconsider its course of action. A convenient example is the use of brainstorming (which is an effective way to develop a list of theories, ideas, and opinions of group members) to test theories (which always requires data, not the opinions of the team members).

The tools are briefly described and illustrated here. A more thorough treatment is available from a number of texts, including the course notes for *Quality Improvement Tools* or from *Modern Methods for Quality Control and Improvement* by Wadsworth, Stephens, and Godfrey (1986).

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*In response to inquiries from users of previous editions of this handbook, the editors include this introduction to some of the more important and popularly used quality improvement tools. Material in this appendix is adapted from material provided in the course *Quality Improvement Tools* presented by Juran Institute, Inc., Wilton, CT.

Quality Improvement Steps and Activities	Box Plot	Brainstorming	Cause-Effect Diagram	Data Collection	Flow Diagrams	Graphs and Charts	Histogram	Pareto Analysis	Scatter Diagram	Stratification
1. Identify a Project										
a. Nominate projects		■		■	■					
b. Evaluate projects		x	x	■	□	□		■		
c. Select a project				■				■		□
d. Ask: Is it quality improvement?	x		x	■	□		x	■	x	□
2. Establish the Project										
a. Prepare a mission statement					□	□		□		□
b. Select a team					□					
c. Verify the mission				□	□	□				
3. Diagnose the Cause										
a. Analyze symptoms	□	x	x	■	■	□	□	■		■
b. Confirm or modify the mission		x	x	■	■	■		■		□
c. Formulate theories		■	■		□					□
d. Test theories	■	x	x	■	■	■	■	■	■	■
e. Identify root cause(s)	■	x	x	■	■	■	■	■	■	■
4. Remedy the Cause										
a. Evaluate alternatives		■	□	■	■		□	□	□	□
b. Design remedy	□	x	x	□	■	■	□	□	□	□
c. Design controls	□	x	x		■		□	□	□	
d. Design for culture		■								
e. Prove effectiveness				■	■		□	□	□	
f. Implement					■					
5. Hold the Gains										
a. Design effective quality controls	□	x	x		■		□	□	□	
b. Foolproof the remedy					■					
c. Audit the controls				■		■		■		
6. Replicate Results and Nominate New Projects										
a. Replicate the project results				■	■		□	□	□	
b. Nominate new projects					■			■		

■ Frequently used □ Occasionally used · Rarely used x Never used

FIGURE V.1 Applications for quality improvement tools. (*Juran Institute.*)

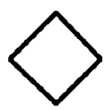
THE TOOLS

Flow Diagram. A graphic representation of the sequence of steps needed to produce some output. The output may be a physical product, a service, information, or a combination of the three. The symbols of a flow diagram are specific to function and are explained in Figure V.2. Figure V.3 shows the use of these symbols in the flow diagram of an airline ticketing process.

Brainstorming. A group technique for generating constructive and creative ideas from all participants. Use of this tool should provide new ideas, or new applications and novel use of existing ideas. The technique is outlined in Figure V.4.

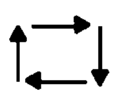
Cause-Effect ("Fishbone") Diagram. Developed by Kaoru Ishikawa, this tool is frequently called the Ishikawa diagram in his honor. Its purpose is to organize and display the interrelationships of various theories of root cause of a problem. By focusing attention on the possible causes of a specific

The *activity symbol* is a rectangle that indicates a single step in the process. A brief description of the activity is shown inside the rectangle.

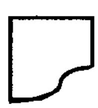


The d*ecision symbol* is a diamond that designates a decision or branch point in the process. The description of the decision or branch is written inside the symbol, usually in the form of a question. The answer to the question determines the path that will be taken out of the decision symbol. Each path is labeled to correspond to an answer.

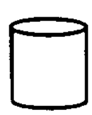
The *terminal symbol* is a rounded rectangle that identifies the beginning or the end of a process. "Start" or "End" is shown inside the symbol.



Flow lines are used to represent the progression of steps in the sequence. The arrowhead on the flow line indicates the direction of the process flow.



The *document symbol* represents written information pertinent to the process. The title or description of the document is shown inside the symbol.



The *data base symbol* represents electronically stored information pertinent to the process. The title or description of the data base is shown inside the symbol.

The *connector* is a circle used to indicate a continuation of the flow diagram. A letter or number is shown inside the circle. This same letter or number is used in a connector symbol on the continued flow diagram to indicate how the processes are connected.

These basic symbols are arranged to show the actual sequence of steps in a process, running consistently from top to bottom or left to right on the page. As we have seen, decision diamonds can lead us to branch back and repeat an earlier step.

FIGURE V.2 Symbols used in flow diagramming.

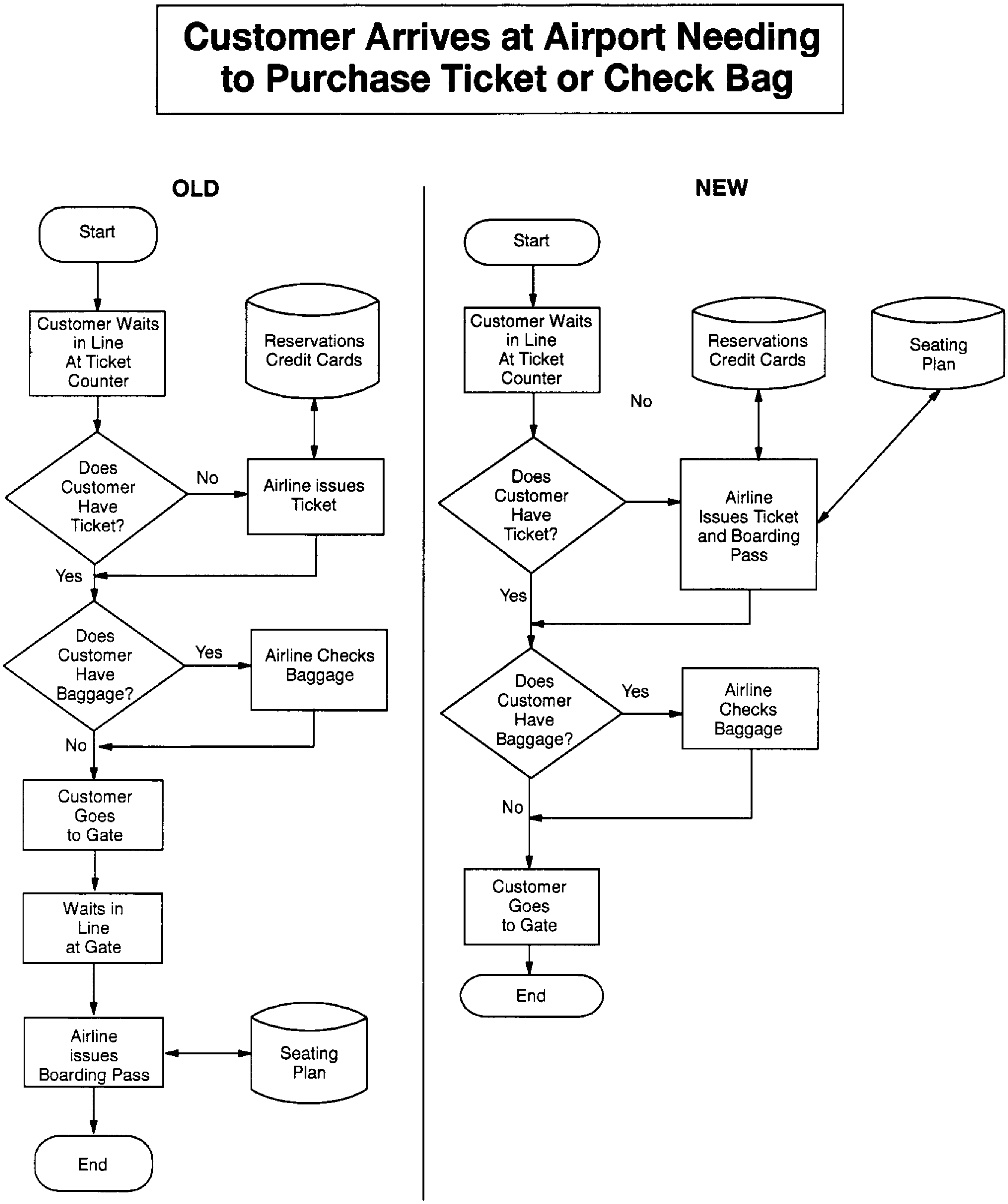


FIGURE V.3 Before and after flow diagrams of an airline ticketing process. (*Juran Institute.*)

- Good ideas are not praised or endorsed. All judgment is suspended initially in preference to generating ideas.
- Thinking must be unconventional, imaginative, or even outrageous. Self-criticism and self-judgment are suspended.
- To discourage analytical or critical thinking, team members are instructed to aim for a large number of new ideas in the shortest possible time.
- Team members should "hitchhike" on other ideas, by expanding them, modifying them, or producing new ones by association.

FIGURE V.4 Brainstorming technique. (*Juran Institute.*)

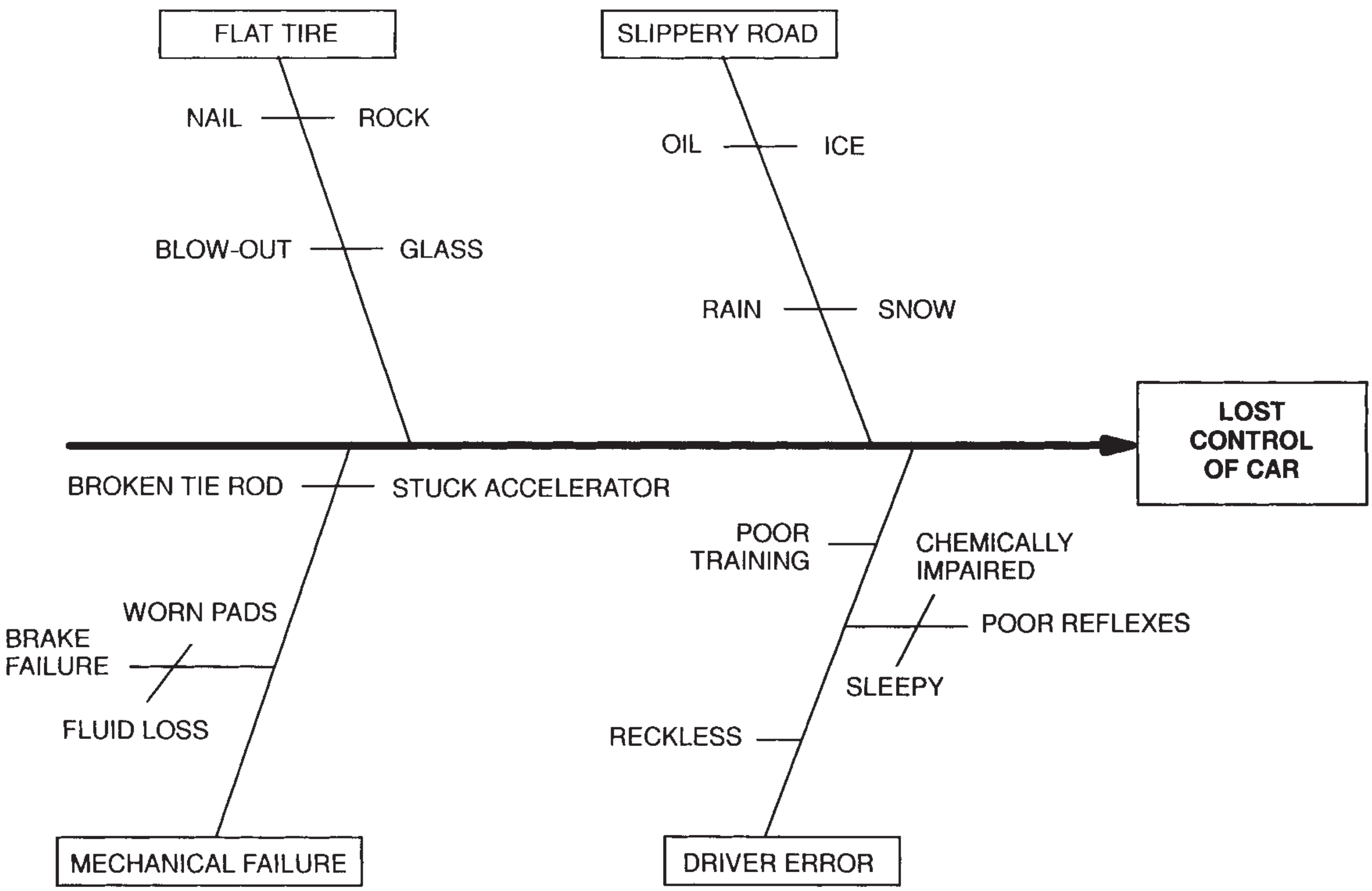


FIGURE V.5 Cause-effect diagram for lost control of car. (*Juran Institute.*)

problem in a structured, systematic way, the diagram enables a problem-solving team to clarify its thinking about those potential causes, and enables the team to work more productively toward discovering the true root cause or causes. Figure V.5 is an example.

Data Collection. The gathering of the objective data needed to shed light on the problem at hand, and in a form appropriate for the tool selected for the analysis of the data. Types of data collection include check sheets (providing data and trends), data sheets (simple tabular or columnar format), and checklists (simple listing of steps to be taken). Figures V.6 and V.7 are examples.

Graphs and Charts. A broad class of tools used to summarize quantitative data in pictorial representations. Three types of graphs and charts that prove especially useful in quality improvement are line graphs, bar graphs, and pie charts. A *line graph* connects points which represent pairs of numeric

COMPONENTS REPLACED BY LAB

Enter a mark for each component replaced. Mark like the following: / // /// //// 𝍸

Time Period: 22 Feb to 27 Feb 1988
Repair Technician: Bob

TV SET MODEL 1013

Integrated circuits	𝍸
Capacitors	𝍸 𝍸 𝍸 𝍸 𝍸 //
Resistors	//
Transformers	////
Commands	
CRT	/

TV SET MODEL 1017

Integrated circuits	///
Capacitors	𝍸 𝍸 𝍸 𝍸 𝍸 //
Resistors	/
Transformers	//
Commands	𝍸 𝍸 𝍸 / //
CRT	/

TV SET MODEL 1019

Integrated circuits	/
Capacitors	𝍸 𝍸 𝍸 𝍸 ///
Resistors	/
Transformers	//
Commands	
CRT	/

FIGURE V.6 Check sheet for TV component failures. (*Juran Institute.*)

data, to display the relationship between two continuous numerical variables (e.g., cost and time). In Figure V.8 each pair of data consists of a year and the cost of poor quality recorded in that year. The cost of poor quality is shown as a function of the year. A *bar graph* also portrays the relationship between pairs of variables, but only one of the variables need be numeric (Figure V.9). A *pie chart* (Figure V.10) shows the proportions of the various classes of a phenomenon being studied that make up the whole.

Stratification. This is the separation of data into categories. It is used to identify which categories contribute to the problem being solved and which categories are worthy of further investigation. It is

- Read temperature to nearest degree off meter number 5.
- Record the temperature in the table below.
- Reading should be taken on the hour (± 5 minutes).
- Use the "Notes" section to record anything unusual.

Date: *6-7-88*

Line #: *13*

Inspector: *Ginny Smith*

* Question? Contact Larry Fine x2222

Time of Day	Temperature (°F)
0800	240
0900	242
1000	236
1100	236
1200	236

Time of Day	Temperature (°F)
1300	227
1400	230
1500	224
1600	220
1700	220

Notes:
- *1100 hours reading taken at 1112*
- *The line was stopped between 1310 and 1330*

FIGURE V.7 A data sheet showing solder bath temperature. (*Juran Institute.*)

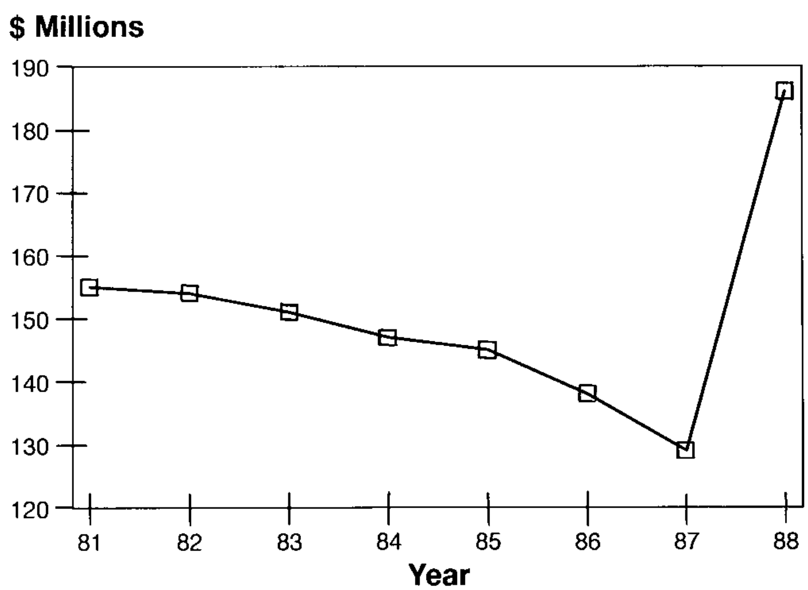


FIGURE V.8 A deceptive vertical scale, intended to show the cost of poor quality. (*Juran Institute.*)

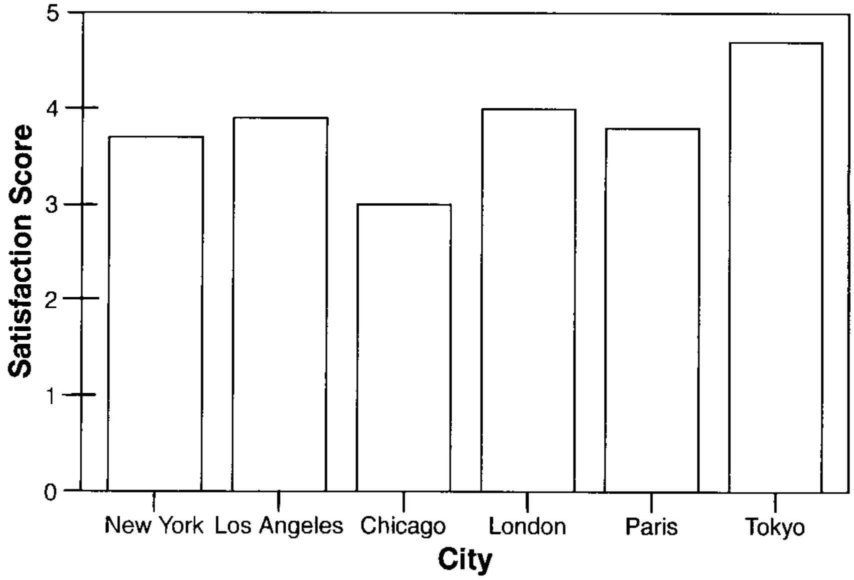


FIGURE V.9 A bar graph showing average customer satisfaction scores by city. (*Juran Institute.*)

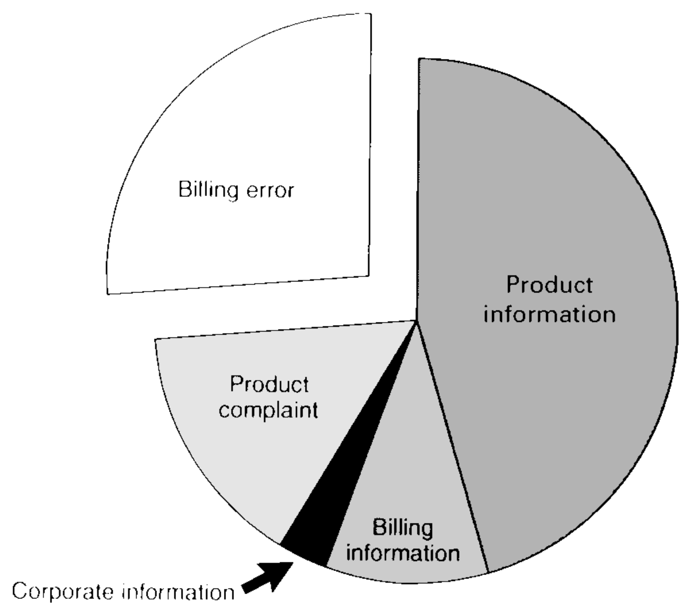


FIGURE V.10 A pie chart showing phone calls received by customer service in one month. (*Juran Institute.*)

an analysis technique that helps pinpoint the location or source of a quality problem. It may be necessary to stratify the data in many different ways. Figures V.11 and V.12 illustrate stratification of data related to field failure of an electronic component. The first stratification is by supplier, the second by shipper. The analysis reveals that the problem relates to shippers (specifically a new shipper), not suppliers. Stratification is the basis for the application of other tools, such as Pareto analysis and scatter diagrams.

Pareto Analysis. This is a tool used to establish priorities, dividing contributing effects into the "vital few" and "useful many." A Pareto diagram includes three basic elements: (1) the contributors

FIGURE V.11 Second-stage stratification of failure. Shows RF driver failure by serial number. (*Juran Institute.*)

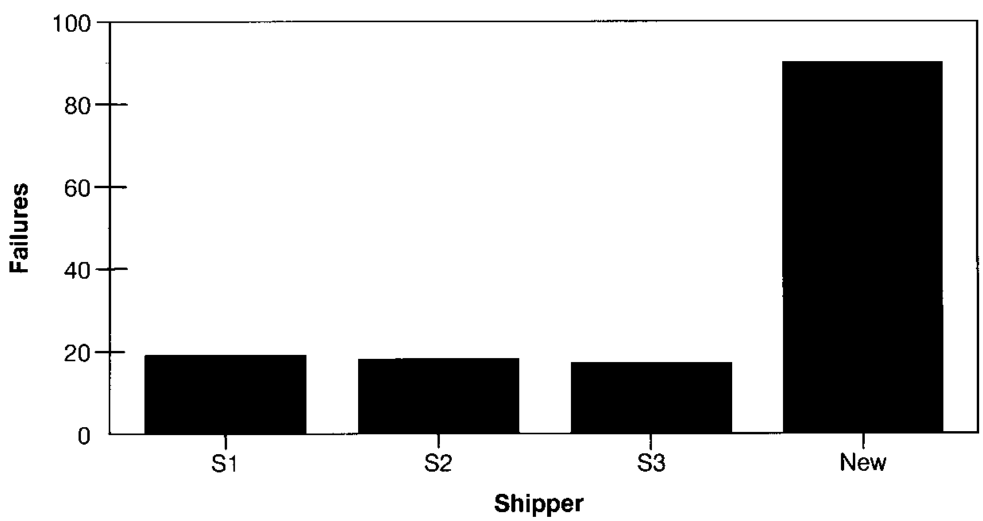


FIGURE V.12 Stratification by new variable. Shows RF driver failures by shipper. (*Juran Institute.*)

① Order-Form Item	② Number of Errors	Percent of Total	③ Cumulative-Percent of Total
G	44	29	
J	38	25	29
M	31	21	54
Q	16	11	75
B	8	5	86
D	5	3	91
C	3	2	95
A	1	0.67	97
O	1	0.67	98
R	1	0.67	98
N	1	0.67	99
L	1	0.66	99
I	0	0	100
E	0	0	100
H	0	0	100
K	0	0	100
F	0	0	100
P	0	0	100
TOTAL	150	100	100

FIGURE V.13 Pareto table of errors on order forms. (*Juran Institute.*)

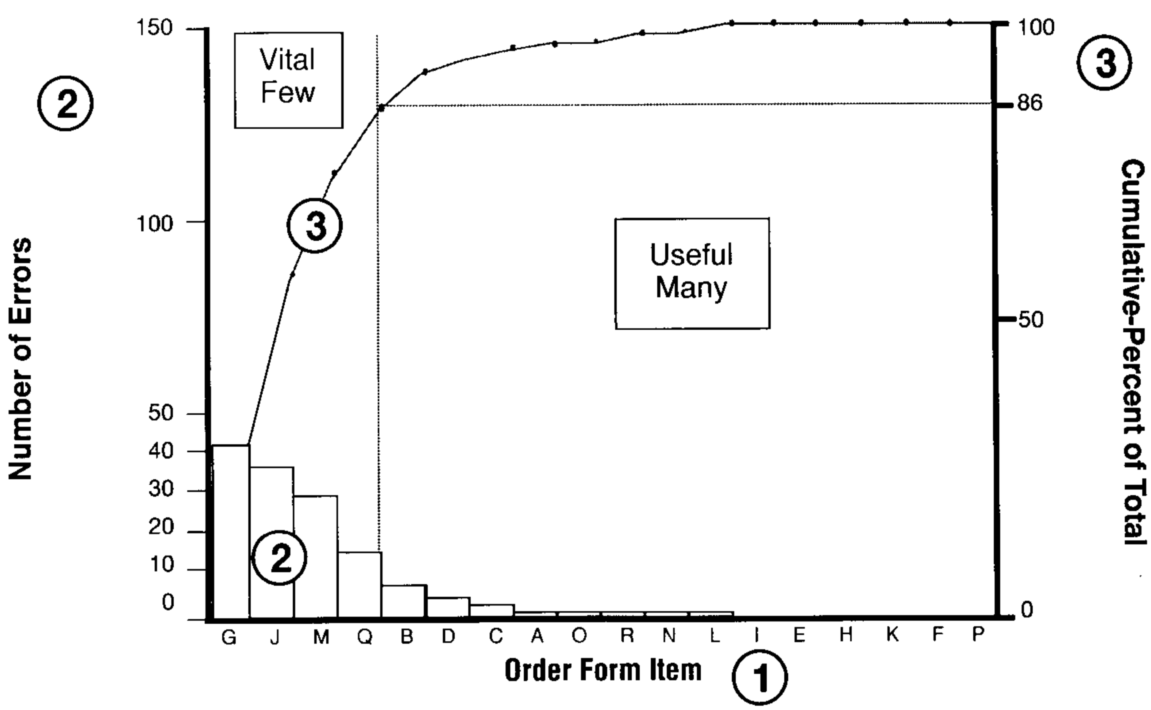


FIGURE V.14 Pareto diagram of errors on order forms. (*Juran Institute.*)

to the total effect, ranked by the magnitude of contribution; (2) the magnitude of the contribution of each expressed numerically; and (3) the cumulative-percent-of-total effect of the ranked contributors. Figure V.13 shows a Pareto table. Figure V.14 shows the same data in a Pareto diagram. Note the three basic elements as reflected in each figure.

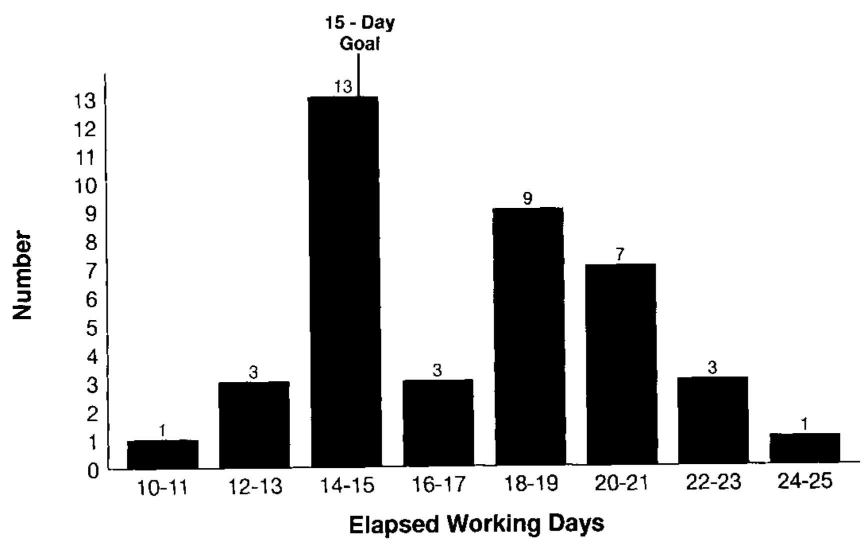
Histogram. This is a picture of the distribution of a set of measurements. A histogram is a graphic summary of variation in a set of data. Four concepts related to variation in a set of data underlie the usefulness of the histogram: (1) values in a set of data almost always show variation, (2) variation displays a pattern, (3) patterns of variation are difficult to see in simple numerical tables, and (4) patterns of variation are easier to see when the data are summarized pictorially in a histogram. Analysis consists of identifying and classifying the pattern of variation displayed by the histogram, then relating what is known about the characteristic pattern to the physical conditions under which the data were created to explain what in those conditions might have given rise to the pattern. The data in Figure V.15*a* shows days elapsed between an interdepartmental request for an interview and the actual interview. In Figure V.15*b,* the histogram helped a team recognize the unacceptable range of time elapsed from request to interview. It also provided the team with a vivid demonstration of a human-created phenomenon—the rush at day 15 to get as many requests completed within the 15-day goal. The histogram directed the team's attention toward steps to reduce the duration (and with it the spread) of the process.

Scatter Diagram. This is a tool for charting the relationship between two variables to determine whether there is a correlation between the two which might indicate a cause-effect relationship (or indicate that no cause-effect relationship exists). Figure V.16 shows scatter diagrams used to explore three potential causes for clerical errors. Potential causes, chosen from a cause-effect diagram are: fatigue, working with a mixture of alphabetic and numeric keyboard characters, and distracting background noise. The diagrams indicate the alphanumeric mixture appears to be the most likely root cause of the clerical errors.

Box Plot. This is a graphic, five-number summary of variation in a data set. The data are summarized by: the smallest value, second quartile, median, third quartile, and largest value. The box plot can be used to display the variation in a small sample of data or for comparing the variation in

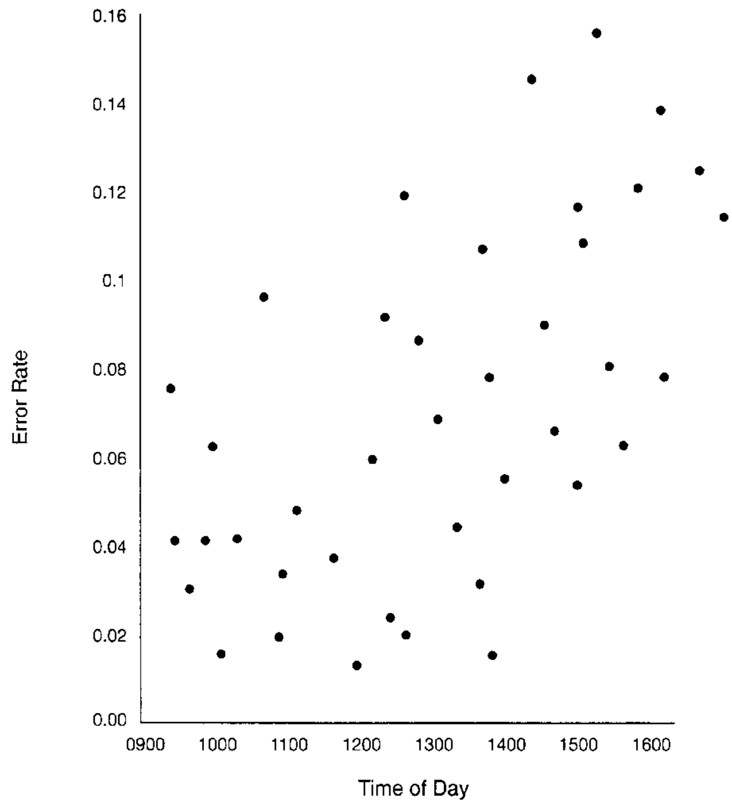
14	**15**	**18**	**19**	**13**
12	**18**	**22**	**14**	**18**
15	**17**	**19**	**15**	**17**
18	**20**	**10**	**15**	**15**
20	**14**	**17**	**20**	**21**
15	**24**	**15**	**18**	**14**
23	**13**	**23**	**21**	**20**
18	**21**	**18**	**15**	**15**

(a)



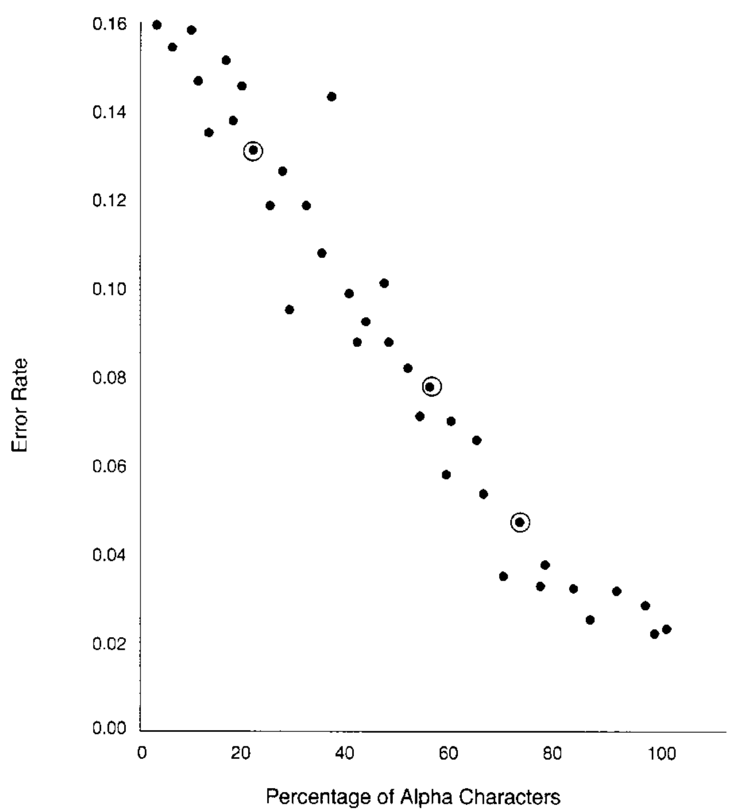
(b)

FIGURE V.15 Response to job evaluation requests. (*a*) Data showing elapsed time (in working days) from receipt of request to preliminary review and contact with manager. (*b*) Histogram. (*Juran Institute.*)



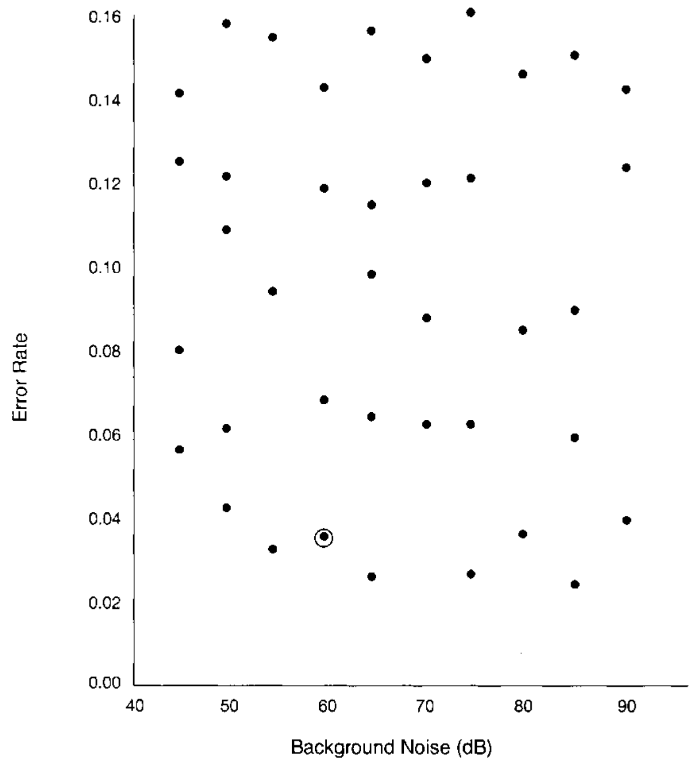
Error Rate
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0.00
0900
1000
1100
1200
1300
1400
1500
1600
Time of Day

(a)



Error Rate
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
20
40
60
80
100
Percentage of Alpha Characters

(b)



(c)

FIGURE V.16 Scatter diagrams used to explore potential causes of error in clerical data-entry errors. (*a*) Time of day; (*b*) the percentage of alphabetical characters; and (*c*) background noise. (*Juran Institute.*)

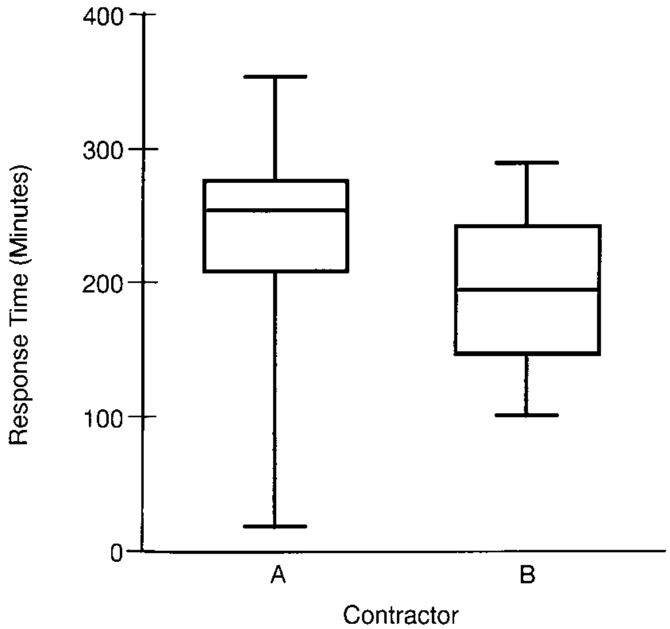
A		B	
243	345	192	251
207	268	156	102
272	290	228	215
45	251	125	145
226	183	279	188

(a)

Contractor	1	2	3	4	5	6	7	8	9	10
A	45	183	207	226	243	251	268	272	290	345
B	102	125	145	156	188	192	215	228	251	279

(b)

FIGURE V.17 Box plots used to compare response times (in minutes) of two copier repair contractors, A and B. (*a*) Raw data; (*b*) ordered data set; and (*c*) basic box plots. (*Juran Institute.*)



(c)

FIGURE V.17 Box plots used to compare response times (in minutes) of two copier repair contractors, A and B. (*a*) Raw data; (*b*) ordered data set; and (*c*) basic box plots. (*Juran Institute.*)

a large number of related distributions. The box plot (sometimes called a “box and whisker chart”) can be useful even when the number of data points is too small to produce a meaningful histogram. In analyzing the performance of two copy-repair contractors, a potential customer created the analysis in Figure V.17. It is based on 10 repair calls each to contractors A and B. Figure V.17*a* and *b* shows the response time of two copy machine contractors as raw data and as “ordered” (sequenced) data. Figure 17*c* shows the same data as a box plots. The comparison of the two plots favors contractor B: B’s median response time is less than A’s and exhibits less variation.

REFERENCE

Tukey, J. W. (1977). *Exploratory Data Analysis.* Addison-Wesley, Reading, MA.

Wadsworth, Harrison M., Stephens, Kenneth S., and Godfrey, A. Blanton (1986). *Modern Methods for Quality Control and Improvement.* John Wiley and Sons, New York.