BUILDING FROM THE BASICS

Master these quality tools
and **do your job better**

QUALITY CONTROL is about models, methods, measuring and managing. It's about uncovering a problem and finding the solution. It's about using the right techniques at the right time to make things better.

One of the forefathers of quality, Kaoru Ishikawa, knew how to make things better. He taught quality and promoted it in Japan for decades. He believed that 95% of a company's problems could be solved by a select number of quality tools.

The powerful collection of tools that Ishikawa had in mind is referred to by different names: "the old seven," "the first seven" or "the basic seven." Whatever you call them, it's imperative to know them all—inside and out—if you are to succeed as a quality professional.

We asked seven of QP's frequent contributors to each cover one of the tools in about 500 words. Their respective explanations (presented here in no particular order) get to the heart of these tools. True, they could have written much, much more, but these illuminating snapshots give you the basics you need to understand—or explain to others—how these tools are used.

Chances are, as a quality practitioner, you're familiar with most of the seven. If you feel the need to brush up more on one or two, however, there are additional resources listed at the end of each article. QP's website (www.qualityprogress.com) offers articles on the basic tools, and ASQ's website is stocked with publications (www.asq.org/books-and-publications.html) and other resources to help you learn about quality.

Each of these seven tools is indispensable and can make a difference in the way you work. As the American psychologist Abraham Maslow noted, "If the only tool you have is a hammer, everything starts to look like a nail."

The Tools

Histograms

Statistics and data analysis procedures can be divided into two general categories: quantitative techniques and graphical techniques.

Quantitative techniques are statistical procedures that yield numeric or tabular output. Examples of quantitative techniques include hypothesis testing, analysis of variance, point estimation, confidence intervals and least-squares regression. Graphical techniques include histograms, scatter plots, probability plots, residual plots, box plots, block plots and ballots.

Exploratory data analysis (EDA) relies heavily on these and other similar graphical techniques. Graphical procedures are not just tools used within an EDA context; they are the shortest path to gaining insight into a data set in terms of testing assumptions, model selection and statistical model validation, estimator selection, relationship identification, factor effect determination and outlier detection. In addition, good statistical graphics can effectively communicate the underlying message that is present within the data.

A histogram is a graphical display of tabulated frequencies, which are shown as bars. It illustrates what proportion of cases fall into each of several categories. A histogram differs from a bar chart in that it is the area, not the height, of the bar that denotes the value—a crucial distinction when the categories are not of uniform width. The categories are usually specified as nonoverlapping intervals of a variable. The categories (bars) must be adjacent. Figure 1 is an example of a histogram.

Although A. M. Guerry published a histogram in 1833, Karl Pearson (1857-1936) first used the word "histogram" in 1891. Pearson was a scientist in Victorian London. As a student at Cambridge University, Pearson learned to use applied mathematics as a pedagogical tool for determining the truth (in other words, one that provided the standards and the means of producing reliable knowledge).

Pearson's passionate interest in mathematical statistics was a means to the truth. He established the foundations of contemporary mathematical statistics and helped create the modern

Histogram example / FIGURE 1

Worksheet example

The Bulldogs bowling team wants to improve its standing in the league. Team members decided to study their scores for the past month. The 55 bowling scores are:

103	107	111	115	115	118	119	121	122	124	124
125	126	127	127	129	134	135	137	138	139	141
142	144	145	146	147	148	148	149	150	151	152
153	153	154	155	155	155	156	157	159	160	161
163	163	165	165	167	170	172	176	177	183	198

Using the table on the histogram worksheet, they estimate B (the number of bars) to be seven. The highest score was 198, and the lowest was 103, so the range of values is:

R = largest – smallest

R = 198 – 103 = 95

The width of each bar is:

W = R ÷ B

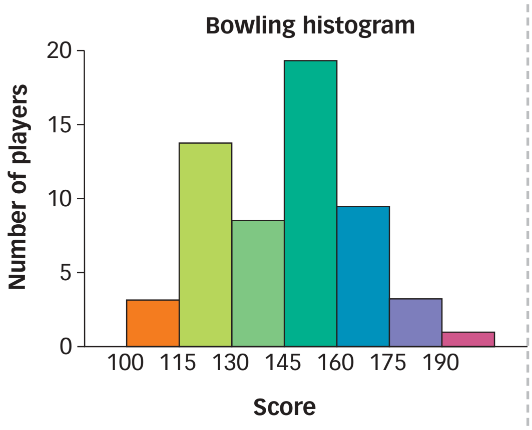
W = 95 ÷ 7 = 13.6

The bowling scores have no decimal places, so the bar width must not have decimal places. They round 13.6 up to 14. Because 14 is an awkward number to work with, they decide to adjust W to 15. Choosing 100 to be the lower edge of the first bar, the lower edges of the other bars are

100 + 15 = 115

115 + 15 = 130, and so on

The histogram they drew seems to indicate a double-peaked, or bimodal, distribution: a group of players who score in the low 100s and another more talented group that scores in the mid-100s. To improve the team's standing, members can try to improve everyone's score, which would shift the entire histogram to the right. Or, they could focus their efforts on improving the poorer players, which would narrow the distribution, making the team as a whole more consistent.



Source: Nancy R. Tague, *The Quality Toolbox*, second edition, ASQ Quality Press, 2005.

world view. His statistical method not only transformed our vision of nature, but also gave scientists a set of quantitative tools with which to conduct research.

Pearson introduced the histogram Nov. 18, 1891. While presenting a lecture on maps and chartograms, he coined the term to describe a time diagram. He explained that the histogram could be used for historical purposes to illustrate blocks of time for "charts about reigns or sovereigns or periods of different prime ministers."

Figure 1 is an example of a histogram with bimodal distribution. Other histogram distributions are comb, truncated or heart-cut, and dog food.[1]

—James J. Rooney

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1. Nancy R. Tague, *The Quality Toolbox*, ASQ Quality Press, 2005, pp. 298-299.

Control Charts

Control Charts

Control charts are statistically based graphical tools used to monitor the behavior of a process. Walter A. Shewhart developed them in the mid-1920s while working at Bell Laboratories. More than 80 years later, control charts continue to serve as the foundation for statistical quality control.

The graphical and statistical nature of control charts helps us:

- Quantify the variation of a process.
- Center a process.
- Monitor a process in real time.
- Determine whether to take action on a process.

The structure of control charts

Constructing control charts is straightforward and, more often than not, aided by computer software designed specifically for this purpose. Minitab and JMP, among others, are commonly used.

Figure 2 illustrates the general form for a control chart. Its critical components listed here correspond with the numbers in the figure:

1. X-axis: This axis represents the time order of subgroups. Subgroups represent samples of data taken from a process. It is critical that the integrity of the time dimension be maintained when plotting control charts.

2. Y-axis: This axis represents the measured value of the quality characteristic under consideration when using variables charts. When attributes charts are used, this axis is used to quantify defectives or defects.

3. Center line: The center line represents the process average.

4. Control limits: Control limits typically appear at $\pm 3\sigma$ from the process average. More details about control limits can be found in the online version of this article at www.qualityprogress.com.

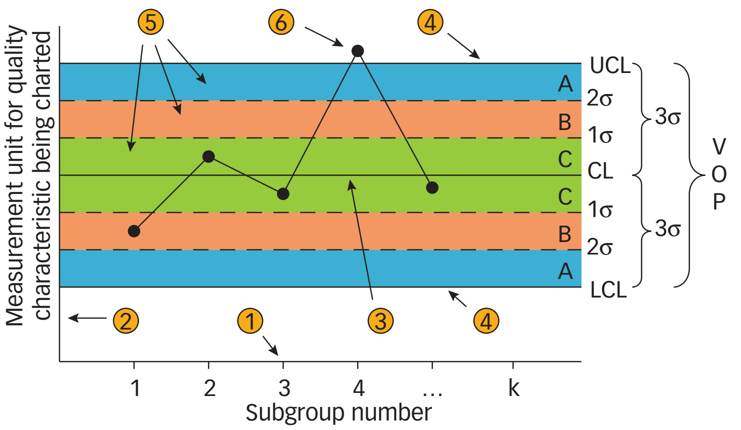
5. Zones: The zones represent the distance between each standard deviation and are useful when discussing specific out-of-control rules.

6. Rational subgroups: The variation within subgroups should be as small as possible to make it easier to detect subgroup-to-subgroup variation.

Notice there are no specification limits present on the control chart in Figure 2. This is by design, not by accident.

The presence of specification limits on control

Control chart structure / FIGURE 2



VOP = voice of process
UCL = upper control limit
LCL = lower control limit
CL = center line

charts could easily lead to inaction, particularly when a process is out of control but within specification.

Types of control charts

Control charts can be categorized into two types: variables and attributes. Charts fall into the variables category when the data to be plotted result from measurement of a variable or continuous scale. Attributes charts are used for count data in which each data element is classified in one of two categories, such as good or bad.

Generally, variables charts are preferred over attributes charts because the data contain more information and are typically more sensitive to detecting process shifts than attributes charts. A more detailed discussion on variables and attributes charts can be found in the online version of this article.

Using control charts

A control chart that has not triggered any out-of-control condition is considered stable, predictable and operating in a state of statistical control. The variation depicted on the chart is due to common-cause variation.

Points falling outside the limits are attributed to special-cause variation. Such points, regardless of whether they constitute "good" or "bad" occurrences, should be investigated immediately while the cause-and-effect relationships and individual memories are fresh and access to documentation for process changes is readily available.

As the time between the out-of-control event and the beginning of the investigation increases, the likelihood of determining root causes diminishes greatly. Hence, the motto "time is of the essence" is most appropriate.

Highly effective tool

A control chart is relatively easy to develop and use, and it can be a highly effective statistical tool when selected properly and used correctly. Its selection and use alone, however, is not sufficient. When so indicated, control charts must be acted on in a timely manner so the root causes may be identified and removed from the process.

One last thing: When in doubt, avoid tampering with the process.

—*T.M. Kubiak*

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Pareto Analysis

Pareto Analysis

In 1950, Joseph M. Juran rephrased the theories of Italian economist Vilfredo Pareto (1848-1923) as the Pareto principle, often referred to as the 80-20 rule. The rule postulates that in any series of variables (problems or errors), a small number will account for most of the effect (for example, 80% of customer complaints come from 20% of customers, or 80% of a company's profit comes from 20% of products made). Juran referred to the "vital few" versus the "useful many."

A Pareto chart graphically displays the relative importance of differences among groups of data within a set—a prioritized bar chart. Depicting values from the highest to the lowest in the form of bars (left to right), the Pareto chart has many potential uses for decision making, for example:

- Relative frequency of categories of occurrences.

- Which 20% of sources caused 80% of the errors.
- Relative costs incurred in producing different types of defectives.
- Determining which category or categories should be the focus of improvement efforts.

For example

Crackers Are Us (CAU) is a fictitious bakery that produces crackers for the consumer market. Crackers are sold to distributors, which sell to retail stores. The product package and the company's website provide contact information for submitting consumer complaints. CAU's complaint unit logs every complaint. Overall, complaints (the numbers reflect units) for the past month were the highest on record. The month's summary is shown in Table 1.

A Pareto chart graphically displays the data (see Figure 3). It appears that 78% of the complaints came from 20% of the complaint categories. Further analysis may indicate a need for nested Pareto charts, which are more discrete breakdowns of the top 80% or weighting of the categories by dollar cost.

Ensure the categories chosen are clearly differentiated to avoid overlap. The intention of the graphic is to clarify the data represented. Remember the data source: Garbage in is garbage out.

The Pareto chart is a valuable means for visualizing the relative importance of data.

—Russ Westcott

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OTHER RESOURCES

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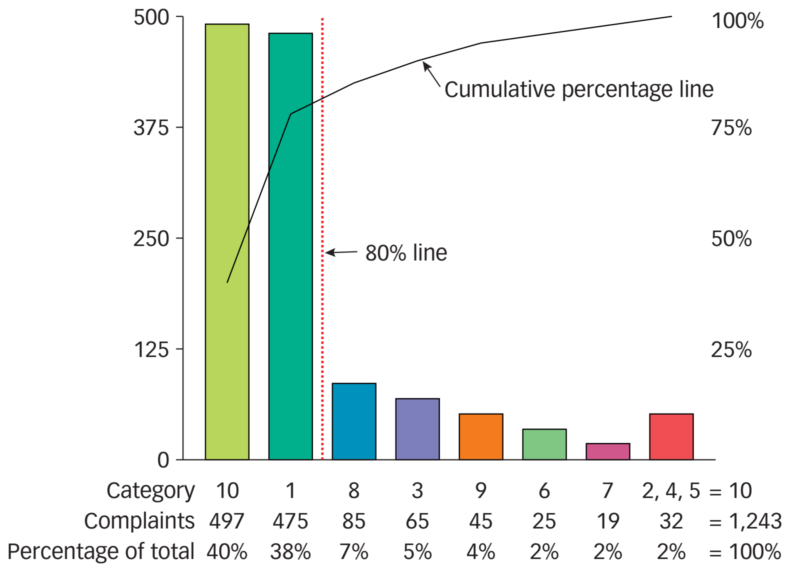
www.ncdot.org/programs/CPI/download/CPIToolbox/PARETO.pdf.

Monthly complaint summary / TABLE 1

Complaint type	Category	Number of complaints	Percentage of total
Too soft (break easily)	1	475	38
Too hard (difficult to chew)	2	5	0
Too crumbly (disintegrate easily)	3	65	5
Too bland (not enough flavor or seasoning)	4	15	1
Too irregular in shape (not standardized shape)	5	12	1
Too unappealing (color, smell, appearance)	6	25	2
Too much salt (or other seasoning)	7	19	2
Too much fat (trans fat or other fat)	8	85	7
Too few beneficial nutrients (too much filler)	9	45	4
Too damaged (soaked, burned, dented)	10	497	40
Total complaints		1,243	100

Pareto chart / FIGURE 3



Cause and Effect Diagrams

Cause and Effect Diagrams

This now-familiar tool was reportedly developed by Kaoru Ishikawa of Tokyo University. The Japanese name is *Tokusei Yoin Zu*, or “characteristics diagram.”[1]

The cause and effect diagram has been defined as a “tool for analyzing process dispersion. It is also referred to as the Ishikawa diagram and the fishbone diagram because the complete diagram resembles a fish skeleton. The diagram illustrates the main causes and sub-causes leading to an effect (symptom).”[2]

Ishikawa defined the effect to control or improve as the quality characteristic (Y in Figure 4) and the potential causes as the factors (X variables in Figure 4).[3] He first used the diagram to show the relationship between cause and effect in 1943.

When developing the tool, Ishikawa reported that in almost half of the cases, the reason for variation, or dispersion, was due to:

1. Raw materials.
2. Machinery or equipment.
3. Work method.

Joseph M. Juran described the diagram in the context of quality improvement, indicating that it is an example of a graphical method used to arrange a number of theories in a manner that allows the user to better understand interrelations.[4]

Figure 5 illustrates a traditional manufacturing example in which the tool “identifies many possible causes for an effect or problem. It can be used to structure a brainstorming session. It immediately sorts ideas into useful categories.”[5] In a service industry example, the main characteristic groupings can include people, processes, policies or technology. Characteristic groupings will vary.

Wikipedia adds that “a common use of the Ishikawa diagram is in product design to identify desirable factors leading to an overall effect.”[6]

Chrysler, Ford and General Motors included a high-level example of the diagram while discussing control charts for variables in their *Statistical Process Control (SPC) Reference Manual*.[7]

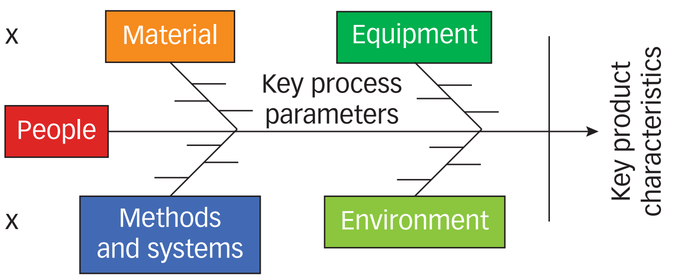
Then, they applied the diagram in their *Measurement Systems Analysis Reference Manual* third edition, (see Online Figure 4) to identify some potential sources for measurement system variability,[8] using the following characteristic groupings: standard, workpiece, instrument, person and procedure, and environment.

I have used an adaptation or variation of the diagram over the years. Figure 6 uses the typical fishbone diagram groupings to define inputs that need verification in the process model graphic. The figure illustrates that “fundamental quality management science recognizes the need for appropriate controls on the quality of the inputs as well as controls for the process itself and the output.”[9]

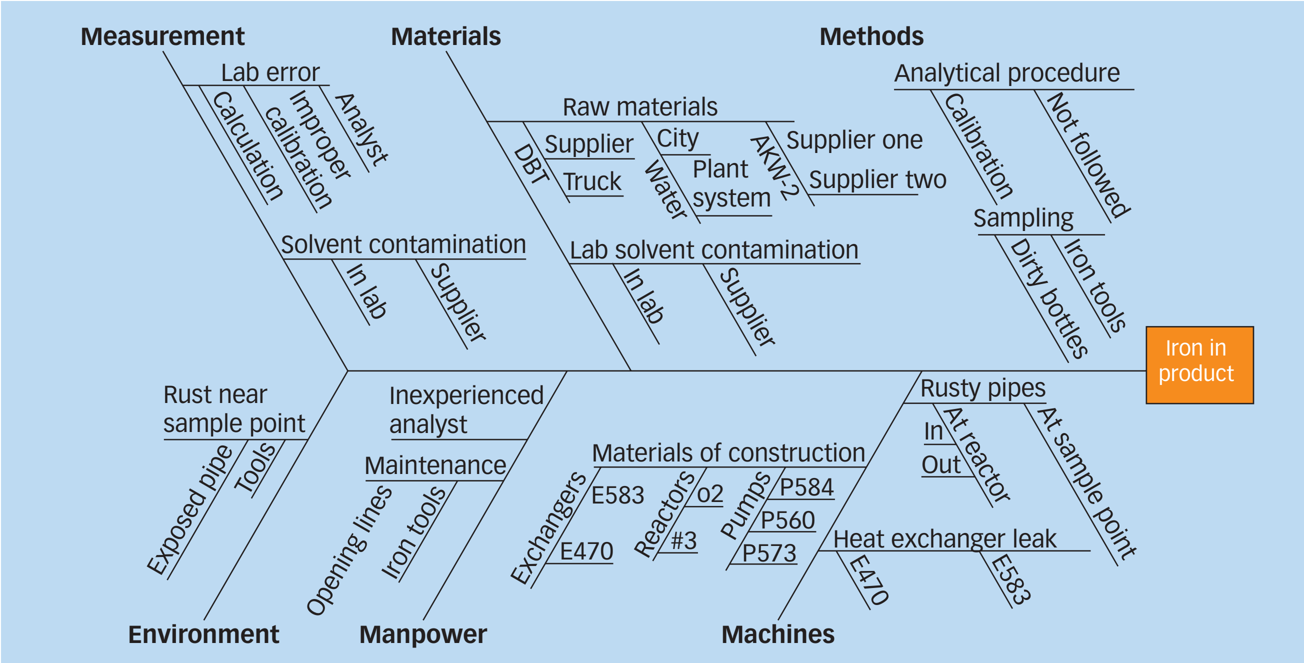
I have also used a more traditional application of the diagram (Figure 4) to depict the relationship between key product (Y) and key process characteristics (X variables) in a Six Sigma context.

The Society of Automotive Engineers published sev-

High-level fishbone for key characteristics / FIGURE 4



Fishbone diagram / FIGURE 5



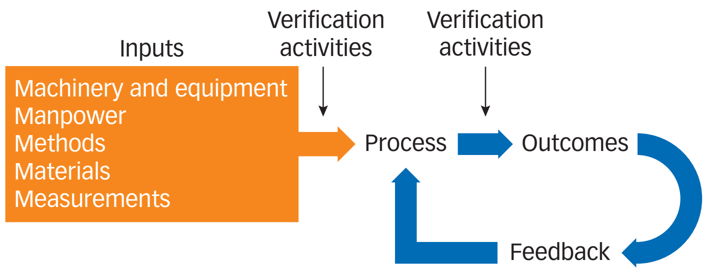
Source: ASQ

eral papers on Six Sigma in 2007 that applied the diagram as a diagnostic tool for problem solving that can improve service quality (noise)[10] and identify potential causes of manufacturing process variation.[11]

As with many quality tools, such as failure mode effects analysis and control plans, this diagram should be constructed using brainstorming methods by a cross-functional team to capture broad organizational input.

–R. Dan Reid

Process model / FIGURE 6



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OTHER RESOURCES

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Ishikawa, Kaoru, "Cause and Effect Diagram," Proceedings, International Conference on Quality Control, JUSE, Tokyo, 1969, pp. 607-610.

Ishikawa, Kaoru, "Industrial Engineering and Technology Guide to Quality Control,"Asian Productivity Organization, 1976, chapter 3, cause-and-effect diagram.

Check Sheets

Stop arm, horn, brakes and vacuum!

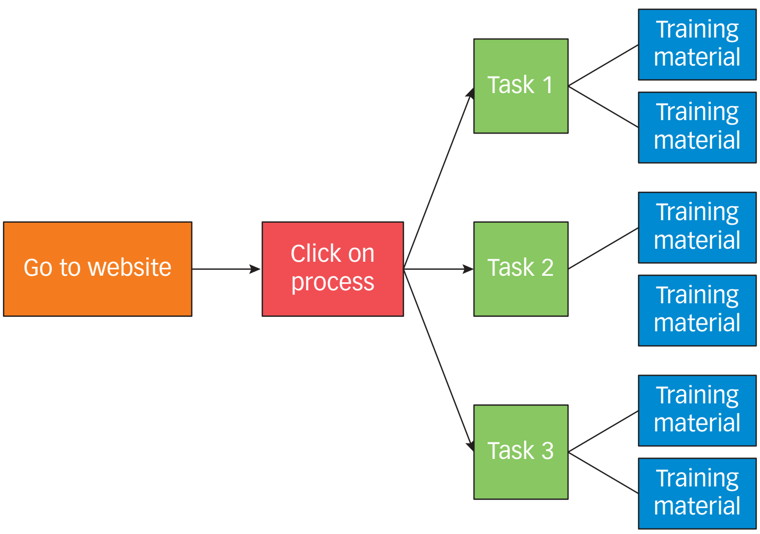
As a 16-year-old going through school bus driver training, this was a very important checklist. As simple as this seems, the instructor boiled down starting the bus route to these four import checks (see Figure 7). Yes, there were other inspections to be made. But when you sat down in that driver's seat, these were the last things that were to be done prior to moving the bus and starting the route. If any of these four items weren't working, the bus did not move, and the mechanic was to be called.

So what about the checklist, otherwise known as a check sheet? What role does this tool play in executing processes? Is there still relevance for such a simple tool in today's high-tech world? Here is a simple review of a quality tool with a very high return on investment.

School bus route start check sheet / FIGURE 7

Parameter check	Yes	No
1. Stop arm: Does the stop arm deploy and do the stop lights work?		
2. Horn: Does the horn sound when pressed?		
3. Brakes: Does the pedal stay off the floor when the brakes are pumped?		
4. Vacuum: With the stop arm out and the brake pedal depressed, does the vacuum gauge read the appropriate level?		

Automated check sheet / FIGURE 8



Memory jogger

Joseph M. Juran considered the check sheet a type of lesson learned. He likened the check sheet to a memory jogger, as a reminder of what to do and what not to do.[1] In environments in which repetitive activity is commonplace, the check sheet is a perfect tool to do just that: jog the memory to make sure processes are followed completely.

Making the connection between a memory jogger and a process is a logical role the check sheet can play.

Perhaps the strongest message ISO 9000:2008 delivers is that the reliance on memory is not the way business is conducted.

Historical uses

In case the phrase "check sheet" is a new term for you, here are a couple of points to consider. If you've ever made a grocery list, completed a form of some type or executed an inspection plan, you've used a check sheet.

From manufacturing to medicine, from the public domain to the private sector, check sheets have been used to ensure that what is to be accomplished is completed in a reproducible and repeatable fashion, opportunity after opportunity. Check sheets help drive consistency in execution on every occasion.

Uses and forms

Check sheets can be created by watching an individual do a series of tasks and jotting them down as they're performed. Check sheets can be created by breaking down a process into its critical tasks and capturing them in a work instruction.

Today's technology enables the user to go to a website, call up the process that is to be executed and easily access the process (check sheet) for the task that must be completed.

Figure 8 shows how automation can assist in developing and implementing a check sheet. As long as the individuals doing the tasks have access, they can get all the information they need to execute the process flawlessly. If needed, a simple click can give them access to training material for the elements of the check sheet.

Get started

Whether the opportunity is in manufacturing, quality inspections, medical or IT, check sheets are a helpful tool. Whether they are simple memory joggers or sophisticated applications, check sheets accomplish the same purpose: They help remind the person doing the tasks what must be done.

—Keith Wagoner

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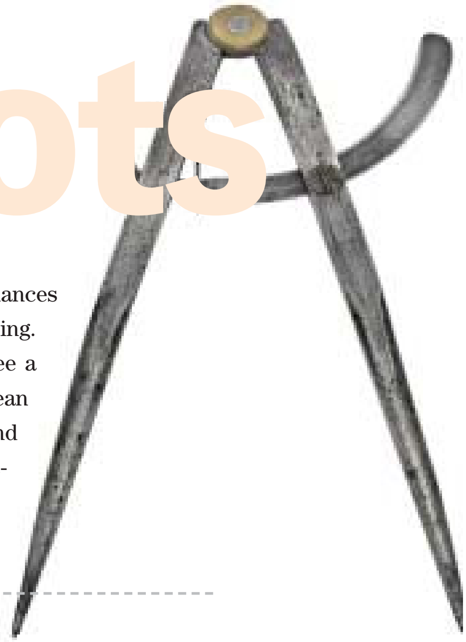
Scatter Plots

Scatter Plots



Plot the data. Is there a statistics professor anywhere on the planet who doesn't stress that? If you are investigating a potential relationship between two variables, then a scatter plot is the tool to use.

A scatter plot is a simple visual form of graphical analysis. Let's use a general example to flesh out its usefulness.

You are wondering if temperature at a point in your process is related to the number of defects you observe. Data from 20 lots have been collected and recorded in Table 2.

Using that data, you can set up a plot with the independent variable (temperature) on the x-axis and the dependent variable (number of defects in the lot) on the y-axis. You can plot the 20 observations in this example (or in any situation) on a piece of grid paper or by using a tool such as Excel.

Seeing is believing

In Excel, put the data in columns, highlight the temperature and defects columns, click the Chart Wizard icon, select XY Scatter and follow the menu prompts until you're finished. When the plot is complete, take a look at the result (Figure 9, p. 28).

Because this is meant to be a visual tool, believe your eyes. If there appears to be a pattern, such as a line or a curve, then you have a relationship. What do you see in the example? There seems to be pretty clear evidence there is a direct relationship between the two factors. If you need to look very hard for a pattern or find yourself wondering if one is there, chances are there isn't a relationship worth pursuing.

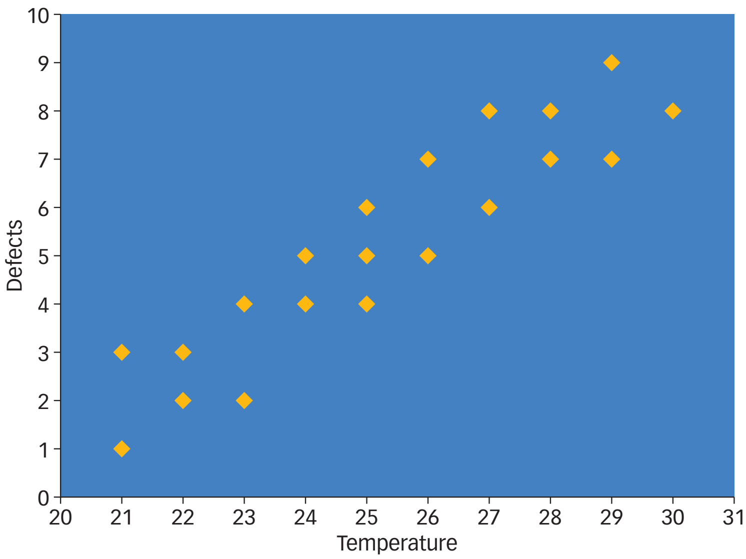
A few words of warning: You may see a relationship, but that does not always mean one variable drives the other (cause and effect). Both may be driven by a third factor. Just because your grass grows and your neighbor's grass grows at about the

Lot data / TABLE 2

Lot	Temperature	Defects
1	22	2
2	29	9
3	21	3
4	30	8
5	25	4
6	23	4
7	22	3
8	29	7
9	26	7
10	25	5
11	28	7
12	27	8
13	24	4
14	26	5
15	25	6
16	27	6
17	23	2
18	28	8
19	21	1
20	24	5

same rate doesn't mean one causes the other. They are both driven by other factors, such as the weather or fertilization practices. The indication of a relationship merely means additional investigation is worthwhile.

Defects vs. temperature / FIGURE 9



Next step

What do you do next? Talk with the process experts, search the literature and gather and plot more data. You may want to better define the relationship by using additional quality tools more advanced than the ones dealt with in this collection.

You can quantify a relationship by establishing a correlation coefficient. You also can create a predictive model of the relationship: It may be linear (for straight lines), quadratic (for curved lines) or some combination.

If you want to learn more, look up correlation coefficient, predictive model, linear relationship or quadratic relationship in Excel using the help function, in your favorite textbook or on the internet.

—Peter E. Pylipow

ADDITIONAL INFORMATION

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Stratification

Stratification

Stratification is a fancy word for a simple concept: breaking down data into categories so you can make sense of it. The concept is as old as rational thinking itself. For decades, giants of quality improvement, such as Walter Shewhart, W. Edwards Deming, Joseph M. Juran and Kaoru Ishikawa, have recommended its use.

To illustrate how handy it can be to have this tool in your arsenal, consider the following scenario:

Get a handle on the problem

An airline company was trying to understand its relatively high rate of baggage-handling errors. Someone asked whether there were certain time periods when the problem was worse or better. That way, the airline could pinpoint a time and investigate what may have been going on then.

The team stratified the data by week and produced a control chart of the weekly data, only to find random variation. Further stratification by day of the week and time of day also failed to pinpoint the problem.

The team asked whether it was possible that only certain airports accounted for the high error rate. To answer the question, it stratified the data by airport and whether it was the departure or arrival city. But, again, the team found nothing unusual.

Finally, someone came up with the theory that, because passengers were checking in earlier and earlier these days, the bags were being misplaced in storage areas while awaiting the arrival of the incoming aircraft. When the team stratified the data by time of check-in, they found that the majority of the errors had occurred on bags checked in more than three hours prior to departure.

Take your pick

The airline team stratified—broke down, categorized and separated—the data several ways during their exploration to get closer to the root cause of the problem. They could have stratified the numbers in many other ways: by weight or size of bag, by whether check-in was at curbside or the inside counter, by agent or by baggage handling crew at the departure site or destination airport.

In practice, there are always many ways to stratify data. Knowledge of the system and intuition are the best guides. A cause-effect diagram can also be used to guide this thinking.

Stratification is an underlying tool that is often used with the other six basic quality tools. In the early stages of this scenario, the airline team produced a control chart after stratifying the data by week to see if there were any abnormal weeks.

Check sheets often contain columns or rows to tally stratification information, such as time of day or operator. A Pareto diagram stratifies data by categories, such as cause or location. Histograms and scatter diagrams can also be used to display and compare the data after stratification.

Think ahead

The most important time to think about stratification is before you collect data. If the airline team had not collected the basic data involving time of check-in, they would not have been able to look at whether that was a factor in the baggage-handling problem without taking several months to collect the necessary data.

As a result, the team discovered what many quality professionals already know: A little bit of thinking and planning in the present will save you—and your customers—lots of headaches in the future. QP

—*Paul Plsek*

ADDITIONAL INFORMATION

Jack B. ReVelle, "All About Data," *Quality Progress*, www.asq.org/quality-progress/2006/01/problem-solving/all-about-data.html.

Authors

JAMES J. ROONEY is a senior risk and reliability engineer with ABS Consulting, Public Sector Division, in Knoxville, TN. He earned a master's degree in nuclear engineering from the University of Tennessee. Rooney is a fellow of ASQ and holds the following ASQ certifications: biomedical auditor, hazard analysis and critical control point auditor, manager of quality/organizational excellence, quality auditor, quality engineer, quality improvement associate, quality process analyst, quality technician, reliability engineer and Six Sigma Green Belt.

T.M. KUBIAK is an author and consultant in Weddington, NC. He is a co-author of The Certified Six Sigma Black Belt Handbook. *Kubiak, a senior member of ASQ, serves on many ASQ boards and is a past chair of ASQ's Publication Management Board.*

RUSS WESTCOTT is president of R.T. Westcott & Associates in Old Saybrook, CT. He is an ASQ fellow, a certified manager of quality/organizational excellence and a quality auditor. He is editor of the third edition of The CMQ/OE Handbook, *co-editor of* The Quality Improvement Handbook *and author of* Simplified Project Management for the Quality Professional *and* Stepping Up to ISO 9004:2000. *Westcott is also an instructor of the ASQ CMQ/OE refresher course.*

R. DAN REID, an ASQ fellow and certified quality engineer, is a purchasing manager at General Motors Powertrain. He is co-author of the three editions of QS-9000 and ISO/TS 16949; the Chrysler, Ford, GM Advanced Product Quality Planning With Control Plan; Production Part Approval Process and Potential Failure Modes and Effects Analysis *manuals; ISO 9001:2000; ISO IWA 1, and its replacement AIAG's new* Business Operating Systems for Health Care Organizations. *Reid also was the first delegation leader of the International Automotive Task Force.*

KEITH WAGONER is a senior service operations manager for Wachovia Bank in Charlotte, NC. He holds a bachelor's degree in liberal studies from State University of New York, Albany. He is a senior member of ASQ and a certified quality engineer.

PETER E. PYLIPOW is a senior design excellence engineer with Vistakon—Johnson and Johnson Vision Care Inc. He earned a master's degree in management engineering from Rensselaer Polytechnic Institute in Troy, NY. Pylipow is a senior member of ASQ and an ASQ certified quality manager, quality engineer and quality auditor.

PAUL PLSEK is president of Paul E. Plsek and Associates in Roswell, GA. He is a full-time consultant on improvement, innovation and change in complex systems. Plsek earned a master's in engineering from the Polytechnic Institute of New York in Brooklyn. He is a member of ASQ and an author whose books include Creativity, Innovation and Quality *(ASQ Quality Press) and* Quality Improvement Tools *(Juran Institute Publication).*