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(*b*. New Canton, Illinois, 18 March 1891; *d*. Troy Hills, New Jersey, 11 March 1967)

physics, research statistics.

Shewhart, the "father" of statistical quality control, was the son of Anton and Esta Barney Shewhart. He received an A.B. from the University of Illinois in 1913 and an A.M. in 1914. On 4 August 1914 he married Edna Hart. He received a Ph.D. in physics from the University of California in 1917, having been an assistant in physics (1914–1915) and a Whiting Fellow (1914–1916).

Following receipt of his doctorate, Shewhart was an assistant in physics at the University of Illinois (1916–1917), then head of the physics department at the Wisconsin Normal School in Lacrosse (1917–1918). The rest of his professional career was spent in the Bell System, initially with the Western Electric Company (1918–1924), then in the Bell Telephone Laboratories from their incorporation in 1925 until his retirement in 1956.

Sometime around 1920, the Western Electric Company, manufacturer of telephone equipment for the Bell Telephone System, learned from experience that repeated adjustment of a manufacturing process to compensate for observed departures from the process average can result in greater variability. (A mathematical explanation was provided by Preston C. Hammer in 1950.) On the other hand, a "large" deviation from, or a succession of values above (or, below), the process average may indicate a need for corrective action. An answer was needed to the question of how to distinguish situations that call for corrective action from situations in which the process should be left alone. The problem of finding an answer was handed to Shewhart. He devised (1924) a new statistical tool, known today as the control chart, that signals when search for a cause of variation, and removal of this cause, will indeed reduce variation; and when search for a cause of variation, accompanied by action on the system, will only intensify the variation.

A control chart is a graph showing repeated determinations of some characteristic of a production process plotted in chronological order, with a horizontal center line corresponding to the average value of the characteristic, and upper and lower control limits such that plotted points outside these limits will tend to indicate the presence of a cause (or causes) of variation in addition to the random variation inherent in the process. Points outside these action limits are deemed to signal the need for a special investigation of the process to identify the disturbing cause(s). The plot of observed or measured values in *chronological order* is the essential feature of a control chart; and it marked an important departure from traditional statistical practice, in which observed or measured values are lumped together without regard to their chronological order to form a sample for which measures of location (average, median, mode), measures of dispersion (average deviation, standard deviation, range), and so on are then evaluated.

During the 1920's, Shewhart published a series of articles in the *Bell System Technical Journal* on the construction, application, and usefulness of control charts of various kinds, culminating in his definitive exposition of statistical quality control, *Economic Control of Quality of Manufactured Product* (1931), in which he recognized two distinct causes of variation: (a) chance causes, producing random variation intrinsic to the process, and (b) assignable causes (now sometimes called special causes), the kind that one should search for, try to identify, and eliminate. He noted that when all assignable causes have been removed, the variation of the outputs of the process will be stable, the process will be in "a state of statistical control," and its variation cannot be further reduced. Hence, if less variation is desired, this can be attained only by introducing a new process. A control chart is thus a triple-valued statistical tool: (1) it serves to define the goal of process performance that management might strive to achieve; (2) it is an instrument for attaining this goal; and (3) it is a tool for judging whether the goal of statistical control has been attained.

For action limits separating when to look from when to not look for assignable causes, Shewhart recommended "three-sigma" control limits, that is, horizontal lines at distances 3σ above and below the center line, with σ being the standard deviation of the plotted values implied by the inherent random variation of the process under study. From experience with a wide range of industrial processes, he had found that 3σ limits provided an approximate economic balance between the costs of mistakenly signaling the presence of nonexistent assignable causes and the costs of failure to signal the presence of existent assignable causes. Adopted by the American Society for Testing Materials in its *1933 A.S.T.M. Manual on Presentation of Data*, and with the coming of World War II recommended also in the American Standards Association's American War Standards Z 1.1–1941, Z 1.2–1941, and Z 1.3–1942, 3σ limits became, and have largely remained, the standard practice in American industry.

In 1935 the British Standards Institution adopted Shewhart control chart techniques with two changes. First, instead of 3σ control limits, it recommended an outer pair of .001–probability action limits such that, when inherent chance causes alone are operative, the probability of a plotted point falling above the upper action limit (or below the lower action limit) would be .001. Second, it recommended an inner pair of .025–probability warning limits similarly determined, with the appearance of a succession of plotted values above the upper (or below the lower) inner limit to be taken as a warning, if not as a positive indication, of lack of control. The aim of the inner warning limits was to aid in identifying the onset of trouble.

Whereas the 3σ and .001–probability control limits are very nearly the same in the case of control charts for averages of successive sets of n (≥4) individual values, such is not the case for control charts for product variation, that is, charts for standard deviations or ranges of sets of n individual values, or for defects per unit area (or failures per unit time). The sampling distributions of these measures are skewed with the long “tail” to the right. Consequently, in these cases the upper 3σ limit will lie below the upper, 001–probability limit, so that the risk of looking for assignable causes of increased product variation (or increased rate of defects or failures) will be greater than .001 when no change has occurred. The situation will be the opposite in the case of the lower limits, but to a lesser degree. The net result of using 3σ limits will be an increased risk of looking for trouble when there is none, the actual increase depending on the degree of skewness.

Although the foregoing reasoning seems to favor the probability limits, Shewhart remained firm in support of 3σ limits on at least two grounds. First, as noted above, he had found from extensive experience that 3σ limits yielded an approximate economic balance between the costs of failure to notice real trouble when present, and the costs of crying, “Wolf! Wolf!” when there was no trouble. Second, 3σ limits are computationally defined and do not depend, as do probability limits, on the assumed mathematical form of the random variation of product characteristics (or on the assumed mathematical form of the sampling distributions of standard deviations, ranges, and so on, evaluated from small sets of measurements).

Instead of inner warning limits, Shewhart (1941) recommended looking for warnings in nonrandom patterns of the plotted points: a “long run” of, say, seven or more consecutive points above (or below) the center line would suggest the possibility of a shift up (down) of average performance; a “long run up” (“down”) of, say, seven or more consecutive increases (decreases) would suggest the onset of a trend; and when there are no significantly long runs above or below the center line (or up or down), if, nonetheless, the total number (N) of runs above and below (or up and down) is exceptionally small (say $N \leq N_{.005}$), or excessively large (say, $N \geq N_{.995}$), or there are a great many short runs above and below (or up and down), these departures from randomness may be indicative of erratic or oscillatory behavior calling for investigation.

As Shewhart stressed (1939, Chap. 2), bringing a production process into a state of statistical control and keeping it in control (or restoring it to control) are necessary for prediction of performance of future product. Without statistical control, such prediction is not logically possible. For a production process that has been in control for a substantial period, he showed (*ibid.*), with the aid of empirical sampling experiments, how to construct prediction limits bounding a statistical tolerance range (or interval) within which a prescribed percentage of future product performance may be expected to fall as long as the process remains in control; he emphasized that such statistical tolerance intervals (limits) differ markedly from the statistician’s confidence intervals (limits). Others promptly provided mathematical theory and tables for determining statistical tolerance limits of various kinds.

Whereas Shewhart’s early writings and first book (1931) were focused on statistical control of industrial production processes, in his second book (1939) he extended the applications of statistical process control to the measurement processes of science, and stressed the importance of operational definitions of basic quantities in science, industry, and commerce.

In 1950, W. Edwards Deming, at the request of the Union of Japanese Scientists and Engineers, give a series of lectures in Japan on Shewhart’s statistical quality control of industrial processes. These lectures were the catalyst that gave birth to Japan’s industrial efficiency and emphasis on highest attainable quality of manufactured products.

Shewhart was a founding member and fellow of the Institute of Mathematical Statistics (president, 1937, 1944); founding member of the American Society for Quality Control (first honorary member, 1947; first Shewhart Medalist, 1948); a fellow of the American Statistical Association (president, 1945), International Statistical Institute, Royal Statistical Society (honorary fellow, 1954), Econometric Society, Royal Economic Society, American Association for the Advancement of Science (Council member, 1942–1949), and New York Academy of Science; and a member of the American Mathematical Society, Mathematical Association of America, American Physical Society, American Society for Testing Materials, Psychometric Society, Acoustical Society of America, Philosophy of Science Association, and Association for Symbolic Logic. In 1954, Shewhart was awarded the Holley Medal by the American Society of Mechanical Engineers, and in 1962 he received an honorary doctorate from the Indian Statistical Institute of Calcutta.

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his ideas and procedures to the attention of users of statistical methods. For a fuller appreciation of Shewhart's greatness, see his "Nature and Origin of Standards of Quality," in *Bell System Technical Journal*, **37** (1958), 1–22, written in 1935.

During the 1920's and early 1930's, Shewhart wrote a series of papers that reveal the evolution of his thinking and methods that jelled in his 1931 book: "On the Measurement of a Physical Quantity Whose Magnitude Is Influenced by Primary Causes Beyond the Control of the Observer and on the Method of Determining the Relation Between Two Such Quantities," in *Proceedings of the National Academy of Sciences*, **8** (1922), 248-251; "Some Applications of Statistical Methods to the Analysis of Physical and Engineering Data," in *Bell System Technical Journal*, **3** (1924), 43–87; "The Application of Statistics as an Aid in Maintaining Quality of a Manufactured Product," in *Journal of the American Statistical Association*, **20** (1925), 546–548; "Correction of Data for Errors of Measurement," in *Bell System Technical Journal*, **5** (1926), 11–26; "Correction of Data for Errors of Averages Obtained from Small Samples," *ibid*., 308–319; "Finding Causes of Quality Variations," in *Manufacturing Industries*, **11** , no. 2 (1926), 125–128; "Quality Control Charts," in *Bell System Technical Journal*, **5** (1926), 593–603: "Quality Control." *ibid*., **6** (1927), 722–735: "Economic Aspects of Engineering Applications of Statistical Methods," in *Journal of the Franklin Institute*, **205** (1928), 395–405; "Note on the Probability Associated with the Error of a Single Observation," in *Journal of Forestry*, **26** (1928), 600–607; "Small Samples: New Experimental Results," in *Journal of the American Statistical Association*, **23** (1928), 144–153, written with F. W. Winters; "Significance of an Observed Range," in *Journal of Forestry*, **26** (1928), 899–905; "Basis for Analysis of Test Results of Die-Casting Alloy Investigation," in *American Society for Testing Materials, Proceedings*, **29** (1929), 200–210: "Economic Quality Control of Manufactured Product," in *Bell System Technical Journal*, **9** (1930), 364–389; "Applications of Statistical Method in Engineering," in *Journal of the American Statistical Association*, **26** (1931). March supp., 214–221; "Random Sampling," in *American Mathematical Monthly*, **38** (1931), 245–270; and "Statistical Method from an Engineering Viewpoint," in *Journal of the American Statistical Association*, **26** (1931), 262–269.

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II. Secondary Literature. W. Edwards Deming. "Walter A. Shewhart, 1891–1967," in *Review of the International Statistical Institute*, **36** (1968), 372–375, a slightly abridged version of which appeared in *The American Statistician*, **21** , no. 2 (1967), 39–40, and "Shewhart. Walter A.," in *International Encyclopedia of Statistics*, II (New York, 1978), 942–944; Harold F. Dodge, obituary in *International Quality Control*, **23** (1967), 529; and L. H. C, Tippett, obituary in *Journal of the Royal Statistical Society*, **A130** , pt. 4 (1967), 593–594.

Seven articles on Shewhart and his impact on industrial production and quality control in *Industrial Quality Control*, **24** (1967) are rich sources of further information, insight, and perspective: "The First Shewhart Control Chart" (a facsimile of the chart and memorandum of transmittal dated 16 May 1924), 72; Paul S. Olmsted, "Our Debt to Walter Shewhart," 73; "The Shewhart Medal," 74; E. S. Pearson, "Some Notes on W. A. Shewhart's Influence on Application of Statistical Methods in Great Britain," 81–83; William A. Golomski, "Walter A. Shew-hart, Man of Quality: His Work, Our Challenge," 83–85; "Highlights in the Life of Walter A. Shewhart," 109–110; "Tributes to Walter A. Shewhart." 111–122. A brief letter from Edna Shewhart and two more tributes are in *ibid*., 332–333. See also Lloyd S. Nelson, "The Legacy of Walter Shewhart," in *Quality Progress*, **12** , no. 7 (1979), 26–28; and "Walter A. Shewhart. Father of Statistical Quality Control," *ibid*., **19** , no. 1 (1986), 50–51.

For the background, philosophical basis, intent, and early history of Shewhart's control chart, see M. D. Fagen, ed., *A History of Engineering and Science in the Bell System* (New York, 1975), chap. 9, esp. sec. 5, which includes a facsimile of the first chart and accompanying memorandum (Fig. 9-6, p. 879).

See also American Society for Testing Materials. *1933 A.S.T.M. Manual on Presentation of Data* (Philadelphia, 1933; 4th rev., 1976); American Standards Association. *Guide for Quality Control*, American War Standard Z1.l–1941 (New York, 1941; also ANSI/ASQC Standard Z1.1–1985), *Control Chart Method of Analyzing Data*, American War Standard Z1.2–1941 (New York, 1941; also ANSI/ASQC Standard Z1.2–1985), and *Control Chart Method for Controlling Quality During Production*, American War Standard Zl.3–1942 (New York, 1942; also ANSI/ASQC Standard Zl.3–1985); Preston C. Hammer. "Interference with a Controlled Process," in *Journal of the American Statistical Association*, **45** (1950), 249–256; and E. S. Pearson, *The Application of Statistical Methods to Industrial Standardization and Quality Control* (London, 1935).

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