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W. J. YOUDEN, 1900–1971

BY CHURCHILL EISENHART AND JOAN R. ROSENBLATT

National Bureau of Standards

William John Youden died suddenly from a heart attack on Wednesday, March 31, 1971, in Washington, D.C. His contributions to statistics, appearing in a steady stream since 1937, included the origination of new families of experiment designs and new techniques of statistical analysis, innovations in the application of experiment designs and statistical techniques in the experimental sciences and engineering, and "missionary work" in acquainting scientists and engineers with the effective use of modern tools of statistical design and experiment analysis.

Born in Australia in 1900, Youden came to America in 1907. He was educated at the University of Rochester (B.S., chemical engineering) and Columbia University (M.A. and Ph. D., chemistry). From 1924 to 1948 he was on the staff of the Boyce Thompson Institute for Plant Research in Yonkers, New York, except for two short leaves of absence and one three-year stint as an operations analyst with the U.S. Army Air Force. In 1948, Youden joined the Applied Mathematics Division of the National Bureau of Standards. In 1965 he retired from full-time employment, but stayed on at NBS as a Guest Worker, a post he still held at the time of his death. A more detailed biography has been published in the *American Statistician* [1]; a biography and a complete list of Youden's publications are to appear in a memorial issue of the *Journal of Quality Technology* [2]. A summary of his contributions to statistics follows.

1. New families of experiment designs.

Youden squares. The formulation of the statistical principles of the design of experiments and the initial development of a number of distinct classes of experiment designs were inspired largely by the needs of agricultural field experiments. The first decade of this work stemmed from R. A. Fisher and his co-worker Frank Yates, at the Rothamsted Experiment Station in England. One of the first "outside" contributions came early in 1937, when Youden, then with the Boyce Thompson Institute for Plant Research, published a paper on "Use of incomplete block replications in estimating tobacco mosaic virus" [4], in which he gave examples and illustrated the application of a new class of symmetrical balanced incomplete block designs that possessed the characteristic "double control" of Latin square designs, without the restriction that the number of replications must equal the number of treatments.

In an earlier ". . . statistical study of the local lesion method for estimating tobacco-mosaic virus" [3], Youden had found Latin square arrangement of the solutions under test to be advantageous: individual plants were identified with the *columns* of a Latin square, leaf positions corresponded to the *rows*, and the respective solutions under test were identified with the *letters*; but "the size of the square, and consequently the number of solutions tested simultaneously, was limited since only five or six suitable leaves are found on a plant". In his 1937 paper Youden showed that by means of his new rectangular designs it was possible to correct completely for the influence of leaf position, and make allowances for plant differences, while the number of test solutions that could be compared simultaneously could be increased to 7, using only 3 leaves; to 13, with 4 leaves, to 21, with 5 leaves; and to 31, using plants with 6 suitable leaves.

Termed "Youden Squares" by Fisher and Yates [23], Youden's new experiment designs were found immediately to be of broad utility in biological and medical research generally; and applicable but of less value in agricultural field trials. With the coming of World War II they proved of value in scientific and engineering experimentation connected with the research and development activities of the war effort: motor vehicles were identified with the columns, wheel positions with the rows; or motor-vehicle or aircraft engines with the columns, cylinder positions with the rows; and so forth. In the meanwhile the basic mathematical theory of the constructibility and construction of Youden Squares had been developed (by Yates, H. O. Hartley, R. C. Bose, and others) to the point where it was recognized that whereas a Youden Square is always a Latin square from which one or more rows (or columns or diagonals) are missing, the converse is not always true; because when more than one row is removed from a Latin square the remainder may not constitute a symmetrical balanced incomplete block design.

Linked blocks and chain blocks. After joining the National Bureau of Standards in 1948, Youden originated a number of additional new families of experiment designs. First came his *linked blocks* [6] and *chain blocks* [7], developed to take advantage of some of the special circumstances of spectrographic determinations of chemical elements carried out by the comparison of spectrum lines recorded on photographic plates. Linked block designs are incomplete block designs having the property that any two blocks have exactly the same number l of treatments in common. (Thus they must be duals of balanced incomplete block designs with each treatment pair occurring in $\lambda = l$ blocks.) Bose [17], in a note on the existence and construction of connected partially balanced incomplete block (PBIB) designs with two associate classes and $r = 2$ replications, showed that some of Youden's linked blocks ($l = 1$) comprised one of three subclasses of these designs. But Youden's linked block designs were invented to meet experimenters' needs, not defined according to combinatorial principles: e.g., for $r = 3$, he had devised four more, which also turn out to be PBIB designs with two associate classes but three different combinatorial types [20].

Chain block designs were developed for situations in which the number of treatments considerably exceeds the block size while, within blocks, comparisons are of such high precision that at most two replications are needed, some treatments being replicated only once. Mandel [24] continued the development of the chain block designs, providing a scheme for two-way elimination of heterogeneity.

Partially replicated Latin squares. Next Youden, in conjunction with J. S. Hunter, originated a class of designs which they termed partially replicated Latin squares [10]. They described the need for these designs as follows: "Probably it was inevitable that the Latin square arrangement would be tried when the rows and columns were used for factors that not only were likely to interact with the treatments (letters) but also with each other. The form or appearance of a Latin square remains, but the substance is lost. The fractional replication of a factorial experiment that results from this practice is a particularly unfortunate one as all main effects are directly confounded with two-factor interactions and the residual . . . [this] becomes a snare for the unwary . . . and will continue to trap novices in . . . experiment design. For this reason there may be some advantage in making available a slight extension of the Latin square that will give an indication as to whether or not the usual requirement of additive effects for rows, columns and treatments has been met."

Calibration designs. Youden and his co-worker W. S. Connor began, in 1952, to exploit a special class of partially balanced incomplete block designs having block size two [8], in the thermometer and meter-bar calibration programs of the NBS. The thermometer-calibration application involves observation of the reading of *each* of the two thermometers comprising a "block," but the meter-bar application [25] involved observation of only the *difference* of the lengths of the two meter bars comprising a block, and marked the start of the development of a system of *calibration designs* which Youden did not develop further and exploit as a special sub-class until 1962 [14]. Since then the mathematics of the constructibility and construction of this new class of designs has been developed further by R. C. Bose and J. M. Cameron [18], [19] and these designs are being applied extensively by Cameron in various calibration programs of the NBS, in collaboration with persons directly associated with these programs [22].

Constrained randomization. In a Special Invited Address [11] at the Detroit meeting of the Institute of Mathematical Statistics on September 8, 1956, Youden referred "to the difficult position of the statistician who rules against . . . a systematic sequence when advanced on the grounds of convenience and insists on it when it pops out of a hat," and introduced a technique for constrained randomization. He employed experiment design concepts to select, from the set of all ordered sequences of pairs of treatments, a subset excluding "undesirable" sequences such as aabbcc . . . while preserving uniform distribution of the pairs of positions available for treatment and error contrasts.

2. New techniques of statistical analysis. Although Youden's contributions to science and scientific method lie principally in the area of experiment design and applications of standard and novel designs in the biological, physical and engineering sciences, he was also the originator of at least three new statistical techniques: an *index for rating diagnostic tests* [5], the *two-sample chart* for "Graphical diagnosis of interlaboratory test results" [12], and an *extreme rank sum test for outliers*, devised for the purpose of testing the statistical significance of outlier laboratories in interlaboratory collaborative tests [15].

Both the two-sample chart and the extreme rank sum test were devised by Youden to meet specific needs for improved techniques that arose in connection with the NBS participation in a nation-wide collaborative program of cement-testing laboratories. They have since been incorporated in various other interlaboratory studies of test methods for properties of materials. The two-sample chart has the same advantageous features (simplicity of construction, visual pinpointing of trouble spots, and comparative ease of more refined analysis) as Shewhart's control chart. Although born in the setting of test methods for properties of materials, the Youden two-sample chart has become a standard tool of the National Conference of Standards Laboratories in its nation-wide program of searching for and rectifying systematic differences among the nation's most accurate instrument calibration programs. (See, for example, [26] pages 19–20, 27–29, 42, 52, 58, 51, and 61–62.)

In the case of the extreme rank sum test, Youden's ideas had been anticipated by Doornbos and Prins [21]. It was characteristic of Youden, however, that his extreme rank sum test was conceived primarily as a device for dramatizing and illuminating the messages contained in experimental results, rather than as a contribution to distribution-free statistical methods.

3. Innovative applications of statistical methods. Youden was one of the first to recognize and to capitalize on important differences between experimentation in the biological and agricultural sciences on the one hand, and in the physical and chemical sciences on the other. Of paramount importance, he noted, is the difference in the magnitude of the errors of measurement in the two areas. In agricultural and biological experimentation unavoidable variation is likely to be large, so the classical designs compensate by incorporating many determinations of the quantities of principal interest. Physical measurements, in contrast, can often be made with high precision; the experimental material is usually comparatively homogeneous so that quantities of interest can often be determined with acceptably small standard errors from as few as two or three, or even from only a single indirect determination. Furthermore, he noted and took advantage of the characteristic of many experimental situations in the physical sciences that a "block" and the "plots" within a block are sharply and naturally defined; and the block, at least, and sometimes also the plots, are quite distinct one from another. These considerations led to his effective use of fractional factorial designs and to many clever schemes for deliberately including a few extra observations in an experiment plan in order to accomplish more than one objective at little if any additional cost [9], [13].

4. Youden's contributions to science. By his publications and by his example, Youden contributed significantly to the achievement of objectivity in experimentation and in the setting of more exacting standards for drawing scientific conclusions. His last major address, as retiring President of the Philosophical Society of Washington in 1968, was devoted to exposition of schemes for incorporating investigations of systematic errors into experimental determinations of fundamental physical constants. This plea for explicit efforts by scientists to accumulate objective evidence for the description of the precision and accuracy of their work was entitled "Enduring Values" [16].

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