On Reading Youden: Learning about the Practice of Statistics and Applied Statistical Research from a Master Applied Statistician

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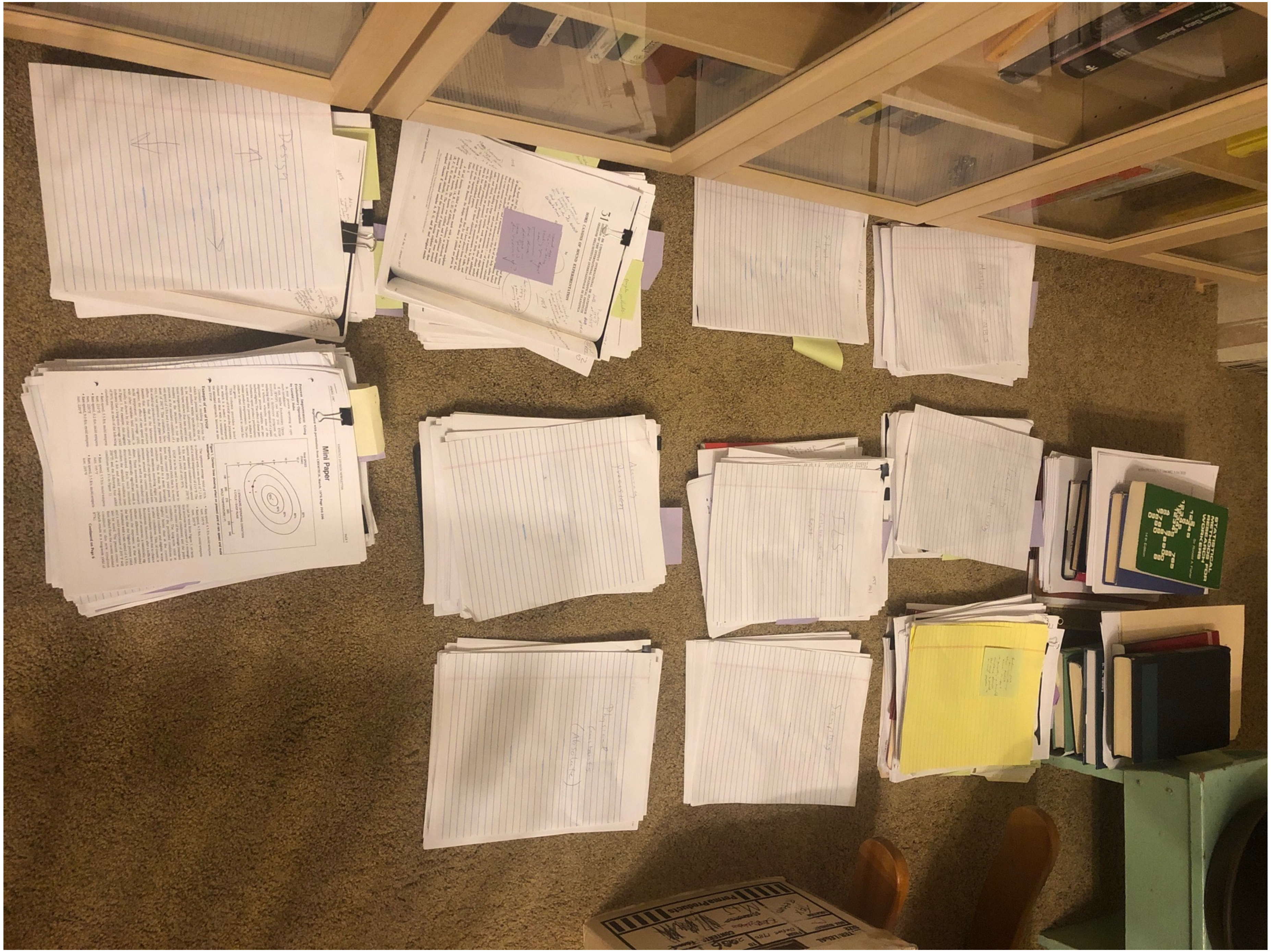
Youden

- 5 books
- 110+ papers
- 6+ obits/bios
- Youden addresses

Books
B-year

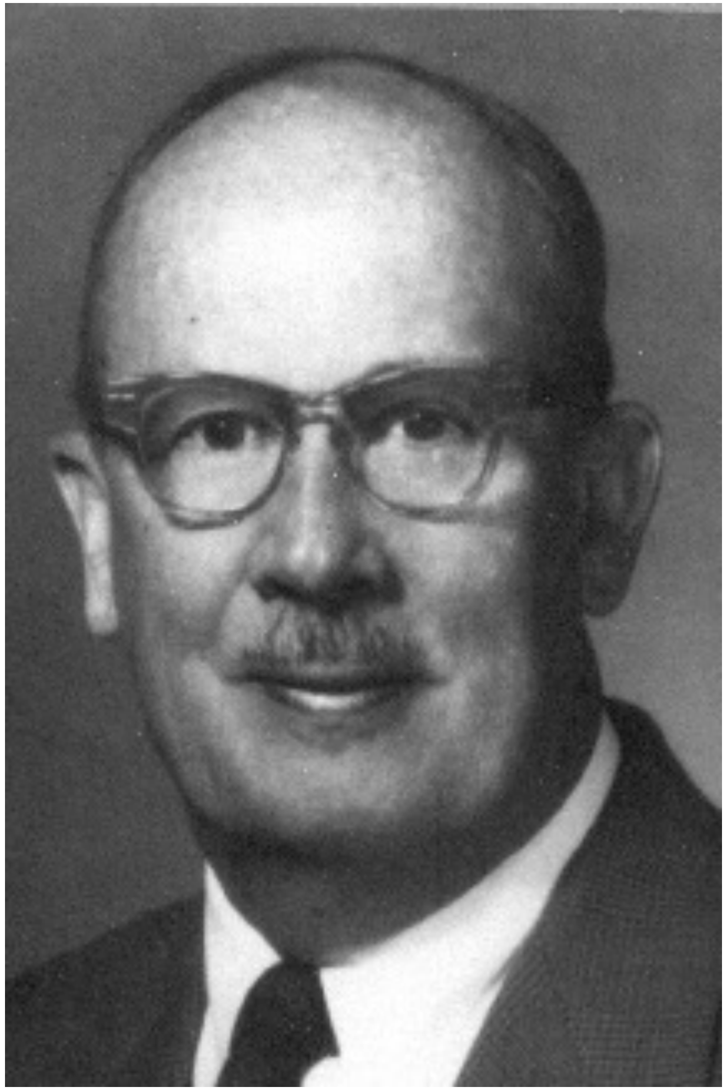
B1960#1-36
(Statistical Design
columns) in
Natrella 1972
bibliography

Papers
P-year-letter
(e.g., P1961c)
from
Joiner and
Wampler 1972
bibliography



Fisher 1925

William John (Jack) Youden, 1900-1971



Outline

- When did Youden become a statistician?
- What can we learn about the practice of statistics?
- What can we learn about applied statistical research?
- Youden: master applied statistician

Experimentation and measurement are intertwined throughout!

Outline

- **When did Youden become a statistician?**
- What can we learn about the practice of statistics?
- What can we learn about applied statistical research?
- Youden: master applied statistician

When Did Youden Become a Statistician?

- PhD, Analytical Chemistry (1924) (Also BS, Chemical Engineering)
- Boyce Thompson Institute (BTI) for Plant Research (1924-1947)
  - US Eighth Army Air Force operations analysis group (1942-1945)
- National Bureau of Standards (NBS) (1948-1965)

When Did Youden Become a Statistician? from life events

- 1924 PhD, Analytical Chemistry, developed a zirconium determination method, precise measurements
- 1924-1947 Boyce Thompson Institute (BTI) for Plant Research
  - Frustrated by existing “analyses” of highly variable biological experimental data (no yardstick for comparisons)
  - 1925 finds Student’s 1908 paper – offers a glimmer a hope
  - 1928 obtains Fisher’s 1925 *Statistical Methods for Research Workers*
    - ANOVA – a statistical yardstick
    - Randomized Block and Latin Square designs (last 9 pages!)
- 1931 takes Hotelling’s mathematical statistics course at Columbia
- 1931 meets Fisher who is visiting Cornell University to show him a design
- 1935 Fisher’s *The Design of Experiments* (expands on Fisher 1925 plus factorial designs)
- 1937-1938 sabbatical with Fisher at Galton Laboratory, University College
- 1941 Gertrude Cox’s design of experiments summer course at NC State College

When Did Youden Become a Statistician? from his pre-NBS publications

- ~24 publications before joining NBS in 1948
- P1931b uses an experimental plan that eliminates a source of error and eliminates another source by differencing the measurements
- P1931c uses $\sigma^2_{observed} = \sigma^2_{population} + \sigma^2_{measurement}$ (Shewhart 1926), understands impact of measurement error on data and presents results as a graphical nomogram
- P1932 uses chi-square goodness-of-fit test for binomial counts and cites 3:1 rule for minimum ratio of population to measurement error variances
- P1934, P1936a uses Latin Square designs and ANOVA (and treatment sum of squares as contrasts)
- P1937a, P1940b invents Youden Square design
- P1937b, 1940a uses incomplete block designs and Latin Square designs
- P1941 uses multiple regression
- Eighth Army Air Force operations analysis group (1942-1945)
    - Takes multiple small samples of large data sets and analyzes them (Miser 1992)
    - P1956 analyses experiment after recognizing it used a Latin Square design – the most expensive Latin Square (4 targets, 4 planes, 4 plane positions in formation)
    - Presents results graphically to operational bombers as bombing charts

When Did Youden Become a Statistician? From his Pre-NBS talk and publications

- T1947, P1947, P1948 (BTI)
  - Makes case for the statistical design of experiments for the physical sciences
  - Advocates for better experimental plans
  - Uses ANOVA (and contrasts) to show how much can be learned from a small amount of data
  - Discusses interlaboratory studies (recognizes between and within lab variation) and hints at the graphical Youden Plot (P1959a)
- Youden becomes an applied statistician by the time he joins NBS in 1948.
- Youden begins to advocate as a statistical missionary to scientists and engineers.

Outline

- When did Youden become a statistician?
- **What can we learn about the practice of statistics?**
- What can we learn about applied statistical research?
- Youden: master applied statistician

What Can We Learn About the Practice of Statistics?

- Applies statistical thinking to improve existing practices
- Advocates for something new to the client – using statistical design of experiments ideas and methods
- Teaches by connecting with something that the client is familiar with
- Clearly explains results to the client, e.g., graphical methods

What Can We Learn About the Practice of Statistics?

applies statistical thinking to improve existing practices

- Improving existing practices of using measurements
  - P1949a chemist takes duplicate, then a third replicate if one is suspect and reports the average of the two closest ("best 2 out of 3")
    - Uses 400 sets of random normals to show how often and far the "outlier" can be
    - States "best 2 out of 3" average is less precise than duplicate average
  - B1951 warns not to round measurements (significant digits) especially to assess precision
  - P1947 advises regression slope estimate better than average of X/Y ratios in calibration (X,Y)=(amount, measurement)

It's hard to detect an outlier.

- P1961i uses permutation distributions
  - Computing chance that a third result will lie between the first two results
  - Computing chance that the first two results bracket the "correct" result
  - Comparing two treatments with BBBAABAAA observed ordering

related to ("best 2 out of 3")

- Dispels misinterpretations with hypothesis testing and confidence intervals B1960#27
  - "The statement does not imply that if one set of measurements yields the interval (a,b), there is a 95% chance for the average of another set to fall in that interval."

What Can We Learn About the Practice of Statistics?
advocates for something new to the client

- Using statistical design of experiments

Using Statistical Design of Experiments

- T1947 refutes “statisticians can be of no help without a vast amount data” and shows that careful experiment planning to meet project’s needs
- T1947 refutes by an example that 1) statisticians can be of no help without a vast amount data (2) valuable information on precision and accuracy can be obtained without making many measurements on a single magnitude (amount) (3) from routine work, useful information on auxiliary information (sources of error) can be obtained at little or no additional cost by careful planning (design)
- 16 runs, compare 2 operators and assess intercept (accuracy) and regression slope (volume to reading relation) as well as common measurement precision

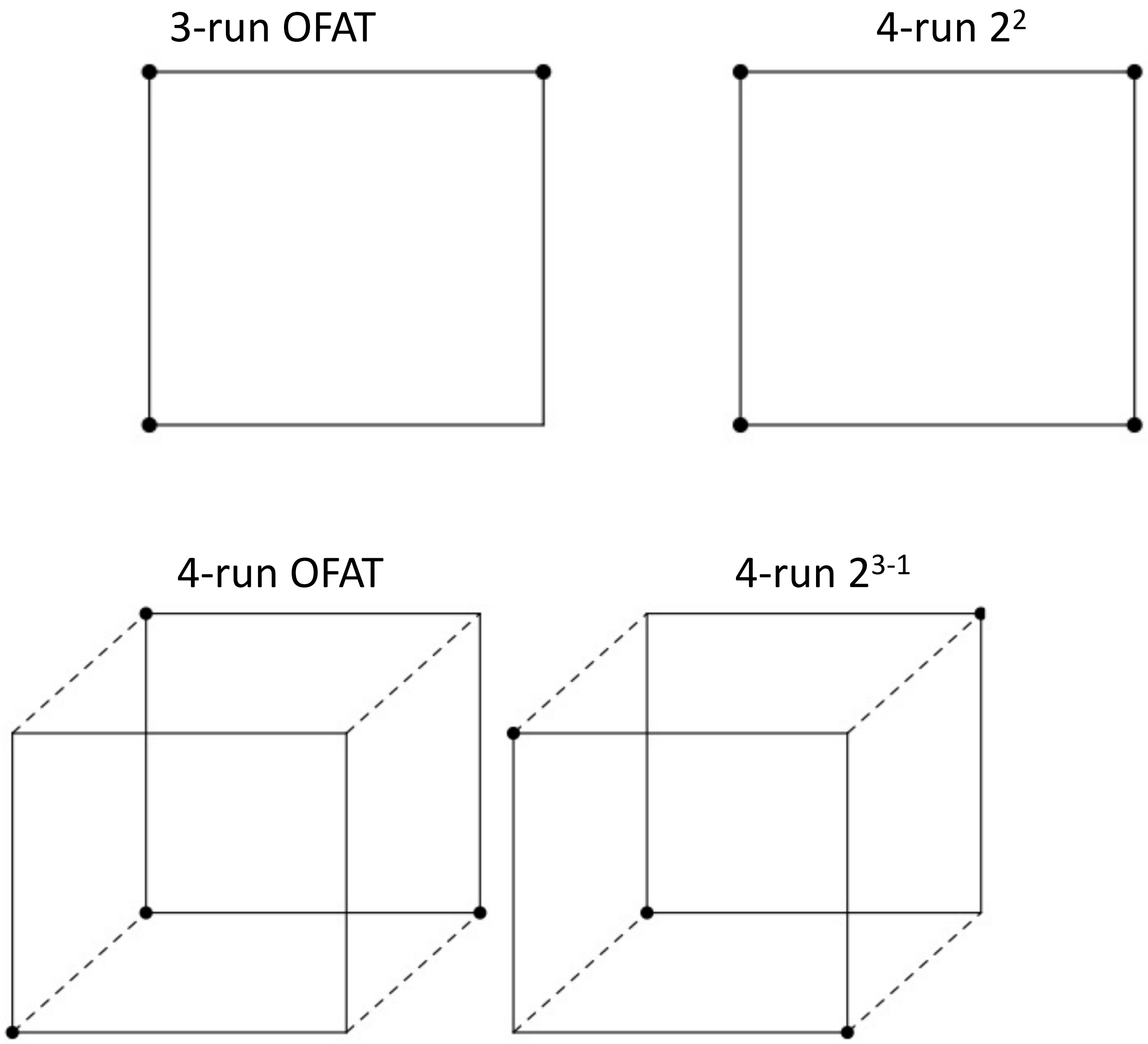
TABLE 3. — Youden’s Burette Experiment

A 50 ml. burette was filled to the zero mark with a sulphate solution and the following samples drawn from the burette :

Sample	Burette Readings Initial	Burette Readings Final	Sample Volume (ml)	Operator making Analysis	Wt. of $BaSO_4$ (mg)
A	0.00	9.00	9.00	K	41.8
B	9.00	25.00	16.00	K	77.4
C	25.00	35.00	10.00	Y	46.7
D	35.00	50.00	15.00	Y	70.2
Burette refilled					
E	0.00	11.00	11.00	Y	50.6
F	11.00	25.00	14.00	Y	66.7
G	25.00	37.00	12.00	K	56.9
H	37.00	50.00	13.00	K	63.1

Using Statistical Design of Experiments: Efficiency, Generalizability

- Advocates for factorial experiments being superior to one-factor-at-a-time (OFAT) experiments B1960#2
- 2 factors, 3-run OFAT versus 4-run 2^2
  - 2^2 – halves main effect estimate variance
  - 2^2 – assesses two-factor interaction
- 3 factors, 4-run OFAT versus 4-run 2^{3-1}
  - 2^{3-1} – halves main effect estimate variance



Using Statistical Design of Experiments

- Emphasizes choosing correct experimental unit B1951
- Advises basis for error needs to be same as basis for comparisons B1951
  - Error based on chemistry duplicates run in parallel on the same day not the right yardstick if measurements on treatments are collected on different days
  - If error estimate too small, falsely detect differences in comparisons, etc.

What Can We Learn About the Practice of Statistics?
teaches by connecting with something the client is familiar with

- In statistical design of experiments, introduces “composite” reference versus client’s standard reference

Balanced Incomplete Block Designs (BIBDs)

- Compare 7 thermometers (A-G) in BIBD block (Run) size 3 B1951
- Standard practice in chemistry: use reference R in each block of size 2 – for 3 replicates of A, B, … requires 21 blocks and 21 replicates of reference R

R	R	R	R	R	R	R
A	B	C	D	E	F	G

- BIBD superior
- One of A-G could be reference thermometer R in BIBD

experiment to calibrate thermometers

TABLE 53. SELECTION OF THERMOMETERS FOR RUNS

Order of Reading	Run No. 1	2	3	4	5	6	7
I	*A*	*B*	*C*	*D*	*E*	*F*	*G*
II	*B*	*D*	*F*	*E*	*G*	*A*	*C*
III	*C*	*F*	*E*	*A*	*B*	*G*	*D*

Motivating Analysis of BIBDs

- Direct comparison, e.g., A and B within Run 1
- Indirect comparison, e.g., A and B using Runs 2 and 6 with F in common
- For thermometer C correction *c* of nominal temperature *T* and Run offset *x*: $T + x + c$
- From Run 1:
  - 2($T + x + c$)-($T + x + a$)-($T + x + b$) = $2c - (a + b) = c_1$
- Shows comparison of thermometer corrections to a "composite" reference

Run 1	$\mathbf{2}c - (a + b) = c_1$
Run 3	$2c - (e + f) = c_3$
Run 7	$2c - (d + g) = c_7$
Run 0	$c - c = 0$
	$7c - (a + b + c + d + e + f + g) = c_1 + c_3 + c_7$
	$c - average\ correction = \frac{1}{7}(c_1 + c_3 + c_7) = \bar{c}$

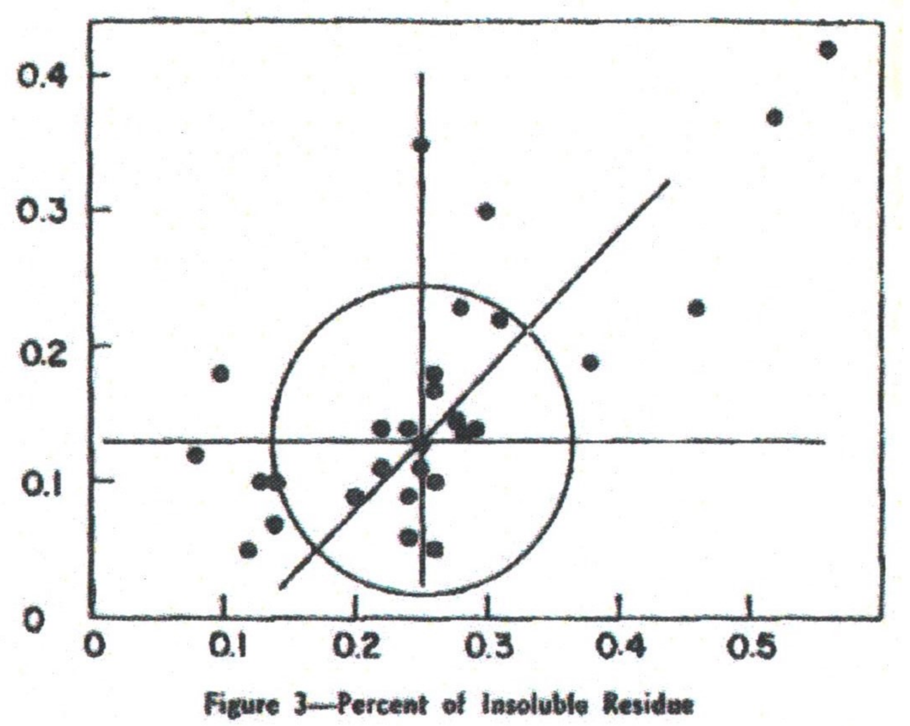
What Can We Learn About the Practice of Statistics?
clearly explains results to the client

- Clearly explains results to the client using graphical methods

Youden Plot

- Interlaboratory Studies (ILS): is a measurement method ready (reproducible) for widespread use?
- A large number of labs measure pairs of similar materials (or smaller number of labs replicating measurements of pairs of similar materials)
- Youden Plot – two dimensional plot of the pairs (X, Y)
  - P1959b (and other articles)

~ 29 labs



P1959b

Youden Plot

ANOVA will show that the labs (accuracies) are different – what is already expected!

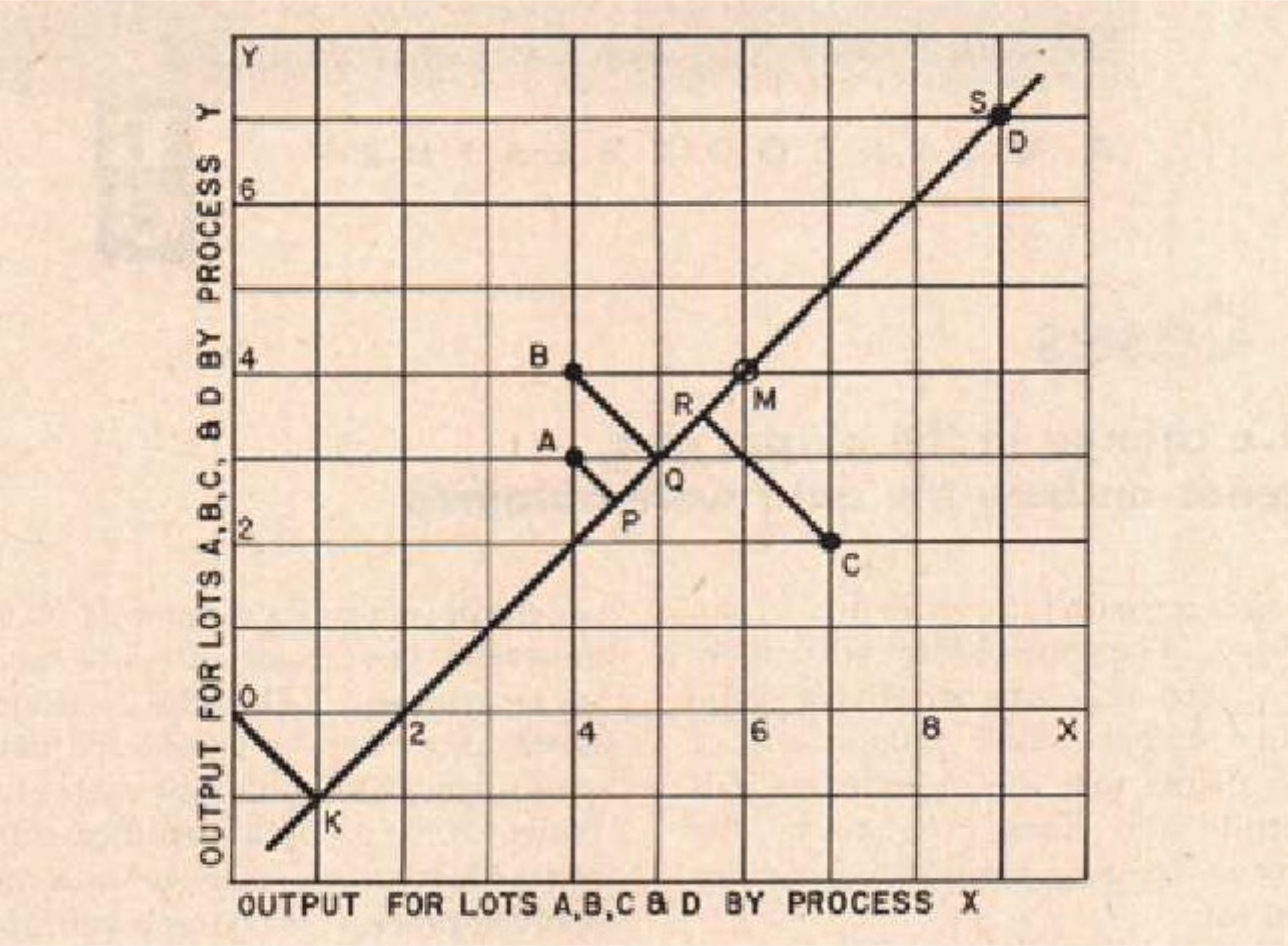
- Graphical assessment reveals more than ANOVA P1959b
- Provides interpretations for different observed patterns
    - Sloppy lab
    - A lab acting on its own
    - Method’s instructions needs improvement
    - Method is not acceptable and needs improvement
- May be able to refute criticism of lack of uniformity of the samples based on observed patterns

Explains ANOVA Graphically

- B1960#30 ANOVA for an experiment like ILS ANOVA for Youden Plot – Lot, Treatment, Error Sum of Squares
- Lot Sum of Squares – distances of projections along 45^o line
- Treatment Sum of Squares – distance O-K between 2 treatments (processes X & Y)
- Error Sum of Squares as perpendicular distances to 45^o line

Lot No.	Process Output X	Process Output Y
A	4	3
B	4	4
C	7	2
D	9	7
Av.	6	4

Grouping	Sum of Squares	D.F.
Lots	25	3
Processes	8	1
Error	7	3
Total	40	7



Graphical Display of Designs

- B1951

- 2^4 Full Factorial Design
  - 4 factors A-D
  - 16 runs

	B_0				B_1			
	C_0		C_1		C_0		C_1	
	D_0	D_1	D_0	D_1	D_0	D_1	D_0	D_1
A_0	(1) *	d	c	cd *	b	bd *	bc *	bcd
A_1	a	ad *	ac *	acd	ab *	abd	abc	$abcd$ *

2^{6-1} Fractional Factorial Design

- 6 factors A-F
- 32 runs, half fraction
- I=ABCDEF

			A_0				A_1			
			B_0		B_1		B_0		B_1	
			C_0	C_1	C_0	C_1	C_0	C_1	C_0	C_1
D_0	E_0	F_0	*			*		*	*	
		F_1		*	*		*			*
	E_1	F_0		*	*		*			*
		F_1	*			*		*	*	
D_1	E_0	F_0		*	*		*			*
		F_1	*			*		*	*	
	E_1	F_0	*			*		*	*	
		F_1		*	*		*			*

Sequential Design

- 2^{6-2} Fractional Factorial Design as 1's
  - 16 runs, quarter fraction
  - I=ABCE=-BCDF
- Follow-up on factors B, C, D, F as 2's and 1's in upper-left quadrant (2^{4-1})
- More follow-up on factors B, C, F as 3's and 1's and 2's in upper left 2x4 table (2^3)

			A_0				A_1			
			B_0		B_1		B_0		B_1	
			C_0	C_1	C_0	C_1	C_0	C_1	C_0	C_1
D_0	E_0	F_0	1	3	3	1				
		F_1	3	2	2	3	1			1
	E_1	F_0		1	1					
		F_1	2			2		1	1	
D_1	E_0	F_0					1			1
		F_1	1			1				
	E_1	F_0						1	1	
		F_1		1	1					

Graphical Display of the Normal Distribution plants ordered by growth from a BTI lab

Figure 9. Draw a line over the plants in photo below, and you have a curve of the normal law of error.

Experimentation and Measurement B1962 (page 53)

Graphical Display of the Normal Distribution from Youden's home printing press

THE
NORMAL
LAW OF ERROR
STANDS OUT IN THE
EXPERIENCE OF MANKIND
AS ONE OF THE BROADEST
GENERALIZATIONS OF NATURAL
PHILOSOPHY ◆ IT SERVES AS THE
GUIDING INSTRUMENT IN RESEARCHES
IN THE PHYSICAL AND SOCIAL SCIENCES AND
IN MEDICINE AGRICULTURE AND ENGINEERING ◆
IT IS AN INDISPENSABLE TOOL FOR THE ANALYSIS AND THE
INTERPRETATION OF THE BASIC DATA OBTAINED BY OBSERVATION AND EXPERIMENT

*Experimentation and Measurement B*1962 (page 55)

On presentation of results

- Advocates for clear presentation like graphics, e.g., wartime bombing charts, Youden plot Miser (1992)
- B1960#28 – “Men who have to make decision are more apt to have confidence if the data “speak for themselves.”
- “It is worth a great deal to shape one’s explanatory theory into a form in which it speaks clearly, easily, and forcefully to operational people.” (Miser (1992) from Youden’s wartime experience)
- P1967a on regulatory work, “AOAC (Association of Analytical Chemists) must not serve as a playground for statisticians to exhibit their special skills at the price of bewildering the chemist. There is an important reason for insisting on simple and intuitively acceptable statistical techniques. Presentation of evidence before a court, or to a producer whose product is rejected, will be more convincing if it is understandable.”

Outline

- When did Youden become a statistician?
- What can we learn about the practice of statistics?
- **What can we learn about applied statistical research?**
- Youden: master applied statistician

What Can We Learn About Applied Statistical Research?

- Invents new statistical designs driven by project needs
- Invents new Interlaboratory Study (ILS) analysis methods
- Finds novel uses of existing methods driven by project needs
- Develops new analyses driven by project needs

What Can We Learn About Applied Statistical Research?
Invents new designs driven by project needs

- Invents new statistical designs driven by project needs
  - Using intuition and validation
- Invents Youden Square P1937a at BTI then uses them at NBS B1951
- Further reduces experimental resources needed – invents Linked Block Designs P1951c and Chain Block Designs P1953b
- Invents Pairs Designs for calibration experiments to eliminate environmental factor P1954a, P1963d
- Invents partially replicated Latin Squares to obtain pure estimate of error P1955b
- Designs sequential experiments by embedding BIBDs P1961c

Youden Square at NBS

- B1951 BIBD is also Youden Square
- 7 thermometers (A-G)
- BIBD block size 3
- Columns – runs (blocks) – BIBD
- Rows (Order of Reading) – RBD

experiment to calibrate thermometers

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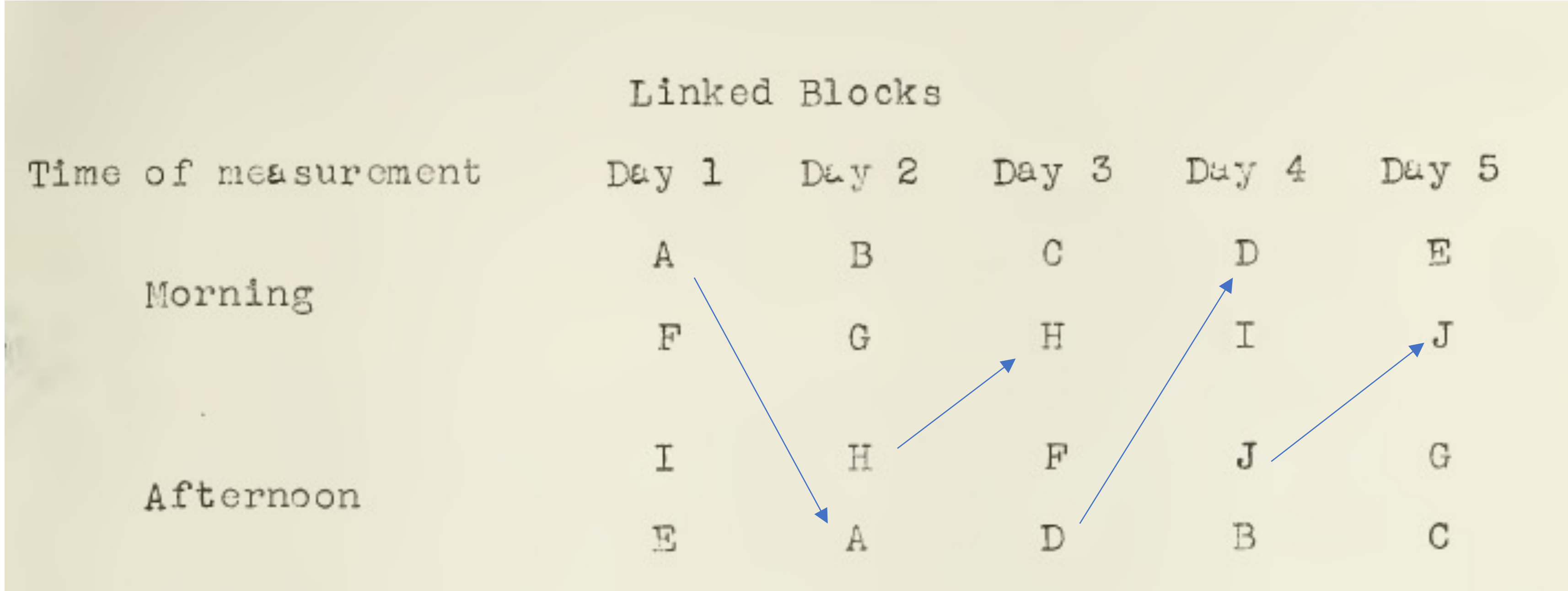
I	*A*	*B*	*C*	*D*	*E*	*F*	*G*
II	*B*	*D*	*F*	*E*	*G*	*A*	*C*
III	*C*	*F*	*E*	*A*	*B*	*G*	*D*

Linked Block Designs

- Comparing objects
- P1951c (P1954d)
- 10 objects A-J
- Each object measured twice
- 5 blocks of size 4
- Reduces replicates from BIBD
  - 10 objects requires 15 blocks of size 4
- Blue arrows show links between blocks
- Linked Block Designs are PBIBDs.

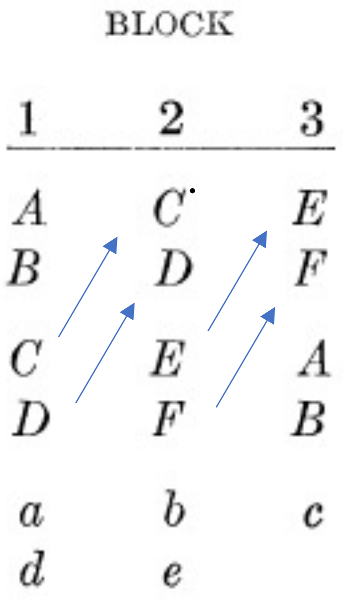


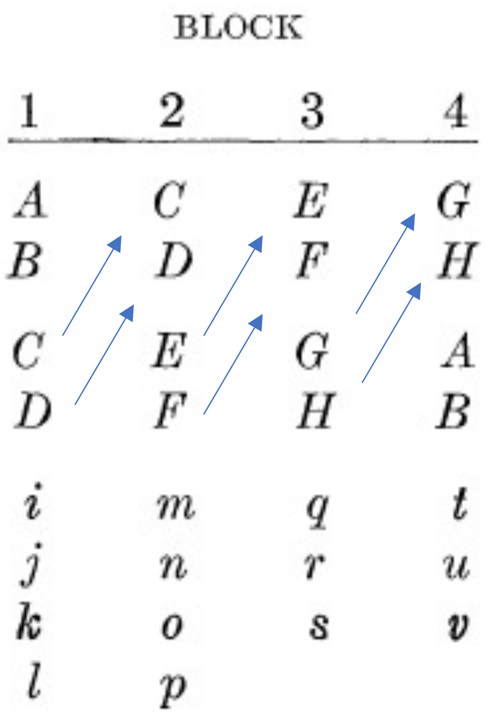
Linked Blocks

Time of measurement	Day 1	Day 2	Day 3	Day 4	Day 5
Morning	A	B	C	D	E
	F	G	H	I	J
Afternoon	I	H	F	J	G
	E	A	D	B	C

Chain Block Designs

- P1953B (P1954d)
  - 11 items (A-G, a-e) in 3 blocks
  - 22 items (A-H, i-v) in 4 blocks
- Reduces replicates from BIBD
  - 11 items requires 11 blocks of size 6
  - 22 items requires 42 blocks of size 11
- Blue arrows show chains (two links) between blocks.
- Chain Block Designs are flexible.
- Chain Block Designs are not PBIBDs.





Pairs Designs and Calibration Experiments

- Calibration – compare new items/objects with one or more standards
  - Thermometers, meter bars, …
- 36 items (1 or more are standards) – 630 pairs
- Pairs designs "calibration experiments" P1954a, P1963d
  - Divide items into two groups
  - All pairs between two groups
    - (18,18) with 324 pairs
    - (1,35) with 15 pairs
  - Special class of PBIBDs

Pairs Designs and Calibration Experiments

- Compare 8 thermometers, 1-8
- Read thermometers in sequence in a bath with slowing rising temperature
- Break into 2 groups – 1,2,3,4 versus 5,6,7,8
- 16 pairs rather than 28 pairs!
- Different bath temperatures across pairs are eliminated
- Don't have to control temperature

TABLE 1. *Temperature readings in order of time*

Run											
1			2			3			4		
Pair	Thermometer	Reading	Pair	Thermometer	Reading	Pair	Thermometer	Reading	Pair	Thermometer	Reading
		°C			°C			°C			°C
1	1	40.00	5	3	40.18	9	2	40.23	13	6	40.26
	7	39.99		8	40.18		6	40.22		3	40.28
2	5	40.08	6	7	40.07	10	8	40.24	14	7	40.15
	3	40.13		2	40.19		4	40.15		4	40.20
3	8	40.15	7	1	40.10	11	7	40.12	15	5	40.27
	2	40.17		6	40.18		3	40.20		2	40.30
4	6	40.13	8	5	40.17	12	5	40.23	16	1	40.21
	4	40.05		4	40.13		1	40.16		8	40.31

Partially Replicated Latin Squares

- P1955b
- Youden previously used Latin Squares pre-NBS with leaf positions as rows and plants as columns
- Selected cells replicated like AA’, BB’, CC’, …
- Obtain pure estimate of error variance

	c_1	c_2	c_3
r_1	A	B	CC'
r_2	C	AA'	B
r_3	BB'	C	A

	c_1	c_2	c_3	c_4	c_5	c_6
r_1	AA'	C	F	E	D	B
r_2	D	BB'	E	F	C	A
r_3	B	D	CC'	A	F	E
r_4	E	F	A	DD'	B	C
r_5	F	A	B	C	EE'	D
r_6	C	E	D	B	A	FF'

	c_1	c_2	c_3	c_4
r_1	AA'	C	B	D
r_2	B	D	A	CC'
r_3	D	BB'	C	A
r_4	C	A	DD'	B

J. S. Hunter on Youden – ”…, he didn’t care to get involved with the mathematics of the problem. He just looked at the block-treatment pattern and would say “it’s right or it’s not right.” He had an intuition about balance and symmetry of designs; he was amazing.” Cornell (1992)

Sequential Embedded BIBDs P1961c

original BIBD temperatures A-G

BIBD of Size 3

	Rod						
Position	1	2	3	4	5	6	7
Top	A	B	C	D	E	F	G
Middle	B	C	D	E	F	G	A
Bottom	D	E	F	G	A	B	C

experimenter wants to first start with fewer temperatures A, C, D, E

BIBD of Size 2

	Rod						
Position	1	2	3	4	5	6	7
Top	A		C	D	E		
Middle		C	D	E			A
Bottom	D	E			A		C

What Can We Learn About Applied Statistical Research?
invents new interlaboratory study analysis methods

- Interlaboratory Study (ILS) – is a measurement method ready for widespread use? (also called round robins, collaborative experiments)
- A large number of labs measure pairs of similar materials (or smaller number of labs replicating measurements of pairs of similar materials)
- Invents new analysis methods
  - Youden Plot P1959b
  - Outlier Rank Sum Test P1963c

Invents New ILS Analysis Methods
Youden Plot

- P1959b (and previous papers)
- Graphically presents ILS data

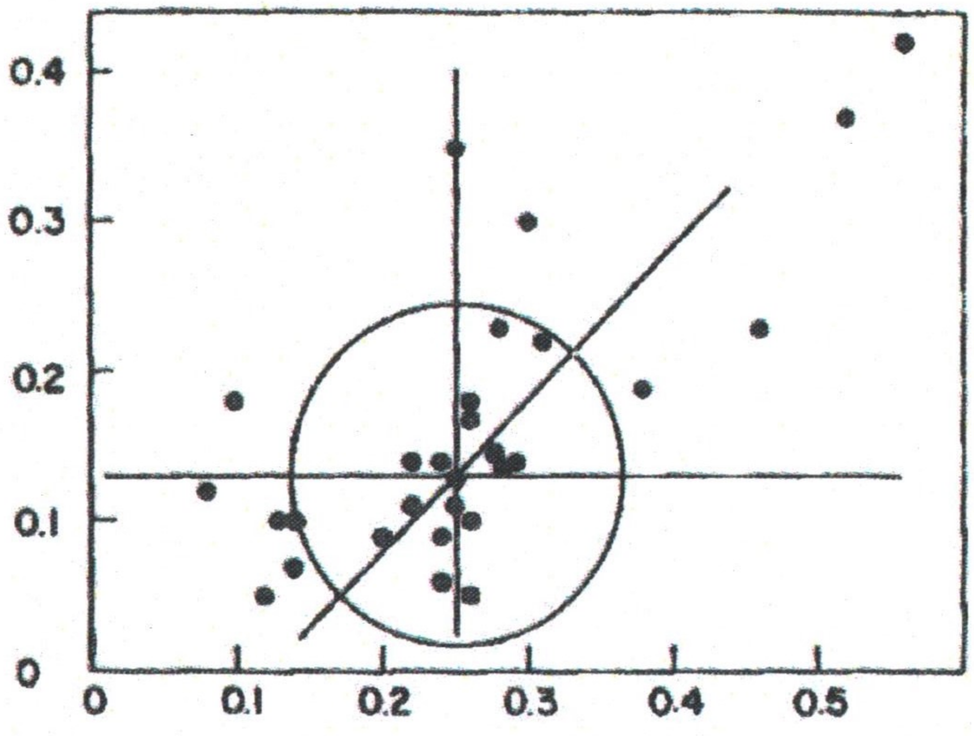


Figure 3—Percent of Insoluble Residue

P1959b

Youden Plots for Methods from Pathology

- P1969 Youden Plot with ~300 “labs” (pathologists)
- P1970b with 822 “labs”

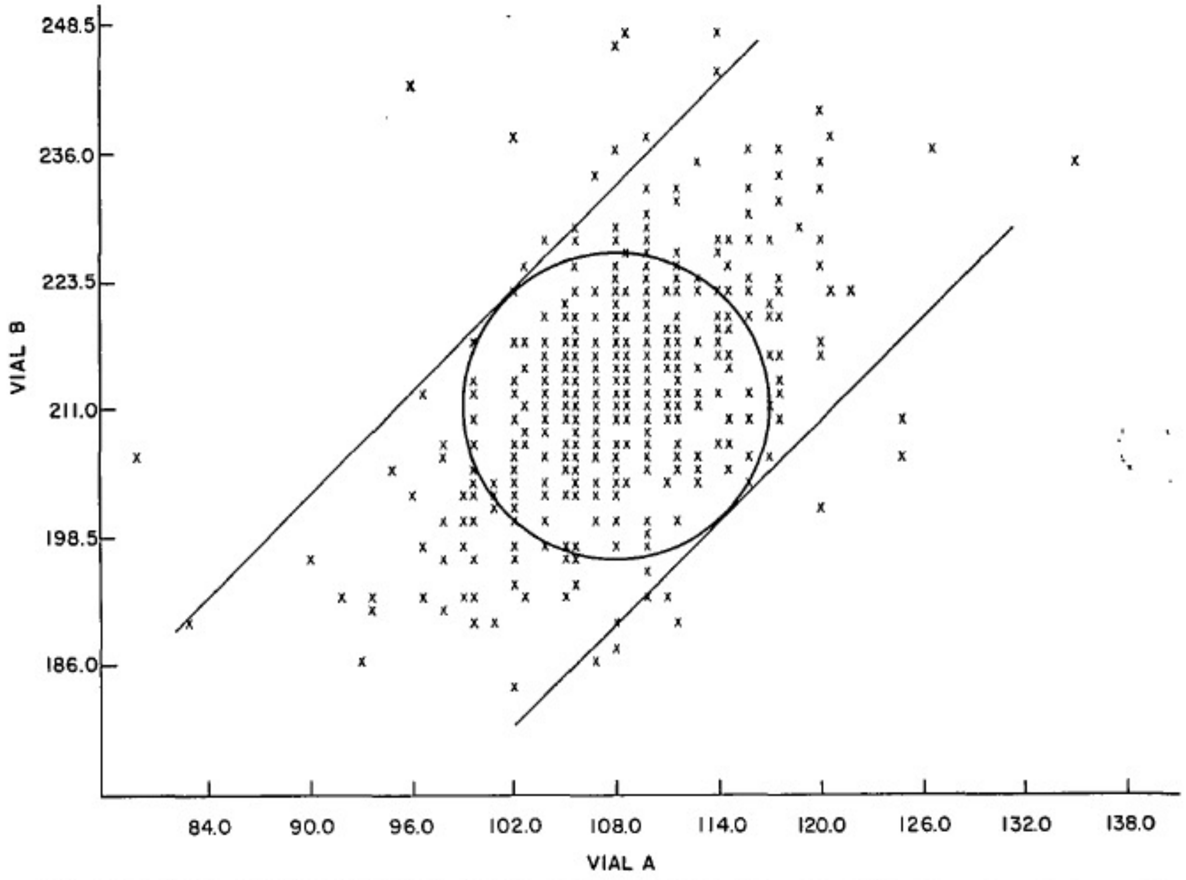


FIG. 2. Graphic display of glucose values submitted by survey participants, using ferricyanide method.

P1969

Invents New ILS Analysis Methods Outlier Rank Sum Test

- Outlier Rank Sum Test to identify discrepant labs P1963c
  - Rank labs within a material from samples of L materials
  - Sum the ranks
  - Look for low and high rank sums based on permutation distribution of ranks

What Can We Learn About Applied Statistical Research? finds novel uses of existing methods driven by project needs

- Ruggedness Test
  - Is measurement method ready for an interlaboratory study (ILS)?
  - Is method robust to small changes in factor settings expected in practice (i.e., between-lab variation)? B1967 from 1961
  - Uses saturated two-level designs (Plackett and Burman 1946) like 2^{7-4} for up to 7 factors, PB12 for up to 11 factors, etc. (before Taguchi's robust parameter design in the 1980s)
- Physical constants P1972a
  - Proposes enduring values, an interval in which all future estimates of the physical constant will fall within
  - Like ruggedness testing, proposes running Plackett and Burman 1946 designs to vary experimental setup factors that reflect factor levels of future experiments (robustness)

What Can We Learn About Applied Statistical Research?
develops new analyses driven by project needs

- Uses ratios instead of differences in comparing national standards (P1954c) based on multiplicative model
- Ingeniously combines trivariate response into a univariate response (P1950g)
- Calibrates objects by matching using a sequence of standards

  (P1959c) as interval-censored data

Outline

- When did Youden become a statistician?
- What can we learn about the practice of statistics?
- What can we learn about applied statistical research?
- **Youden: master applied statistician**

Youden: Master Applied Statistician

- He was not a mathematical (theoretical) statistician.
- He invented a number of designs, but was not a combinatorial designer (combinatorics).
- He practiced statistics to solve the client's problem and performed applied statistical research to meet the project's needs. He improved existing practices and corrected statistical misinterpretations and mistakes. He developed new designs, found surprising new uses of existing designs, and developed new analysis methods.
- He explained statistics in terms that his clients could relate to and clearly communicated new ideas and methods using graphical methods.
- He understood his clients, scientists and engineers, and had the advantage of being one of them before becoming a statistician.
  - "Youden was often heard telling a "client" in consultation, or an audience at one of his well-attended lectures, that he was a "chemist", implying that he really was not a statistician." Ku and Rosenblatt (1972)
- **Youden was a master applied statistician!**

References
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W J Youden

Index for rating diagnostic tests

Authors	William J Youden
Publication date	1950
Journal	Cancer
Volume	3
Issue	1
Pages	32-35
Publisher	Wiley Subscription Services, Inc., A Wiley Company
Description	The ideal diagnostic test should discriminate unerringly between diseased and healthy individuals. When such a test is available, there is no statistical problem. The search for an unerring test yields a series of tests that achieve partial success. There is, therefore, a need for an index to rate diagnostic tests in an objective manner and to provide a means of deciding whether two diagnostic tests really differ in their capacity to discriminate between healthy and diseased individuals. Diagnostic tests undergo modifications in attempts to improve their performance. The medical researcher needs a statistical tool to assist him in detecting as early as possible whether a particular modification has led to an improvement in the results obtained with the diagnostic test. There are two questions that arise in appraising a diagnostic test to which it is not possible to give completely satisfactory answers. First, whenever a diagnostic …
Total citations	Cited by 7840

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Scholar articles
Index for rating diagnostic tests
WJ Youden - Cancer, 1950
Cited by 7840 Related articles All 6 versions

Abstract

From reading Youden's books and papers, Youden (1900-1971), an analytical chemist (1924 PhD), becomes an applied statistician by the time he joins the National Bureau of Standards (NBS) in 1948. This talk traces his transition from chemist to applied statistician and what his body of work mostly at NBS (1948-1965) demonstrates about his practice of statistics and the role that applied statistical research plays in it. There is much we can learn from a master applied statistician.