

THE ANNALS of STATISTICS

AN OFFICIAL JOURNAL OF
THE INSTITUTE OF MATHEMATICAL STATISTICS

Memorial Article

Harold Hotelling, 1895-1973 WALTER L. SMITH 1173

Articles

Hadamard matrices and their applications A. HEDAYAT AND W. D. WALLIS 1184
 Optimality of certain asymmetrical experimental designs CHING-SHUI CHENG 1239
 Optimal designs for the elimination of multi-way heterogeneity CHING-SHUI CHENG 1262
 The convergence of general step-length algorithms for regular optimum design criteria CHIEN-FU WU AND HENRY P. WYNN 1273
 Some algorithmic aspects of the theory of optimal designs CHIEN-FU WU 1286
 On the properties of proper (M, S) optimal block designs MICHAEL A. JACROUX 1302
 On periodic and multiple autoregressions MARCELLO PAGANO 1310
 Diffuse models for sampling and predictive inference DAVID A. LANE AND WILLIAM D. SUDDERTH 1318
 Testing the mean of a normal population under dependence W. ALBERS 1337
 Universal Bayes estimators A. L. RUKHIN 1345
 Approximating tail areas of probability distributions ALAN J. GROSS AND DAVID W. HOSMER, JR. 1352
 Positive dependence of the bivariate and trivariate absolute normal t , χ^2 , and F distributions M. ABDEL-HAMEED AND ALLAN R. SAMPSON 1360
 Estimation of parameters in the ARMA model when the characteristic polynomial of the MA operator has a unit zero TUAN PHAM-DINH 1369

Short Communication

A bound for the Euclidean norm of the difference between the least squares and the best linear unbiased estimators . . . J. K. BAKSALARY AND R. KALA 1390

Note

Correction to "A Glivenko-Cantelli theorem and strong laws of large numbers for functions of order statistics" JON A. WELLNER 1394

Vol. 6, No. 6—November 1978



THE INSTITUTE OF MATHEMATICAL STATISTICS

(Organized September 12, 1935)

The purpose of the Institute of Mathematical Statistics is to encourage the development, dissemination, and application of mathematical statistics.

OFFICERS

President:

Samuel Karlin, Department of Mathematics, Stanford University, Stanford, California 94305

President-Elect:

George E. P. Box, Department of Statistics, University of Wisconsin, 1210 W. Dayton St., Madison, Wisconsin 53706

Past President:

Elizabeth Scott, Department of Statistics, University of California, Berkeley, California 94720

Executive Secretary:

Martin Fox, Department of Statistics and Probability, Michigan State University, East Lansing, Michigan 48824

Treasurer:

Heebok Park, Department of Statistics, California State University, Hayward, California 94542

IMS Business Office, 3401 Investment Blvd., Suite 6, Hayward, California 94545

Program Secretary:

William L. Harkness, Pennsylvania State University, University Park, Pennsylvania 16801

Editor: *Annals of Statistics*

Rupert G. Miller, Jr., Department of Statistics, Stanford University, Stanford, California 94305

Editor: *Annals of Probability*

Patrick Billingsley, Department of Statistics, University of Chicago, Chicago, Illinois 60637

Managing Editor:

Donald R. Truax, Department of Mathematics, University of Oregon, Eugene, Oregon 97403

Membership. Membership dues including a subscription to one *Annals* and *The Institute of Mathematical Statistics Bulletin* are \$24.00 per year for residents of the United States or Canada and \$16.00 per year for residents of other countries. Special rates of \$12.00 per year are available to students. Rates in each category are one-third higher for members who wish both *Annals* as well as the *Bulletin*. Inquiries regarding membership in the Institute should be sent to the Treasurer at the Business Office.

Subscription Rates. Current volumes (six issues per calendar year) of the *Annals of Probability* and *Annals of Statistics* are each \$35.00. Members of the Institute of Mathematical Statistics pay different rates (see above). Single issues are \$7.00. Back numbers of both *Annals* and the *Annals of Mathematical Statistics* (Volume 1 through 43) may be purchased from the Treasurer.

The Annals of Statistics. Volume 6, Number 6, November 1978. Published bimonthly in January, March, May, July, September, and November by The Institute of Mathematical Statistics, IMS Business Office, 3401 Investment Blvd., Suite 6, Hayward, California 94545.

Mail to the *Annals of Statistics* should be addressed to either the Editor, Managing Editor or the Treasurer, as described above. It should not be addressed to Waverly Press.

PRINTED AT THE
WAVERLY PRESS, INC., BALTIMORE, MARYLAND 21202 U.S.A.

Second-class postage paid at Hayward, California and at additional mailing offices

Copyright © 1978 by the Institute of Mathematical Statistics

EDITORIAL STAFF

EDITOR

RUPERT G. MILLER, JR.

ASSOCIATE EDITORS

RUDOLF J. BERAN
ROBERT H. BERK
DONALD A. BERRY
LAWRENCE D. BROWN
THOMAS M. COVER
A. PHILIP DAWID
MORRIS L. EATON
FRIEDHELM EICKER
PETER C. FISHBURN

EDWARD J. HANNAN
DAVID L. HANSON
A. HEDAYAT
AGNES M. HERZBERG
DAVID V. HINKLEY
SØREN JOHANSEN
M. VERNON JOHNS
M. ROSS LEADBETTER
ROBERT M. LOYNES
ROBB J. MUIRHEAD

J. N. K. RAO
ROBERT J. SERFLING
DAVID O. SIEGMUND
KEI TAKEUCHI
J. VAN RYZIN
WILLEM R. VAN ZWET
GRACE WAHBA
N. DONALD YLIVISAKER
JAMES V. ZIDEK

EDITORIAL ASSISTANT

KAROLA LOF

MANAGING EDITOR

D. R. TRUAX

EDITORIAL ASSISTANTS

RALPH KRUMDIECK

SUSAN LANSPERY

PAST EDITORS

ANNALS OF MATHEMATICAL STATISTICS

H. C. CARVER, 1930–1938
S. S. WILKS, 1938–1949
T. W. ANDERSON, 1950–1952
E. L. LEHMANN, 1953–1955
T. E. HARRIS, 1955–1958

WILLIAM KRUSKAL, 1958–1961
J. L. HODGES, JR., 1961–1964
D. L. BURKHOLDER, 1964–1967
Z. W. BIRNBAUM, 1967–1970
INGRAM OLKIN, 1970–1972

ANNALS OF STATISTICS

INGRAM OLKIN, 1972–1973
I. R. SAVAGE, 1974–1976

ANNALS OF PROBABILITY

RONALD PYKE 1972–1975

EDITORIAL POLICY

The main purpose of the *Annals of Statistics* and the *Annals of Probability* is to publish contributions to the theory of statistics and probability and to their applications. The emphasis is on importance and interest, not formal novelty and correctness. Especially appropriate are authoritative expository papers and surveys of areas in vigorous development. All papers are refereed.

IMS INSTITUTIONAL MEMBERS

- AEROSPACE CORPORATION**
El Segundo, California
- ARIZONA STATE UNIVERSITY**
Tempe, Arizona
- ARTHUR D. LITTLE, INC.**
Cambridge, Massachusetts
- BELL TELEPHONE LABORATORIES, TECHNICAL LIBRARY**
Murray Hill, N.J.
- BOWLING GREEN STATE UNIVERSITY, DEPT. OF MATHEMATICS**
Bowling Green, Ohio
- CALIFORNIA STATE UNIVERSITY, FULLERTON, DEPARTMENT OF MATHEMATICS**
Fullerton, California
- CALIFORNIA STATE UNIVERSITY, HAYWARD, DEPARTMENT OF STATISTICS**
Hayward, California
- CASE WESTERN RESERVE UNIVERSITY, DEPARTMENT OF MATHEMATICS**
Cleveland, Ohio
- CORNELL UNIVERSITY, DEPARTMENT OF MATHEMATICS**
Ithaca, New York
- FLORIDA STATE UNIVERSITY, DEPARTMENT OF STATISTICS**
Tallahassee, Florida
- FORD MOTOR COMPANY, ENGINEERING AND RESEARCH LIBRARY**
Dearborn, Michigan
- GENERAL MOTORS CORPORATION, RESEARCH LABORATORIES**
Warren, Michigan
- GEORGE WASHINGTON UNIVERSITY, DEPARTMENT OF STATISTICS**
Washington, D.C.
- INDIANA UNIVERSITY, MATHEMATICS DEPT.**
Bloomington, Indiana
- INSTITUTE FOR DEFENSE ANALYSES**
Arlington, Virginia
- INTERNATIONAL BUSINESS MACHINES CORPORATION**
Armonk, New York
- IOWA STATE UNIVERSITY, STATISTICAL LABORATORY**
Ames, Iowa
- JOHNS HOPKINS UNIVERSITY, DEPARTMENT OF BIOSTATISTICS, DEPARTMENT OF MATHEMATICAL SCIENCES**
Baltimore, Maryland
- LOUISIANA STATE UNIVERSITY, DEPARTMENT OF EXPERIMENTAL STATISTICS**
Baton Rouge, Louisiana
- MARQUETTE UNIVERSITY, MATHEMATICS AND STATISTICS DEPARTMENT**
Milwaukee, Wisconsin
- MASSACHUSETTS INSTITUTE OF TECHNOLOGY MATHEMATICS DEPARTMENT**
Cambridge, Massachusetts
- MIAMI UNIVERSITY, DEPARTMENT OF MATHEMATICS**
Oxford, Ohio
- MICHIGAN STATE UNIVERSITY, DEPARTMENT OF STATISTICS AND PROBABILITY**
East Lansing, Michigan
- NATIONAL SECURITY AGENCY**
Fort George G. Meade, Maryland
- NEW MEXICO STATE UNIVERSITY, DEPARTMENT OF MATHEMATICAL SCIENCES**
Las Cruces, New Mexico
- NORTHERN ILLINOIS UNIVERSITY, DEPARTMENT OF MATHEMATICAL SCIENCES**
De Kalb, Illinois
- NORTHWESTERN UNIVERSITY, DEPARTMENT OF MATHEMATICS**
Evanston, Illinois
- OHIO STATE UNIVERSITY, DEPARTMENT OF STATISTICS**
Columbus, Ohio
- OREGON STATE UNIVERSITY, DEPARTMENT OF STATISTICS**
Corvallis, Oregon
- PENNSYLVANIA STATE UNIVERSITY, DEPARTMENT OF STATISTICS**
University Park, Pennsylvania
- PRINCETON UNIVERSITY, DEPARTMENT OF STATISTICS**
Princeton, New Jersey
- PURDUE UNIVERSITY LIBRARIES**
Lafayette, Indiana
- QUEEN'S UNIVERSITY, DEPT. OF MATHEMATICS, KINGSTON**
Ontario, Canada
- RICE UNIVERSITY, DEPARTMENT OF MATHEMATICAL SCIENCES**
Houston, Texas
- THE ROCKEFELLER UNIVERSITY**
New York, New York
- SANDIA CORPORATION, SANDIA BASE**
Albuquerque, New Mexico
- SIMON FRASER UNIVERSITY, MATHEMATICS DEPARTMENT**
Burnaby, Canada
- SOUTHERN ILLINOIS UNIVERSITY, MATHEMATICAL STUDIES**
Edwardsville, Illinois
- SOUTHERN METHODIST UNIVERSITY, DEPARTMENT OF STATISTICS**
Dallas, Texas
- STANFORD UNIVERSITY, GIRSHICK MEMORIAL LIBRARY**
Stanford, California

STATE UNIVERSITY OF NEW YORK, BUFFALO,
DEPARTMENT OF STATISTICS
Amherst, New York

TEMPLE UNIVERSITY, MATHEMATICS DEPARTMENT
Philadelphia, Pennsylvania

TEXAS A & M UNIVERSITY, DEPT. OF MATHEMATICS
College Station, Texas

TEXAS TECH UNIVERSITY, DEPARTMENT OF MATHEMATICS
Lubbock, Texas 79409

THE TOBACCO INSTITUTE
Washington, D.C.

UNION OIL COMPANY OF CALIFORNIA, UNION RESEARCH CENTER
Brea, California

UNITED STATES ARMY RESEARCH AND DEVELOPMENT CENTER
Aberdeen Proving Ground, Maryland

UNIVERSITY OF ALBERTA, DEPARTMENT OF MATHEMATICS
Edmonton, Alberta, Canada

UNIVERSITY OF ARIZONA, DEPARTMENT OF MATHEMATICS
Tucson, Arizona

UNIVERSITY OF BRITISH COLUMBIA, DEPARTMENT OF MATHEMATICS
Vancouver, B.C., Canada

UNIVERSITY OF CALGARY, MATHEMATICS DEPARTMENT
Calgary 44, Alberta, Canada

UNIVERSITY OF CALIFORNIA, BERKELEY, STATISTICAL LABORATORY
Berkeley, California

UNIVERSITY OF CINCINNATI, DEPARTMENT OF MATHEMATICAL SCIENCES
Cincinnati, Ohio

UNIVERSITY OF GUELPH, MATHEMATICS AND STATISTICS DEPARTMENT
Guelph, Ontario, Canada

UNIVERSITY OF ILLINOIS AT CHICAGO CIRCLE, DEPARTMENT OF MATHEMATICS
Chicago, Illinois

UNIVERSITY OF ILLINOIS, MATHEMATICS DEPT.
Urbana, Illinois

UNIVERSITY OF IOWA, DIVISION OF MATHEMATICAL SCIENCES
Iowa City, Iowa

UNIVERSITY OF MANITOBA, DEPARTMENT OF STATISTICS
Winnipeg, Manitoba, Canada

UNIVERSITY OF MARYLAND, DEPARTMENT OF MATHEMATICS
College Park, Maryland

UNIVERSITY OF MASSACHUSETTS, MATHEMATICS AND STATISTICS DEPARTMENT
Amherst, Massachusetts

UNIVERSITY OF MICHIGAN, DEPARTMENT OF STATISTICS
Ann Arbor, Michigan

UNIVERSITY OF MINNESOTA, SCHOOL OF STATISTICS
Minneapolis, Minnesota

UNIVERSITY OF MISSOURI, DEPARTMENT OF STATISTICS
Columbia, Missouri

UNIVERSITY OF MISSOURI AT ROLLA, DEPARTMENT OF MATHEMATICS
Rolla, Missouri

UNIVERSITY OF MONTREAL, DEPARTMENT OF MATHEMATICS
Montreal, Quebec, Canada

UNIVERSITY OF NEBRASKA, MATHEMATICS AND STATISTICS DEPARTMENT
Lincoln, Nebraska

UNIVERSITY OF NEW MEXICO, DEPARTMENT OF MATHEMATICS AND STATISTICS
Albuquerque, New Mexico

UNIVERSITY OF NORTH CAROLINA, DEPARTMENT OF STATISTICS
Chapel Hill, North Carolina

UNIVERSITY OF OREGON, MATHEMATICS DEPARTMENT
Eugene, Oregon

UNIVERSITY OF OTTAWA, DEPARTMENT OF MATHEMATICS
Ottawa, Ontario, Canada

UNIVERSITY OF ROCHESTER, LIBRARY
Rochester, New York

UNIVERSITY OF SOUTH CAROLINA, DEPARTMENT OF MATHEMATICS AND COMPUTER SCIENCE
Columbia, South Carolina

UNIVERSITY OF TEXAS, DEPARTMENT OF MATHEMATICS
Austin, Texas

UNIVERSITY OF TEXAS, MATHEMATICS DEPT.
San Antonio, Texas

UNIVERSITY OF UTAH, DEPT. OF MATHEMATICS
Salt Lake City, Utah

UNIVERSITY OF VICTORIA, DEPT. OF MATHEMATICS
Victoria, British Columbia, Canada

UNIVERSITY OF WASHINGTON, DEPARTMENT OF MATHEMATICS
Seattle, Washington

UNIVERSITY OF WATERLOO, STATISTICS DEPARTMENT
Waterloo, Ont., Canada

UNIVERSITY OF WISCONSIN, MADISON, DEPARTMENT OF STATISTICS
Madison, Wisconsin

UNIVERSITY OF WISCONSIN, MILWAUKEE, DEPARTMENT OF MATHEMATICS
Milwaukee, Wisconsin

VIRGINIA COMMONWEALTH UNIVERSITY, DEPARTMENT OF MATHEMATICAL SCIENCES
Richmond, Virginia

WAYNE STATE UNIVERSITY, DEPARTMENT OF MATHEMATICS
Detroit, Michigan

WEST CHESTER STATE COLLEGE
West Chester, Pennsylvania

WESTINGHOUSE ELECTRIC CORPORATION, RESEARCH LABORATORIES
Pittsburgh, Pennsylvania

THE ANNALS OF STATISTICS

INSTRUCTIONS FOR AUTHORS

Submission of Papers. Papers to be submitted for publication should be sent to the Editor of the *Annals of Statistics*. (For current address, see the latest issue of the *Annals*.) The original (or xerox copy) should be submitted with three additional copies on paper that will take ink corrections. The manuscript will *not* normally be returned to the author; when expressly requested by the author, one copy of the manuscript will be returned.

Preparation of Manuscripts. Manuscripts should be typewritten, entirely double-spaced, including references, with wide margins at sides, top and bottom. Dittoed or mimeographed papers are acceptable only if completely legible; xerox copies are preferable. When technical reports are submitted, all extraneous sheets and covers should be removed.

Submission of Reference Papers. Copies (preferably two) of unpublished or not easily available papers cited in the manuscript should be submitted with the manuscript.

Title and Abbreviated Title. The title should be descriptive and as concise as is feasible, i.e., it should indicate the topic of the paper as clearly as possible, but every word in it should be pertinent. An abbreviated title to be used as a running head is also required, and should be given below the main title. This should normally not exceed 35 characters. For example, a title might be "A Limit Theorem for Conditioned Recurrent Random Walk Attracted to a Stable Law," with the running head "Limit Theorem for Recurrent Random Walk" or possibly "Recurrent Random Walk Attracted to a Stable Law," depending on the emphasis to be conveyed.

Summary. Each manuscript is required to contain a summary, which will be printed immediately after the title, clearly separated from the rest of the paper. Its main purpose is to inform the reader quickly of the nature and results of the paper; it may also be used as an aid in retrieving information. The length of a summary will clearly depend on the length and difficulty of the paper, but in general it should not exceed 150 words. It should be typed on a separate page, under the heading "Summary," followed by the title of the paper. Formulas should be used as sparingly as possible. The summary should not make reference to results or formulas in the body of the paper—it should be self-contained.

Footnotes: Footnotes should be reduced to a minimum and, where possible, should be replaced by remarks in the text or in the references; formulas in footnotes should be avoided. Footnotes in the text should be identified by superscript numbers and typed together, double-spaced, on a separate page.

Key Words. Included as the first footnote on page 1 should be the headings:

American Mathematical Society 1970 subject classifications. Primary—; Secondary—.
Key words and phrases.

The classification numbers representing the primary and secondary subjects of the article may be found with instructions for its use, as an Appendix to *Mathematical Reviews* Index to Volume 39, June 1970. (See, also, *The Notices of the American Mathematical Society*, June 1970, *Bulletin of the Institute of Mathematical Statistics*, September 1974; or a current index issue of *Mathematical Reviews*.) The key words and phrases should describe the subject matter of the article; generally they should be taken from the body of the paper.

Identification of Symbols. Manuscripts for publication should be clearly prepared to insure that all symbols are properly identified. Distinguish between "oh" and "zero"; "ell" and "one"; "kappa" and "kay," etc. Indicate also when special type is required (Greek, German, script, boldface, etc.); other letters will be set in italics. Acronyms should be introduced sparingly.

Figures and Tables. Figures, charts, and diagrams should be prepared in a form suitable for photographic reproduction and should be professionally drawn twice the size they are to be printed. (These need not be submitted until the paper has been accepted for publication.) Tables should be typed on separate pages with accompanying footnotes immediately below the table.

Formulas. Fractions in the text are preferably written with the solidus or negative exponent; thus, $(a + b)/(c + d)$ is preferred to $\frac{a + b}{c + d}$, and $(2\pi)^{-1}$ or $1/(2\pi)$ to $\frac{1}{2\pi}$. Also, $a^{b(c)}$ and $a_{b(c)}$ are preferred to a^{bc} and a_{bc} , respectively. Complicated exponentials should be represented with the symbol exp. A fractional exponent is preferable to a radical sign.

References. References should be typed double-spaced and should follow the style:

- [5] Wilks, S. S. (1938). The large-sample distribution of the likelihood ratio for testing composite hypotheses. *Ann. Statist.* 1 60–62.

In textual material, the format ". . . Wilks (1938) . . ." is normally preferred to ". . . Wilks [5] . . ." Multiple references can be distinguished as ". . . Wilks (1938a) . . ." Abbreviations for journals should be taken from a current index issue of *Mathematical Reviews*.

Proofs. Author will ordinarily receive galley proofs. Corrected galley proofs should be sent to the Managing Editor of the *Annals of Statistics*. (For current address, see the latest issue of the *Annals*.)