

Lothar Sachs

# Applied Statistics

A Handbook of Techniques

Second Edition

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## A Handbook of Techniques

Second Edition

Translated by Zenon Reynarowych

With 59 Figures



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## PREFACE TO THE SECOND ENGLISH EDITION

This new edition aims, as did the first edition, to give an impression, an account, and a survey of the very different aspects of applied statistics—a vast field, rapidly developing away from the perfection the user expects. The text has been improved with insertions and corrections, the subject index enlarged, and the references updated and expanded. I have tried to help the newcomer to the field of statistical methods by citing books and older papers, often easily accessible, less mathematical, and more readable for the non-statistician than newer papers. Some of the latter are, however, included and are attached in a concise form to the cited papers by a short “[see also . . .]”.

I am grateful to the many readers who helped me with this revision by asking questions and offering advice. I took suggestions for changes seriously but did not always follow them. Any further comments are heartily welcome. I am particularly grateful to the staff of Springer-Verlag New York.

Klausdorf/Schwentine

LOTHAR SACHS

## PREFACE TO THE FIRST ENGLISH EDITION

An English translation now joins the Russian and Spanish versions. It is based on the newly revised fifth edition of the German version of the book. The original edition has become very popular as a learning and reference source with easy to follow recipes and cross references for scientists in fields such as engineering, chemistry and the life sciences. Little mathematical background is required of the reader and some important topics, like the logarithm, are dealt with in the preliminaries preceding chapter one. The usefulness of the book as a reference is enhanced by a number of convenient tables and by references to other tables and methods, both in the text and in the bibliography. The English edition contains more material than the German original. I am most grateful to all who have in conversations, letters or reviews suggested improvements in or criticized earlier editions. Comments and suggestions will continue to be welcome. We are especially grateful to Mrs. Dorothy Aepli of St. Paul, Minnesota, for providing numerous valuable comments during the preparation of the English manuscript. The author and the translator are responsible for any remaining faults and imperfections. I welcome any suggestions for improvement.

My greatest personal gratitude goes to the translator, Mr. Zenon Reynarowych, whose skills have done much to clarify the text, and to Springer-Verlag.

Klausdorf

LOTHAR SACHS

# FROM THE PREFACES TO PREVIOUS EDITIONS

## FIRST EDITION (November, 1967)

"This cannot be due merely to chance," thought the London physician Arbuthnott some 250 years ago when he observed that in birth registers issued annually over an 80 year period, male births always outnumbered female births. Based on a sample of this size, his inference was quite reliable. He could in each case write a plus sign after the number of male births (which was greater than the number of female births) and thus set up a sign test. With large samples, a two-thirds majority of one particular sign is sufficient. When samples are small, a  $\frac{4}{5}$  or even a  $\frac{9}{10}$  majority is needed to reliably detect a difference.

Our own time is characterized by the rapid development of probability and mathematical statistics and their application in science, technology, economics and politics.

This book was written at the suggestion of Prof. Dr. H. J. Staemmler, presently the medical superintendent of the municipal women's hospital in Ludwigshafen am Rhein. I am greatly indebted to him for his generous assistance. Professor W. Wetzel, director of the Statistics Seminar at the University of Kiel; Brunhilde Memmer of the Economics Seminar library at the University of Kiel; Dr. E. Weber of the Department of Agriculture Variations Statistics Section at the University of Kiel; and Dr. J. Neumann and Dr. M. Reichel of the local University Library, all helped me in finding the appropriate literature. Let me not fail to thank for their valuable assistance those who helped to compose the manuscript, especially Mrs. W. Schröder, Kiel, and Miss Christa Diercks, Kiel, as well as the medical laboratory technician F. Niklewitz, who prepared the diagrams. I am indebted to Prof. S. Koller, director of the Institute of Medical Statistics

and Documentation at Mainz University, and especially to Professor E. Walter, director of the Institute of Medical Statistics and Documentation at the University of Freiburg im Breisgau, for many stimulating discussions.

Mr. J. Schimmler and Dr. K. Fuchs assisted in reading the proofs. I thank them sincerely.

I also wish to thank the many authors, editors, and publishers who permitted reproduction of the various tables and figures without reservation. I am particularly indebted to the executor of the literary estate of the late Sir Ronald A. Fisher, F.R.S., Cambridge, Professor Frank Yates (Rothamsted), and to Oliver and Boyd, Ltd., Edinburgh, for permission to reproduce Table II 1, Table III, Table IV, Table V, and Table VII 1 from their book "Statistical Tables for Biological, Agricultural and Medical Research"; Professor O. L. Davies, Alderley Park, and the publisher, Oliver and Boyd, Ltd., Edinburgh, for permission to reproduce a part of Table H from the book "The Design and Analysis of Industrial Experiments;" the publisher, C. Griffin and Co., Ltd. London, as well as the authors, Professor M. G. Kendall and Professor M. H. Quenouille, for permission to reproduce Tables 4a and 4b from the book "The Advanced Theory of Statistics," Vol. II, by Kendall and Stuart, and the figures on pp. 28 and 29 as well as Table 6 from the booklet "Rapid Statistical Calculations" by Quenouille; Professors E. S. Pearson and H. O. Hartley, editors of the "Biometrika Tables for Statisticians, Vol. 1, 2nd ed., Cambridge 1958, for permission to adopt concise versions of Tables 18, 24, and 31. I also wish to thank Mrs. Marjorie Mitchell, the McGraw-Hill Book Company, New York, and Professor W. J. Dixon for permission to reproduce Tables A-12c and A-29 (Copyright April 13, 1965, March 1, 1966, and April 21, 1966) from the book "Introduction to Statistical Analysis" by W. J. Dixon and F. J. Massey Jr., as well as Professor C. Eisenhart for permission to use the table of tolerance factors for the normal distribution from "Techniques of Statistical Analysis," edited by C. Eisenhart, W. M. Hastay, and W. A. Wallis. I am grateful to Professor F. Wilcoxon, Lederle Laboratories (a division of American Cyanamid Company), Pearl River, for permission to reproduce Tables 2, 3, and 5 from "Some Rapid Approximate Statistical Procedures" by F. Wilcoxon and Roberta A. Wilcox. Professor W. Wetzel, Berlin-Dahlem, and the people at de Gruyter-Verlag, Berlin W 35, I thank for the permission to use the table on p. 31 in "Elementary Statistical Tables" by W. Wetzel. Special thanks are due Professor K. Diem of the editorial staff of Documenta Geigy, Basel, for his kind permission to use an improved table of the upper significance bounds of the Studentized range, which was prepared for the 7th edition of the "Scientific Tables." I am grateful to the people at Springer-Verlag for their kind cooperation.



## SECOND AND THIRD EDITIONS

Some sections have been expanded and revised and others completely rewritten, in particular the sections on the fundamental operations of arithmetic extraction of roots, the basic tasks of statistics, computation of the standard deviation and variance, risk I and II, tests of  $\sigma = \sigma_0$  with  $\mu$  known and unknown, tests of  $\pi_1 = \pi_2$ , use of the arc sine transformation and of  $\pi_1 - \pi_2 = d_0$ , the fourfold  $\chi^2$ -test, sample sizes required for this test when risk I and risk II are given, the  $U$ -test, the  $H$ -test, the confidence interval of the median, the Sperman rank correlation, point bivariate and multiple correlation, linear regression on two independent variables, multivariate methods, experimental design and models for the analysis of variance. The following tables were supplemented or completely revised: the critical values for the standard normal distribution, the  $t$ - and the  $\chi^2$ -distribution, Hartley's  $F_{\max}$ , Wilcoxon's  $R$  for pairwise differences, the values of  $e^{-\lambda}$  and  $\arcsin \sqrt{p}$ , the table for the  $z$ -transformation of the coefficient of correlation and the bounds for the test of  $\rho = 0$  in the one and two sided problem. The bibliography was completely overhauled. Besides corrections, numerous simplifications, and improved formulations, the third edition also incorporates updated material. Moreover, some of the statistical tables have been expanded (Tables 69a, 80, 84, 98, and 99, and unnumbered tables in Sections 4.5.1 and 5.3.3). The bibliographical references have been completely revised. The author index is a newly added feature. Almost all suggestions resulting from the first and second editions are thereby realized.

## FOURTH EDITION (June, 1973)

This revised edition, with a more appropriate title, is written both as an introductory and follow-up text for reading and study and as a reference book with a collection of formulas and tables, numerous cross-references, an extensive bibliography, an author index, and a detailed subject index. Moreover, it contains a wealth of refinements, primarily simplifications, and statements made more precise. Large portions of the text and bibliography have been altered in accordance with the latest findings, replaced by a revised expanded version, or newly inserted; this is also true of the tables (the index facing the title page, as well as Tables 13, 14, 28, 43, 48, 56, 65, 75, 84, 183, and 185, and the unnumbered tables in Sections 1.2.3, 1.6.4, and 3.9.1, and on the reverse side of the next to last sheet). Further changes appear in the second, newly revised edition of my book "Statistical Methods. A Primer for Practitioners in Science, Medicine, Engineering, Economics, Psychology, and Sociology," which can serve as a handy companion volume for quick orientation. Both volumes benefited from the suggestions of the many who offered constructive criticisms—engineers in particular. It will be of interest



to medical students that I have covered the material necessary for medical school exams in biomathematics, medical statistics and documentation. I wish to thank Professor Erna Weber and Akademie-Verlag, Berlin, as well as the author, Dr. J. Michaelis, for permission to reproduce Tables 2 and 3 from the paper "Threshold value of the Friedman test," *Biometrische Zeitschrift* 13 (1971), 122. Special thanks are due to the people at Springer-Verlag for their complying with the author's every request. I am also grateful for all comments and suggestions.

## FIFTH EDITION (July, 1978)

This new edition gave me the opportunity to introduce simplifications and supplementary material and to formulate the problems and solutions more precisely. I am grateful to Professor Clyde Y. Kramer for permission to reproduce from his book (*A First Course in Methods of Multivariate Analysis*, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 1972) the upper bounds of the Bonferroni  $\chi^2$ -statistics (Appendix D, pp. 326–351), which were calculated by G. B. Beus and D. R. Jensen in September, 1967. Special thanks are due the people at Springer-Verlag for their complying with the author's every request. I welcome all criticisms and suggestions for improvement.

LOTHAR SACHS

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$b_2$ , Tables 34B and C from *Biometrika Tables for Statisticians, Volume I* and to the editors of the *Biometrical Journal* for permission to reproduce additional data on  $\sqrt{b_1}$  and  $b_2$ .

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Dr. J. Michaelis, Professor Erna Weber and Akademie-Verlag, Berlin, for permission to reproduce Tables 2 and 3 from the paper "Threshold values of the Friedman Test."

Professor J. H. Zar and the Permissions Editor of Prentice-Hall, Inc., Englewood Cliffs, N.J. for permission to reproduce critical values of Spearman's  $r_s$  from J. H. Zar, "Biostatistical Analysis," Table D.24.

Bounds (critical values) for the  $t$ -,  $\chi^2$ -, and  $F$ -distributions for  $P = 0.95$  ( $\alpha = 0.05$ )

DF $\nu$	$t$		$\chi^2$	$F$ upper bounds																	$\nu_2$	
	One sided	Two sided		$\nu_1$																		
				1	2	3	4	5	6	7	8	9	10	12	15	20	30	60	100	200	$\infty$	
1	6.31	12.71	3.84	161	200	216	225	230	234	237	239	241	242	244	245	248	249	250	252	253	254	254
2	2.92	4.30	5.99	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.36	19.37	19.39	19.40	19.41	18.43	18.46	18.47	18.49	18.49	18.50	18.50
3	2.35	3.18	7.81	10.13	9.56	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.64	8.62	8.60	8.58	8.54	8.53
4	2.13	2.78	9.49	7.71	6.94	6.69	6.39	6.28	6.16	6.08	6.04	6.00	5.98	5.91	5.86	5.80	5.77	5.76	5.70	5.66	5.65	5.63
5	2.02	2.67	11.07	6.61	6.79	6.41	6.19	6.02	5.90	5.82	5.78	5.74	5.72	5.64	5.60	5.54	5.50	5.48	5.44	5.41	5.39	5.37
6	1.94	2.45	12.59	5.99	6.14	5.76	5.53	5.39	5.28	5.21	5.15	5.10	5.08	5.00	4.96	4.90	4.86	4.83	4.80	4.77	4.75	4.73
7	1.89	2.36	14.07	5.59	5.74	5.36	5.13	5.00	4.88	4.81	4.75	4.70	4.68	4.60	4.56	4.50	4.46	4.43	4.40	4.37	4.35	4.33
8	1.86	2.31	15.51	5.32	5.48	5.10	4.87	4.74	4.62	4.55	4.49	4.44	4.42	4.34	4.30	4.24	4.20	4.17	4.14	4.11	4.09	4.07
9	1.83	2.28	16.92	5.12	5.28	4.90	4.67	4.54	4.42	4.35	4.29	4.24	4.22	4.14	4.10	4.04	4.00	3.97	3.94	3.91	3.89	3.87
10	1.81	2.23	18.31	4.96	5.11	4.73	4.50	4.37	4.25	4.18	4.12	4.07	4.05	3.97	3.93	3.87	3.83	3.80	3.77	3.74	3.71	3.69
11	1.80	2.20	19.68	4.84	4.98	4.60	4.37	4.24	4.12	4.05	3.99	3.94	3.92	3.84	3.80	3.74	3.70	3.67	3.64	3.61	3.58	3.56
12	1.78	2.18	21.03	4.75	4.89	4.50	4.27	4.14	4.02	3.95	3.89	3.84	3.82	3.74	3.70	3.64	3.60	3.57	3.54	3.51	3.48	3.46
13	1.77	2.16	22.36	4.67	4.81	4.41	4.18	4.05	3.93	3.86	3.80	3.75	3.73	3.65	3.61	3.55	3.51	3.48	3.45	3.42	3.39	3.37
14	1.76	2.14	23.68	4.60	4.74	4.34	4.11	3.98	3.86	3.79	3.73	3.68	3.66	3.58	3.54	3.48	3.44	3.41	3.38	3.35	3.32	3.30
15	1.75	2.13	25.00	4.54	4.68	4.28	4.05	3.92	3.80	3.73	3.67	3.62	3.60	3.52	3.48	3.42	3.38	3.35	3.32	3.29	3.26	3.24
16	1.75	2.12	26.30	4.49	4.63	4.23	4.00	3.87	3.75	3.68	3.62	3.57	3.55	3.47	3.43	3.37	3.33	3.30	3.27	3.24	3.21	3.19
17	1.74	2.11	27.59	4.46	4.59	4.19	3.96	3.83	3.71	3.64	3.58	3.53	3.51	3.43	3.39	3.33	3.29	3.26	3.23	3.20	3.17	3.15
18	1.73	2.10	28.87	4.41	4.55	4.15	3.92	3.79	3.67	3.60	3.54	3.49	3.47	3.39	3.35	3.29	3.25	3.22	3.19	3.16	3.13	3.11
19	1.73	2.09	30.14	4.38	4.52	4.12	3.89	3.76	3.64	3.57	3.51	3.46	3.44	3.36	3.32	3.26	3.22	3.19	3.16	3.13	3.10	3.08
20	1.72	2.08	31.41	4.35	4.49	4.10	3.87	3.74	3.62	3.55	3.49	3.44	3.42	3.34	3.30	3.24	3.20	3.17	3.14	3.11	3.08	3.06
21	1.72	2.08	32.67	4.32	4.47	4.07	3.84	3.71	3.59	3.52	3.46	3.41	3.39	3.31	3.27	3.21	3.17	3.14	3.11	3.08	3.05	3.03
22	1.72	2.07	33.92	4.30	4.44	4.04	3.81	3.68	3.56	3.49	3.43	3.38	3.36	3.28	3.24	3.18	3.14	3.11	3.08	3.05	3.02	3.00
23	1.71	2.07	35.17	4.28	4.42	4.02	3.79	3.66	3.54	3.47	3.41	3.36	3.34	3.26	3.22	3.16	3.12	3.09	3.06	3.03	3.00	2.98
24	1.71	2.06	36.42	4.26	4.40	4.00	3.77	3.64	3.52	3.45	3.39	3.34	3.32	3.24	3.20	3.14	3.10	3.07	3.04	3.01	2.98	2.96
25	1.71	2.06	37.68	4.24	4.38	3.98	3.75	3.62	3.50	3.43	3.37	3.32	3.30	3.22	3.18	3.12	3.08	3.05	3.02	2.99	2.96	2.94
26	1.71	2.06	38.93	4.23	4.37	3.97	3.74	3.61	3.49	3.42	3.36	3.31	3.29	3.21	3.17	3.11	3.07	3.04	3.01	2.98	2.95	2.93
27	1.70	2.06	40.11	4.21	4.35	3.95	3.72	3.59	3.47	3.40	3.34	3.29	3.27	3.19	3.15	3.09	3.05	3.02	2.99	2.96	2.93	2.91
28	1.70	2.06	41.36	4.20	4.34	3.94	3.71	3.58	3.46	3.39	3.33	3.28	3.26	3.18	3.14	3.08	3.04	3.01	2.98	2.95	2.92	2.90
29	1.70	2.06	42.60	4.18	4.32	3.92	3.69	3.56	3.44	3.37	3.31	3.26	3.24	3.16	3.12	3.06	3.02	2.99	2.96	2.93	2.90	2.88
30	1.70	2.04	43.77	4.17	4.31	3.91	3.68	3.55	3.43	3.36	3.30	3.25	3.23	3.15	3.11	3.05	3.01	2.98	2.95	2.92	2.89	2.87
34	1.69	2.03	48.00	4.13	4.28	3.88	3.65	3.52	3.40	3.33	3.27	3.22	3.20	3.12	3.08	3.02	2.98	2.95	2.92	2.89	2.86	2.84
44	1.68	2.02	60.78	4.08	4.23	3.84	3.61	3.48	3.36	3.29	3.23	3.18	3.16	3.08	3.04	2.98	2.94	2.91	2.88	2.85	2.82	2.80
60	1.68	2.01	87.50	4.03	4.18	3.79	3.56	3.43	3.31	3.23	3.16	3.10	3.08	2.99	2.95	2.89	2.85	2.82	2.79	2.76	2.73	2.71
80	1.67	2.00	113.15	4.00	4.15	3.76	3.53	3.40	3.28	3.21	3.15	3.09	3.07	2.97	2.93	2.87	2.83	2.80	2.77	2.74	2.71	2.69
100	1.67	1.99	138.58	3.98	4.13	3.74	3.51	3.38	3.26	3.19	3.13	3.07	3.05	2.95	2.91	2.85	2.81	2.78	2.75	2.72	2.69	2.67
120	1.67	1.99	163.58	3.96	4.11	3.72	3.49	3.36	3.24	3.17	3.11	3.05	3.03	2.93	2.89	2.83	2.79	2.76	2.73	2.70	2.67	2.65
140	1.67	1.98	188.58	3.95	4.10	3.71	3.48	3.35	3.23	3.16	3.10	3.04	3.02	2.92	2.88	2.82	2.78	2.75	2.72	2.69	2.66	2.64
160	1.66	1.98	213.58	3.94	4.09	3.70	3.47	3.34	3.22	3.15	3.09	3.03	3.01	2.91	2.87	2.81	2.77	2.74	2.71	2.68	2.65	2.63
180	1.66	1.98	238.58	3.93	4.08	3.69	3.46	3.33	3.21	3.14	3.08	3.02	3.00	2.90	2.86	2.80	2.76	2.73	2.70	2.67	2.64	2.62
200	1.66	1.97	263.58	3.92	4.07	3.68	3.45	3.32	3.20	3.13	3.07	3.01	2.99	2.89	2.85	2.79	2.75	2.72	2.69	2.66	2.63	2.61
300	1.66	1.96	388.58	3.90	4.05	3.66	3.43	3.30	3.18	3.11	3.05	3.00	2.98	2.88	2.84	2.78	2.74	2.71	2.68	2.65	2.62	2.60
400	1.66	1.96	463.58	3.89	4.04	3.65	3.42	3.29	3.17	3.10	3.04	2.99	2.97	2.87	2.83	2.77	2.73	2.70	2.67	2.64	2.61	2.59
500	1.66	1.96	538.58	3.88	4.03	3.64	3.41	3.28	3.16	3.09	3.03	2.98	2.96	2.86	2.82	2.76	2.72	2.69	2.66	2.63	2.60	2.58
600	1.66	1.96	613.58	3.87	4.02	3.63	3.40	3.27	3.15	3.08	3.02	2.97	2.95	2.85	2.81	2.75	2.71	2.68	2.65	2.62	2.59	2.57
700	1.66	1.96	688.58	3.86	4.01	3.62	3.39	3.26	3.14	3.07	3.01	2.96	2.94	2.84	2.80	2.74	2.70	2.67	2.64	2.61	2.58	2.56
800	1.66	1.96	763.58	3.85	4.00	3.61	3.38	3.25	3.13	3.06	3.00	2.95	2.93	2.83	2.79	2.73	2.69	2.66	2.63	2.60	2.57	2.55
900	1.66	1.96	838.58	3.84	3.99	3.60	3.37	3.24	3.12	3.05	2.99	2.94	2.92	2.82	2.78	2.72	2.68	2.65	2.62	2.59	2.56	2.54
1000	1.66	1.96	913.58	3.84	3.99	3.60	3.37	3.24	3.12	3.05	2.99	2.94	2.92	2.82	2.78	2.72	2.68	2.65	2.62	2.59	2.56	2.54
1500	1.66	1.96	1388.58	3.83	3.98	3.59	3.36	3.23	3.11	3.04	2.98	2.93	2.91	2.81	2.77	2.71	2.67	2.64	2.61	2.58	2.55	2.53
2000	1.66	1.96	1863.58	3.82	3.97	3.58	3.35	3.22	3.10	3.03	2.97	2.92	2.90	2.80	2.76	2.70	2.66	2.63	2.60	2.57	2.54	2.52
3000	1.66	1.96	2838.58	3.81	3.96	3.57	3.34	3.21	3.09	3.02	2.96	2.91	2.89	2.79	2.75	2.69	2.65	2.62	2.59	2.56	2.53	2.51
4000	1.66	1.96	3613.58	3.81	3.96	3.57	3.34	3.21	3.09	3.02	2.96	2.91	2.89	2.79	2.75	2.69	2.65	2.62	2.59	2.56	2.53	2.51
5000	1.66	1.96	4388.58	3.81	3.96	3.57	3.34	3.21	3.09	3.02	2.96	2.91	2.89	2.79	2.75	2.69	2.65	2.62	2.59	2.56	2.53	2.51
6000	1.66	1.96	5163.58	3.81	3.96	3.57	3.34	3.21	3.09	3.02	2.96	2.91	2.89	2.79	2.75	2.69	2.65	2.62	2.59	2.56	2.53	2.51
7																						

## Important Statistical Tables

An index of statistical tables follows the Contents

Four place common logarithms	12, 13
Four place antilogarithms	14, 15
Random numbers	52
Standard normal distribution	Top of front end-paper, 62, 217
$t$ -distribution	136, 137
$\chi^2$ -distribution	(DF = 1: Top of front end-paper, 349), 140, 141
$F$ -distribution	144–150
Binomial coefficients	158
Factorials	160
$2n \ln n$	353–358
Tolerance limits (normal distribution)	282
Distribution-free tolerance limits	284
Confidence interval:	
Median	317, 318
Lambda (Poisson distribution)	344, 345
$\pi$ (Binomial distribution)	703
Sample sizes:	
Counting	36, 181, 218, 283, 284, 337, 338, 350
Measurement	250, 262, 274, 283, 284
Correlation:	
Spearman's $\rho$	398, 399
Correlation coefficient	425
Finding $z$ in terms of $r$ and conversely	428
Cochran's test	497
Departure from normality test	253
Friedman's test	551
$H$ -test	305
Hartley's test	496
Run test	376, 377
Kolmogoroff–Smirnov goodness of fit test	331
Link–Wallace test	543, 544
Nemenyi comparisons	546, 547
Page test	554
Siegel–Tukey test	287
Standardized mean square successive differences test	375
Studentized range	535, 536
$U$ -test	297–301
Sign test	317, 318
Wilcoxon paired differences test	313
Wilcoxon–Wilcoxon comparisons	556, 557

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# CONTENTS



<b>Index of Statistical Tables</b>	xiii
<b>Preface to the Second English Edition</b>	xvii
<b>Preface to the First English Edition</b>	xviii
<b>From the Prefaces to Previous Editions</b>	xix
<b>Permissions and Acknowledgments</b>	xxiii
<b>Selected Symbols</b>	xxv
<b>Introduction</b>	1
<b>Introduction to Statistics</b>	3
<b>0 Preliminaries</b>	7
0.1 Mathematical Abbreviations	7
0.2 Arithmetical Operations	8
0.3 Computational Aids	19
0.4 Rounding Off	20
0.5 Computations with Inaccurate Numbers	21
<b>1 Statistical Decision Techniques</b>	23
1.1 What Is Statistics? Statistics and the Scientific Method	23
1.2 Elements of Computational Probability	26
▶ 1.2.1 Statistical probability	26
▶ 1.2.2 The addition theorem of probability theory	28
▶ 1.2.3 Conditional probability and statistical independence	31
1.2.4 Bayes's theorem	38
▶ 1.2.5 The random variable	43
1.2.6 The distribution function and the probability function	44

1.3	The Path to the Normal Distribution	47
▶ 1.3.1	The population and the sample	47
▶ 1.3.2	The generation of random samples	49
▶ 1.3.3	A frequency distribution	53
▶ 1.3.4	Bell-shaped curves and the normal distribution	57
▶ 1.3.5	Deviations from the normal distribution	65
▶ 1.3.6	Parameters of unimodal distributions	66
▶ 1.3.7	The probability plot	81
1.3.8	Additional statistics for the characterization of a one dimensional frequency distribution	85
1.3.9	The lognormal distribution	107
1.4	The Road to the Statistical Test	112
1.4.1	The confidence coefficient	112
1.4.2	Null hypotheses and alternative hypotheses	114
1.4.3	Risk I and risk II	117
1.4.4	The significance level and the hypotheses are, if possible, to be specified before collecting the data	120
1.4.5	The statistical test	120
1.4.6	One sided and two sided tests	124
1.4.7	The power of a test	125
1.4.8	Distribution-free procedures	130
1.4.9	Decision principles	133
1.5	Three Important Families of Test Distributions	134
1.5.1	The Student's $t$ -distribution	135
1.5.2	The $\chi^2$ distribution	139
1.5.3	The $F$ -distribution	143
1.6	Discrete Distributions	155
1.6.1	The binomial coefficient	155
▶ 1.6.2	The binomial distribution	162
1.6.3	The hypergeometric distribution	171
1.6.4	The Poisson distribution	175
▶ 1.6.5	The Thorndike nomogram	183
1.6.6	Comparison of means of Poisson distributions	186
1.6.7	The dispersion index	189
1.6.8	The multinomial coefficient	192
1.6.9	The multinomial distribution	193
2	Statistical Methods in Medicine and Technology	195
2.1	Medical Statistics	195
2.1.1	Critique of the source material	196
2.1.2	The reliability of laboratory methods	197
2.1.3	How to get unbiased information and how to investigate associations	202
2.1.4	Retrospective and prospective comparisons	206
2.1.5	The therapeutic comparison	210
2.1.6	The choice of appropriate sample sizes for the clinical trial	214
2.2	Sequential Test Plans	219
2.3	Evaluation of Biologically Active Substances Based on Dosage-Dichotomous Effect Curves	224
2.4	Statistics in Engineering	228
2.4.1	Quality control in industry	228
2.4.2	Life span and reliability of manufactured products	233



2.5	Operations Research	238
2.5.1	Linear programming	239
2.5.2	Game theory and the war game	239
2.5.3	The Monte Carlo method and computer simulation	241
<b>3</b>	<b>The Comparison of Independent Data Samples</b>	<b>245</b>
3.1	The Confidence Interval of the Mean and of the Median	246
▶ 3.1.1	Confidence interval for the mean	247
▶ 3.1.2	Estimation of sample sizes	249
3.1.3	The mean absolute deviation	251
3.1.4	Confidence interval for the median	254
▶ 3.2	Comparison of an Empirical Mean with the Mean of a Normally Distributed Population	255
▶ 3.3	Comparison of an Empirical Variance with Its Parameter	258
3.4	Confidence Interval for the Variance and for the Coefficient of Variation	259
3.5	Comparison of Two Empirically Determined Variances of Normally Distributed Populations	260
3.5.1	Small to medium sample size	260
3.5.2	Medium to large sample size	263
3.5.3	Large to very large sample size ( $n_1, n_2 \geq 100$ )	264
▶ 3.6	Comparison of Two Empirical Means of Normally Distributed Populations	264
3.6.1	Unknown but equal variances	264
3.6.2	Unknown, possibly unequal variances	271
3.7	Quick Tests Which Assume Nearly Normally Distributed Data	275
3.7.1	The comparison of the dispersions of two small samples according to Pillai and Buenaventura	275
3.7.2	The comparison of the means of two small samples according to Lord	276
3.7.3	Comparison of the means of several samples of equal size according to Dixon	277
3.8	The Problem of Outliers and Some Tables Useful in Setting Tolerance Limits	279
3.9	Distribution-Free Procedures for the Comparison of Independent Samples	285
3.9.1	The rank dispersion test of Siegel and Tukey	286
3.9.2	The comparison of two independent samples: Tukey's quick and compact test	289
3.9.3	The comparison of two independent samples according to Kolmogoroff and Smirnov	291
▶ 3.9.4	Comparison of two independent samples: The U-test of Wilcoxon, Mann, and Whitney	293
3.9.5	The comparison of several independent samples: The $H$ -test of Kruskal and Wallis	303
<b>4</b>	<b>Further Test Procedures</b>	<b>307</b>
4.1	Reduction of Sampling Errors by Pairing Observations: Paired Samples	307

4.2	Observations Arranged in Pairs	309
4.2.1	The $t$ -test for data arranged in pairs	309
4.2.2	The Wilcoxon matched pair signed-rank test	312
4.2.3	The maximum test for pair differences	315
4.2.4	The sign test of Dixon and Mood	316
4.3	The $\chi^2$ Goodness of Fit Test	320
4.3.1	Comparing observed frequencies with their expectations	321
4.3.2	Comparison of an empirical distribution with the uniform distribution	322
4.3.3	Comparison of an empirical distribution with the normal distribution	322
4.3.4	Comparison of an empirical distribution with the Poisson distribution	329
4.4	The Kolmogoroff-Smirnoff Goodness of Fit Test	330
4.5	The Frequency of Events	333
4.5.1	Confidence limits of an observed frequency for binomially distributed population. The comparison of a relative frequency with the underlying parameter	333
4.5.2	Clopper and Pearson's quick estimation of the confidence intervals of a relative frequency	340
4.5.3	Estimation of the minimum size of a sample with counted data	341
4.5.4	The confidence interval for rare events	343
4.5.5	Comparison of two frequencies; testing whether they stand in a certain ratio	345
4.6	The Evaluation of Fourfold Tables	346
4.6.1	The comparison of two percentages—the analysis of fourfold tables	346
4.6.2	Repeated application of the fourfold $\chi^2$ test	360
4.6.3	The sign test modified by McNemar	363
4.6.4	The additive property of $\chi^2$	366
4.6.5	The combination of fourfold tables	367
4.6.6	The Pearson contingency coefficient	369
4.6.7	The exact Fisher test of independence, as well as an approximation for the comparison of two binomially distributed populations (based on very small samples)	370
4.7	Testing the Randomness of a Sequence of Dichotomous Data or of Measured Data	373
4.7.1	The mean square successive difference	373
4.7.2	The run test for testing whether a sequence of dichotomous data or of measured data is random	375
4.7.3	The phase frequency test of Wallis and Moore	378
4.8	The $S_3$ Sign Test of Cox and Stuart for Detection of a Monotone Trend	379
5	Measures of Association: Correlation and Regression	382
5.1	Preliminary Remarks and Survey	382
5.1.1	The Bartlett procedure	390
5.1.2	The Kerrich procedure	392
5.2	Hypotheses on Causation Must Come from Outside, Not from Statistics	393