"current comments"

Highly Cited Works in Mathematics. Part 2. "Applied" Mathematics.

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In a previous editorial[1] I presented a list of highly cited works in "pure" mathematics–books and journal articles cited in the *Science Citation Index®* (*SCI®*) during the period 1961-1972. At the end of this editorial, you will find a similar list of books and journal articles in "applied" mathematics, heavily cited in the same 1961-1972 period. I refer the reader to the previous editorial for a detailed explanation of how these lists were compiled from ISI®'s data base of 30 million citations.

Briefly, we first identified highly cited books and journal articles on mathematics and its applications in research, and then classified the items retrieved as either "pure" or "applied" mathematics. Classification was accomplished by a computer algorithm.[2] To make it as "pure" mathematics, the algorithm required that an item have been cited in 1972 at least 4 times by articles from mathematics and statistics journals covered by the *SCI*. It required further that the item be cited in common with some other item by at least 3 articles in those same 1972 issues. Articles that *did* make it were classified as "pure" mathematics, and were listed in the editorial noted above. Others were classified as "applied" mathematics and they are listed on pages 7-9 following.

There will undoubtedly be differences of opinion about whether a particular item belongs on one list or the other, or on either list at all. But the heavy citation is undoubtedly significant as a whole--though undoubtedly for different reasons in connection with different items--and we offer this list, as we did that on "pure" mathematics, as another example of statistical bibliography (bibliometrics).

There are 72 items on the list (space in these pages limited the list to articles cited 90 or more times during the 1961-1972 period). Of the 72 items, 46 (64%) are books, and 26 (36%) are journal articles.[3] A rough analysis of my own shows that of the 72 items, about 39% deal with statistics generally, about 27% with biometrics specifically, about 17% with mathematical physics and technometrics, and about 17% with what I take to be analyses of specific mathematical topics for varied application.[4]

The ranking of these items will not, I hope, become a matter for "subjective-analytical" contention. The ranking is by citation totals over a twelve-year period. Although I believe the citation totals indicate much, I know--as I have said and written many times before and shall continue to say and write--that they do not indicate everything. I hope all will agree, however, that they suggest worthwhile subjects for speculation and study. Why *does* one item rank above another?

For example, Snedecor's well-known *manual*[5] leads the list. The book is responsible for the appearance of Professor Snedecor's name on other "most-cited" lists we have compiled.[6] I am sure it will neither surprise nor offend Professor Snedecor if I say that there may be other items lower ranked on the list that probably exceed his book in scholarly merit in one way or another, if one is thinking in terms of the development of statistical theory or

some such thing. His widely-used handbook was written for the benefit of research workers and students of statistics. It was written to make statistics accessible to non-mathematicians and non-statisticians for improvement of their experimental methodology. The citation record shows (as does the book's publication history) that it has been used as it was written to be used, by those who needed an explanation of statistical method, and examples of its application in their own fields. In other words, the citation record records the *impact* the book has indeed had, the impact I am sure its author hoped it would have, in improving the rigor of experimental analysis. As such it can surely be said to have made a "contribution" to statistics that perhaps more scholarly works have not--and perhaps won't until some other Snedecor digests them and makes them accessible for application by non-statisticians. It is this kind of speculation and examination that I hope these lists will inspire.

One thing is certain, however. As a whole the list shows the critical role played by statistics in not only the "hard" sciences, but in the social sciences as well.[7] It is probably impossible to overemphasize the role of statistics for the future of research in the social sciences and for the future development of social policy. Sociologists continually complain of the lack of data, or of the lack of proper statistical analysis of available data, in historical and sociological studies.[8] In fact, it may be (as some would complain) difficult to think of sociological research within any other framework *but* the statistical. Earlier this year, W. Kruskal reminded us of "that huge cloud of statistical thought and action that suffuses all government activity . . . " and called for an improvement of communication between statisticians working in various areas of the social sciences.[9] Perhaps citation analysis and lists like that which follows, may help in this respect as well.[10]

1. Garfield, E. Highly cited works in mathematics. Part 1. "Pure" mathematics. *Current Contents*® No. 47, 21 November 1973, p. 5-9.

2. I am glad to acknowledge again the aid of Professor Kenneth O. May of the University of Toronto for his comments on problems involved in differentiating between the "pure" and "applied."

3. An interesting comparison is that of 78 items on the "pure" mathematics list, 56 (72%) were books and only 22 (28%) were journal articles.

4. In cases of the last, especially, I suspect some readers may think that an item should have appeared on the list of "pure" mathematics. We have listed them here, however, as "instructed" by our rigorous algorithm.

5. G.W. Snedecor & W.G. Cochran, *Statistical methods*. 6th ed. Ames: Iowa St. Univ. Press, 1967.

6. For example, see: Garfield, E. More on forecasting Nobel Prizes and the most cited scientists of 1972. *Current Contents* No. 40, 3 October 1973, p. 5-7.--In 1967 Snedecor ranked as 10th most cited *author* (904 citations); in 1972 as 5th (1185 citations); and for the period 1961-1972 as 7th (10,279 citations). See also: Garfield, E. Play the new game of twenty citations: wherein ISI reveals the fifty most frequently cited "non-journal" items. *Current Contents* No. 32, 11 August 1971, p. 5-9.--Among "non-journal" items cited in 1967, Snedecor's *Statistical Methods* (with 880 citations) was the most frequently cited monograph.

7. This dual role of statistics presented something of a dilemma in establishing criteria for inclusion of journals in ISI's *Social Sciences Citation Index*™ *(SSCI*™*)*. To have included all statistical journals would have put into the *SSCI* thousands of irrelevant articles on statistical methodology in the hard sciences. Our solution was to select articles from non-biometrics and non-social science journals if they cited two or more articles from social-science journals.

8. See, for example, almost any chapter of S.M. Lipset, *Revolution and Counter Revolution: Change and Persistence in Social Structures*. New York: Basic Books, 1968.

9. Kruskal, W. The Committee on National Statistics. *Science* 180(4092): 1256-8, 1973.

10. As regards the importance of statistics for the social sciences, it is interesting to note the membership in the Allied Social Sciences Associations (ASSA) of the American Statistical Association, the Biometrics Society, and the Institute of Mathematical Statistics as well. The ASSA is holding its 1973 Annual meeting in New York, December 27-30.

A List of Highly Cited Works in Mathematics, 1961-1972. Part 2. "Applied" Mathematics

Rank	Total Citations 1961-1972	Total Citations 1972	Bibliographical Data
(1)	(2)	(3)	(4)
1.	3254	795	Snedecor, G.W. & Cochran, W.G. *Statistical methods.* 6th ed. Iowa, 1967.
2.	2770	273	Duncan, D.B. Multiple range and multiple *F* tests. *Biometrics.* 11: 1-42, 1955.
3.	1824	470	Siegel, S. *Nonparametric statistics for the behavioral sciences.* McGraw, 1960.
4.	1514	524	Steel, R.G. & Torrie, J.H. *Principles and procedures of statistics.* McGraw, 1960.
5.	1444	471	Winer, B.J. *Statistical principles in experimental design.* McGraw, 1962.
6.	622	199	Abramowitz, M. & Stegun, I.A., eds. *Handbook of mathematical functions with formulas, graphs and mathematical tables.* Dover, 1964.
7.	432	79	Cooley, J.W. & Tukey, J.W. An algorithm for the machine calculation of complex Fourier series. *Math. Comput.* 19(90):297-301, 1965.
8.	398	52	Kramer, C.Y. Extension of multiple range tests to group means with unequal numbers of replications. *Biometrics.* 12:307-310, 1956.
9.	341	102	Dixon, W.J. & Massey, F.J.,Jr. *Introduction to statistical analysis. 3rd ed.* McGraw, 1969.
10.	322	23	Wigner, E.P. On unity representations of the inhomogenous Lorentz group. *Ann. Math.* 40:149-204, 1939.
11.	315	45	Lindquist, E.F. *Design and analysis of experiments in psychology and education.* HM, 1956.
12.	307	75	Finney, D.J. *Statistical methods in biological assay.* Hafner, 1964.
13.	299	90	Crank, J. *Mathematics of diffusion.* Oxford, 1956.
14.	264	50	Cochran, W.G. & Cox, G.M. *Experimental designs.* Wiley, 1957.
15.	251	30	Cochran, W.G. Some methods for strengthening the common chi-square tests. *Biometrics.* 10:417-451, 1954.
16.	247	55	Edwards, A.L. *Experimental design in psychological research.* HR&W, 1968.
17.	247	38	Dunnett, C.W. A multiple comparison procedure for comparing several treatments with a control. *J. Amer. Statist. Assoc.* 50:1096-1121, 1955.
18.	246	53	Finney, D.J. *Probit analysis.* Cambridge, 1971.
19.	237	85	Sokal, R.R. & Sneath, P.H. *Principles of numerical taxonomy.* Freeman, 1963.
20.	237	12	Hays, W.L. *Statistics for psychologists.* HR&W, 1963.
21.	234	55	Watson, G.N. *Theory of Bessel functions.* Cambridge, 1944.
22.	232	31	Fisher, M.E. Correlation function and the critical region of simple fluids. *J. Math. Phys.* 5:944-962, 1964.
23.	225	28	Fisher, R.A. *Statistical methods for research workers.* Hafner, 1969.
24.	211	92	Draper, N. & Smith, H. *Applied regression analysis.* Wiley, 1966.

A List of Highly Cited Works in Mathematics, 1961-1972. This list shows, in order of decreasing frequency of citation, works in applied mathematics highly cited during the period 1961-1972. Column 1 shows the rank of the item on this list. Column 2 shows the total number of times the item was cited by journals indexed in the *Science Citation Index* during the period 1961-1972. Column 3 shows the number of times the item was cited in 1972 only. Column 4 gives full bibliographic data. Publisher information in the case of books has been abbreviated. Full information is as follows (as a matter of interest we have included in

Rank	Total Citations 1961-1972	Total Citations 1972	Bibliographical Data
(1)	(2)	(3)	(4)
25.	211	12	Mann, H.B. On a test of whether one of two random variables is stochastically larger than the other. *Ann. Math. Statist.* 18:50-60, 1947.
26.	210	16	Newton, R.G. Analytic properties of radial wave functions. *J. Math. Phys.* 1:319-347, 1960.
27.	206	10	Lehmann, H. Über Eigenschaften von Ausbreitungsfunktionen und Renormierungskonstanten quantisierter Felder. *Nuovo Cimento.* 11:342-357, 1954.
28.	194	14	Suzuki, M. Consequences of current commutation relations in the nonleptonic hyperon decays. *Phys. Rev. Letters.* 15:986-989, 1965.
29.	189	38	Fisher, R.A. Dispersion on a sphere. *P. Roy. Soc. London A.* 217:295-305, 1953.
30.	185	42	Rao, C.R. *Advanced statistical methods in biometric research.* Hafner, 1952.
31.	184	24	Penrose, R. A generalized inverse for matrices. *Camb. Phil. Soc. Proc.* 51:406-413, 1955.
32.	183	12	Cutkosky, R.E. Singularities and discontinuities of Feynman amplitudes. *J. Math. Phys.* 1:429-433, 1960.
33.	162	23	Fisher, R.A. & Yates, F. *Statistical tables for biological, agricultural and medical research.* Hafner, 1964.
34.	160	87	Sokal, R.R. & Rohlf, F.J. *Biometry, the principles and practice of statistics in biological research.* Freeman, 1969.
35.	160	0	Bargmann, V. & Wigner, E.P. Group theoretical discussion of relativistic equations. *P. Natl. Acad. Sci. USA.* 34:211-223, 1948.
36.	143	32	Hooke, R. & Jeeves, T.A. "Direct search" solution of numerical and statistical problems. *J. Assoc. Comp. Mach.* 8:212-229, 1961.
37.	139	50	Papoulis, A. *Probability, random variables and stochastic processes.* McGraw, 1965.
38.	138	17	Wald, A. *Sequential analysis.* Wiley, 1947.
39.	131	12	Peaceman, D.W. The numerical solution of parabolic and elliptic differential equations. *J. Soc. Ind. Appl. Math.* 3:28-41, 1955.
40.	125	26	Lehman, E.L. *Testing statistical hypotheses.* Wiley, 1959.
41.	122	33	Eden, L.J. *et al. Analytic S-matrix.* Cambridge, 1966.
42.	122	20	Middleton, D. *Introduction to statistical communication theory.* McGraw, 1960.
43.	122	20	Walker, H.M. & Lev, J. *Statistical inference.* HR&W, 1953.
44	122	15	Slepian, D. Prolate spheroidal wave functions, Fourier analysis and uncertainty. *Bell Syst. Tech. J.* 40:43-46, 1961.
45.	122	14	Grad, H. On the kinetic theory of rarefied gases. *Comm. Pure Appl. Math.* 2:331-407, 1949.
46.	121	31	Davis, P.J. *Interpolation and approximation.* Blaisdell, 1963.
47.	120	38	Hill, R. *Mathematical theory of plasticity.* Oxford, 1950.

parentheses after the listed abbreviation the number of items each publisher contributed to the list):

AW (1) Reading, Mass.: Addison-Wesley Publishing Co., Inc. Blaisdell (1) New York: Blaisdell Publishing Co., Inc. Cambridge (4) New York: Cambridge University Press Chicago (1) Chicago: University of Chicago Press Dover (3) New York: Dover Publications, Inc. Freeman (2) San Francisco: W.H. Freeman & Co. Hafner (4) New York: Hafner Publishing

Rank	Total Citations 1961-1972	Total Citations 1972	Bibliographical Data
(1)	(2)	(3)	(4)
48.	119	21	Hartley, H.O. The modified Gauss-Newton method for the fitting of non-linear regression functions by least squares. *Technometrics.* 3:269-280, 1961.
49.	116	39	Nalimov, V.V. *Application of mathematical statistics to chemical analysis.* AW, 1962.
50.	114	32	Richtmyer, R.D. *Difference methods for initial-value problems.* Wiley, 1967.
51.	114	21	Riesz, F. & Nagy, B.S. *Functional analysis.* Ungar, 1955.
52.	114	0	Shannon, C.E.Communication in the presence of noise. *PIRE.* 37:10-21, 1949.
53	113	33	Hardy, G.H. *et al. Inequalities.* Cambridge, 1952.
54.	111	40	Hildebrand, F.B. *Introduction to numerical analysis,* McGraw, 1956.
55.	108	31	Sneddon, I.N. *Fourier transformations.* McGraw, 1951.
56.	108	15	Kac, M., Uhlenbeck, G.E. & Hemmer, P.C. On the Van der Waals theory of the vapor-liquid equilibrium. 1. Discussion of a one-dimensional model, *J. Math. Phys.* 4:216-223, 1963.
57.	105	26	Shannon, C.E. & Weaver, W. *Mathematical theory of communication.* Illinois, 1949.
58.	104	29	Cooley, W.W. & Lohnes, P.R. *Multivariate data analysis.* Wiley, 1971.
59.	101	34	Harmon, H.H. *Modern factor analysis.* Chicago, 1967.
60.	101	25	Titchmarsh, E.C. *Theory of functions.* Oxford, 1939.
61.	101	10	Henderson, C.R. Estimation of variance and covariance components. *Biometrics.* 9:226-252, 1953.
62.	98	38	Bailey, N.T.J. *Statistical methods in biology.* Wiley, 1959.
63.	98	32	Erdelyi, A. *Asymptotic expansions.* Dover, 1961.
64.	95	15	Duncan, D.B. Multiple range tests for correlated and heteroscedastic means. *Biometrics.* 13:164-176, 1957.
65.	94	32	Goldstein, A. *Biostatistics.* Macmillan, 1964.
66.	94	14	Box, G.E.P. & Wilson, K.B. On the experimental attainment of optimum conditions. *J. Roy. Stat, Soc. B.* 13:1-45, 1951.
67.	93	35	Harrington, R.F. *Field computation by moment methods.* Macmillan, 1968.
68.	93	17	Powell, M.J.D. Method for minimizing a sum of squares of non-linear functions without calculating derivatives. *Computer J.* 7:303-307, 1965.
69.	91	42	Morrison, D.F. *Multivariate statistical methods.* McGraw, 1967.
70.	91	25	Bendat, J.S. & Peirson, A.G. *Measurement and analysis of random data.* Wiley, 1966.
71.	91	18	Jahnke, E. & Emde, F. *Tables of functions with formulae and curves.* Dover, 1945.
72.	90	23	Bellman, R. *Introduction to matrix analysis.* McGraw, 1960.

Co., Inc. HM (1) Boston: Houghton Mifflin Co. HR&W (3) New York: Holt, Rinehart & Winston, Inc. Illinois (1) Urbana: University of Illinois Press Iowa (1) Ames: Iowa State University Press Macmillan (2) New York: Macmillan Company McGraw (10) New York: McGraw-Hill Book Company Oxford (3) New York: Oxford University Press Ungar (1) New York: Frederick, Ungar, Publishing Co., Inc. Wiley (8) New York: John Wiley & Sons, Inc.