Scientific contribution of Professor Mahalanobis: a bio-bibliometric study

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On the 125th birth anniversary of Professor Prasanta Chandra Mahalanobis, the authors analyse characteristic features, pattern and citation impact of the great Indian scientist and statistician's scientific works. A bibliography of his scientific contributions was prepared. It contained 6 books, 142 journal articles, 87 conference papers and 38 research reports. The study categorizes and presents the data according to year-wise contribution, authorship pattern, collaborators, preferred journals for communication, country-wise publications, top cited authors, citation history and citation impact. The study revealed that his research productivity peaked during 1934 to 1938 at the ages 41–45, with contribution of 77 scientific works. Further, the citation history of top 11 cited papers during 1990–2017 indicates that his publications are still being cited regularly which proves the continued relevance of his theory and applications over time.

Keywords: Bio-bibliometric study, Prasanta Chandra Mahalanobis, scientometric study, statistics, Indian Statistical Institute.

THE year 2017–18 is being celebrated as the 125th birth anniversary year of Professor Prasanta Chandra Mahalanobis (1893–1972), the eminent Indian scientist and statistician. On this occasion, the authors pay their homage to him by portraying his research contributions. The present bio-bibliometric study is an effort to demonstrate the significance of 'Mahalanobis theory and application' in today's research activities by sketching the trend, pattern and citation impact of his work. According to Sen and Gan[1], the term 'bio-bibliometrics' means quantitative and analytical assessment of an author/scientists's publications to evaluate his research impact and scientific achievement.

The Mahalanobis era (1920–1972) is recognized as the golden period of statistics. In 1922, Mahalanobis became a professor of physics at the Presidency College, Calcutta where he taught for over thirty years. He was a physicist by training, a statistician by instinct and a planner by conviction[2]. He not only contributed to statistical theory, but applied it to different disciplines like anthropology, agriculture, psychology, education, biological sciences, economics, demography, meteorology, rainfall and flood control, etc. In 1931, he founded the Indian Statistical Institute (ISI) at Calcutta, for high-level research, training and execution of large scale projects. He was the founder editor of *Sankhya: the Indian Journal of Statistics*, publishing scholarly articles since 1933. He also applied statistical data as an aid to administrative decisions. He submitted the Draft Plan-frame for the second five year plan to Government of India. Mahalanobis was the recipient of *Padma Vibhushan*, the highest civilian award of India and was a fellow of the Royal Society.

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Review of the related literature

Bio-bibliometric studies of other well known Indian scientists summarize some of their early scholarly work. Kalyane and Kademani[3] revealed that during 1958–1993, R. Chidambaram, the well-known nuclear physicist, published a total of 164 papers, of which 114 were published with 55 collaborators. At 22 years of age, he published his first paper and his publication productivity co-efficient was found to be 0.66. In another paper, Kademani and Kalyane[4] analysed the citations of the publications of R. Chidambaram and reported that the publications received a total of 1302 citations. They also studied the categories of citing documents and their distribution.

Parvathamma *et al.*[5], in their bio-bibliometric study of Atul H. Chokshi, analysed 76 research articles and 34 conference papers. They found that his publications have received 2820 citations and his name has been listed in the top 100 most cited authors in materials science. The *Journal of the American Ceramic Society*, USA

Table 1. Year-wise scientific contributions of Mahalanobis

Age of PCM	Year	Scientific contributions				Total	Cumulative total	Times cited	Average citations per publication
		Book	Journal articles	Conference papers	Research report				
26–30	1919–23	–	5	10	–	15	15	42	2.8
31–35	1924–28	–	5	8	1	14	29	403	28.78
36–40	1929–33	–	20	17	3	40	69	428	10.7
41–45	1934–38	1	41	33	2	77	146	6669	86.61
46–50	1939–43	–	16	6	21	43	189	167	3.88
51–55	1944–48	–	10	3	3	16	205	618	38.62
56–60	1949–53	–	10	2	5	17	222	691	40.64
61–65	1954–58	1	09	1	2	13	235	346	26.61
66–70	1959–63	3	16	3	–	22	257	379	17.22
71–75	1964–68	1	7	2	1	11	268	47	4.27
76–78	1969–71	–	3	2	–	5	273	49	9.8
Total		6	142	87	38	273		9839	36.04

was his most preferred journal for publishing research findings.

Mukherjee[6] examined 222 unique publications of Lalji Singh, an eminent Indian scientist in the field of genome analysis. There were at least 805 different authors who collaborated with him in different articles published in 113 journals. On an average, he received 17.83 citations per paper.

Mukhopadhyay[7] assessed the citation profiles of three Indian scientists: J. C. Bose, S. N. Bose and K. C. Kar. The study pointed out that these eminent scientists did not collaborate frequently and revealed that K. C. Kar worked with maximum 28 collaborators in 63 papers. The research publications of S. N. Bose received maximum citations among them.

Das and Bhattacharya[8] revealed that the Nobel Laureate Amartya Sen published 225 papers during 1957–2016. He published most of his papers independently. Most of his papers were published in foreign journals. *The New York Review of Books; Philosophy* and *Public Affairs* and *The Review of Economic Studies* were his most preferred journals.

Objectives of the study

The aim of the present study was to demonstrate the research publication pattern and the time-honoured relevance of research work of Mahalanobis and ideas by assessing citation impact of his scientific contributions. The other objectives of the study are: (i) to illustrate the year and age-wise distribution of publication productivity with their citations, (ii) to assess the research team of Mahalanobis, the authorship pattern, collaboration and citations, (iii) to depict the preferred journals for publishing research articles and the country of origin of the journal with distribution of citations and (iv) to examine the top cited works, their citations history and the citation impact of publications.

Scope and methodology

The present bio-bibliometric study is limited to the scientific publications of Prasanta Chandra Mahalanobis (PCM). The study excludes Bengali publications on Tagore and the state of culture, literature, etc. The bibliographical list of scholarly publications of Mahalanobis was compiled by consulting various sources – *National Biography of PCM*[9], the *Biographical Memoirs of Fellows of the Royal Society*[2] and the *Google Scholar* (GS) database[10]. Besides these, different literature, bibliographical sources and articles were also consulted. The bibliographic data of each selected papers were recorded for further study and analysis.

The study identified 6 books, 142 journal articles, 87 conference papers and 38 research reports. The bibliographic data of 273 scholarly contributions of Mahalanobis were taken as the sample for the present study. The citation impact of publications was taken from the GS database[10] (as on December 2017) that indexes the full text or metadata of scholarly literature across an array of publishing formats and disciplines. The data, thus obtained, was categorized, tabulated and presented using Microsoft Office software.

Data presentation and interpretation

The following sections illustrate the detailed result of the study with data analysis and interpretations.

Year-wise scientific contributions

The scientific contribution of Mahalanobis spread over 52 years from 1919 to 1971. During this long journey, he published 6 books, 142 journal articles, 87 conference papers and 38 research reports cumulating to 273 scientific works. At the age of 26, he published his first article

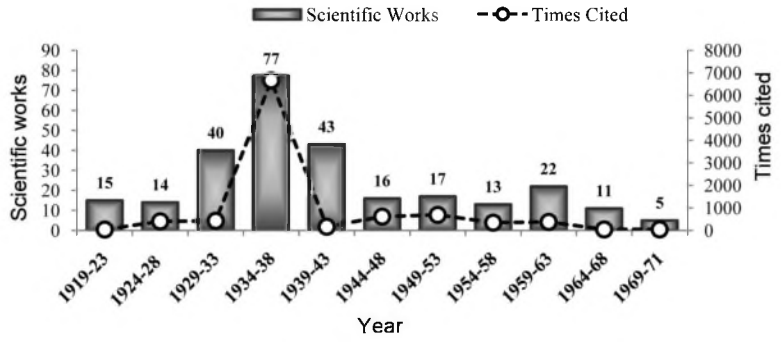

Figure 1. Chronological distribution of scientific contributions of Mahalanobis.

and the journey ended at the age of 78. Table 1 and Figure 1 illustrate the year-wise distribution of his research contribution. Out of 53 years of productive age, the research activities peaked at the age 41 (1934) to 45 (1938), with a contribution of 77 research works consisting of 1 book, 41 journal articles, 33 conference papers and 2 research reports. By 45 years of age he had published 146 scientific works which is more than 50% of his total contribution. The 77 scientific research works during 1934–38 received maximum average citations of 86.61 followed by 17 scientific research works which received 40.64 average citations per paper during 1949–1953.

Authorship pattern

Out of 229 research articles, Mahalanobis authored 156 (68.12%) research papers as the sole author. Table 2 examines the authorship pattern and collaborative scenario of his research work. His single contribution of 156 research papers (68.12%) consists of 103 journal articles (72.53%) and 53 conference papers (61%). The study further revealed that these research papers received the highest average citations per paper (57.48). The remaining 73 research papers (39 journal articles and 34 conference papers) have been written in collaboration with 48 authors. Mahalanobis published 46 research papers (20.08%) including 22 journal articles (15.49%) and 24 conference papers (27.6%) jointly with one author. Four-authored research papers (0.87%) received 22 average citations per paper. This is followed by 25 three-authored research papers (10.91%) which received 16.4 average citations per paper.

Collaborative authors

Table 3 shows the name and contribution of most collaborating authors who shared at least 2 papers with Mahalanobis. He collaborated with 48 authors and published 73 scientific works which received 644 citations. During 1932–39, Mahalanobis published 34 papers (33.33%) including 22 journal articles and 12 conference papers jointly with his colleague, Subhendu Sekhar Bose which received an average citation of 3.62 per paper. His collaboration with R. C. Bose led to 4 research publications with an average of 21 citations per paper. His collaboration with K. C. Banerjee and S. C. Chakravarti also led to 4 publications each. The highest cited papers were with C. R. Rao and D. N. Majumdar respectively with an average citation of 134.5 per paper. It transpires that Mahalanobis first jointly published paper at the age of 39 (1932) and the collaborative contribution continued up to his age of 56 (1949).

Preferred journals for communication of research results

Mahalanobis chose numerous peer-reviewed journals to publish his research work. Table 4 lists these preferred journals. He published 142 articles in 32 journals. These received 3144 citations with an average citation of 22.14 per paper. *Sankhya: the Indian Journal of Statistics* was his most preferred journal with 65 articles, followed by the *Indian Journal of Agricultural Science* with 20 articles and *Science and Culture* with 10 articles each. He also published 9 articles in the *Bulletin of the International Statistical Institute* and 4 articles in the *Record of the Indian Museum.* Mahalanobis published 2 articles each in 7 journals.

Country-wise distribution of journals

Works of Mahalanobis appear both in international and national journals. Table 5 examines the country-wise distribution of preferred journals that are published from 7 countries. He published 117 articles (82.39%) in 18 journals originating from India, followed by 9 articles (6.34%) in one journal originating from the Netherlands, 8 articles (5.63%) in 6 journals from UK and 3 articles (2.11%) in 3 journals of Japan. The citation study shows that articles published in journals from the UK received maximum average citations of 84.25 per paper followed by journals from the USA with average citations of 21.5

Table 2. Authorship pattern and collaboration of Mahalanobis

Authorship	No. of papers		Total papers	Percentage	Times cited	Average citations per paper
	Journal articles	Conf. papers				
Non-collaborative papers	103 (72.53%)	53 (61%)	156	68.12	8968	57.48
Joint authors	22 (15.49%)	24 (27.6%)	46	20.08	190	4.13
Three authors	16 (11.26%)	9 (10.34%)	25	10.91	410	16.40
Four authors	1 (0.7%)	1 (1.15%)	2	0.87	44	22.00
Total	142	87	229	100	9612	41.97

Table 3. Most productive collaborators of Mahalanobis

Author name	No. of papers		Total	Percentage	Times cited	First-last publication year (Years of association)	Average citations per paper
	Journal articles	Conf. papers					
Subhendu Sekhar Bose	22	12	34	33.33	123	1932–39 (8)	3.62
K. C. Banerjee	2	2	4	3.92	0	1935–38 (4)	0
Raj Chandra Bose	1	3	4	2.94	84	1935–37 (3)	21
S. C. Chakravarti	3	1	4	3.92	0	1936–38 (3)	0
Anil Chandra Nag	1	2	3	2.94	8	1933–34 (2)	2.66
Prabhat Ranjan Ray	1	2	3	2.94	43	1933–35 (3)	14.34
Samarendra Nath Roy	1	2	3	2.94	84	1936–37 (2)	28
Chameli Bose	1	1	2	1.96	06	1941–42 (2)	3
C. J. Harrison	2	0	2	1.96	0	1935 (1)	0
C. R. Rao	1	1	2	1.96	269	1946–49 (4)	134.5
D. N. Majumdar	1	1	2	1.96	269	1946–49 (4)	134.5
D. P. Acharya	1	1	2	1.96	0	1936–37 (2)	0
Satyabrata Sen	2	0	2	1.96	37	1940–53 (14)	18.5

Table 4. List of preferred journals with minimum two articles published

Journal	Country	No of articles published	Times cited	Average citations per article
Sankhya: The Indian Journal of Statistics	India	65	1539	23.68
Indian Journal of Agricultural Science	India	20	9	0.45
Science and Culture	India	10	3	0.30
Bulletin of the International Statistical Institute	Netherlands	9	73	8.11
Record of the Indian Museum	India	4	45	11.25
Agriculture Live-stock in India	India	2	0	0.00
Biometrika	UK	2	36	18.00
Journal and Proceedings of Asiatic Society Bengal	India	2	489	244.5
Memoirs of the Indian Meteorology, Rainfall and Flood Department	India	2	3	1.50
Nature	UK	2	9	4.50
Sovremennyi Vostok (Contemporary East)	USSR	2	1	0.50
The Indian Journal of Labour Economics	India	2	6	3.00

per paper and journals from India with average citations of 20.06 per paper. Altogether, the average citation per paper published in journals is 22.14.

Domain-wise distribution of scientific papers

In order to identify the impact of scientific contribution of Mahanalobis in different domains of knowledge, the authors studied the title, keywords, and abstracts of 229 papers. Mahalanobis judged statistics in a broader sense and applied the principles in different disciplines. The study identified 8 domains as demonstrated in Table 6. In *Agriculture*, he published 62 scientific papers which received 3.72 average citations per paper followed by *Mathematics and Statistics* with 52 papers having 143.54 average citations per paper. Some papers dealt with more than one category.

Distribution of scientific papers by citation

Mahalanobis published 229 articles in journals and conferences. Table 7 lists the distribution of scientific

Table 5. Country-wise distribution of journals

Country	No. of journals	Total articles	Percentage	Times cited	Average citations per paper
India	18	117	82.39	2347	20.06
The Netherlands	1	9	6.34	73	8.11
UK	6	8	5.63	674	84.25
Japan	3	3	2.11	06	2.00
USSR	1	2	1.41	1	0.50
USA	2	2	1.41	43	21.50
Mexico	1	1	0.70	–	0.00
Total	32	142	100.00	3144	22.14

Table 6. Distribution of scientific papers by domains

Domain	Scientific papers		Total	Times cited	Average citations per paper
	Journal articles	Conference papers			
Agriculture	44	18	62	231	3.72
Mathematics and statistics	29	23	52	7464	143.54
Anthropology	16	10	26	1111	42.73
Demography and sociology	14	12	26	149	5.73
Economics, planning and industry	17	4	21	607	28.90
Meteorology, rainfall and flood control	7	12	19	0	0
Education and intelligency	8	5	13	10	0.77
Biological sciences	1	3	4	0	0
Others	6	3	9	21	2.33

Table 7. Distribution of scientific papers on the basis of citations received

Citation range	Papers		Total	Percentage	Cumulative percentage	Times cited	Average citations per paper
	Journal	Conference					
≥500	0	1	01	0.44	0.44	6412	6412
≥100 <500	10	0	10	4.37	4.81	2285	228.50
≥50 <100	4	0	04	1.75	6.56	298	74.50
≥20 <50	10	1	11	4.80	11.36	318	28.90
≥10 <20	7	1	08	3.49	14.85	110	13.75
≥1 <10	53	11	64	27.95	42.80	189	2.95
0	58	73	131	57.21	100	0	0
Total	142	87	229	100.00		9612	41.97

papers by citation. The papers have been categorized on the basis of numbers of citations of paper. The paper titled 'On the generalised distance in statistics' published in the *Proceedings of National Institute of Sciences (India)* received highest citations 6412, followed by 10 journal articles (4.37%) with an average citation of 229 per paper. It appears that 11 papers received more than 100 citations, followed by 4 papers with more than 50 citations and 73 papers with one or more citation. It is seen from the table that 131 scientific papers (57.21%) still remained uncited. It further appears that the average citation per paper is 41.97 for articles published altogether in journals and conferences.

Top cited papers

A total of 229 scientific papers were studied and ranked on the basis of their citations. Table 8 reveals the top 11 most cited research papers (1 conference paper and 10 journal articles). The conference paper on 'The generalised distance in statistics' received maximum citations so far (6412) followed by the journal article 'On test and measures of group divergence, Part I: Theoretical formulae' with 353 citations. It further appears that the top eleven research papers (in terms of number of citations) were written by Mahalanobis independently, except the paper 'Anthropometric survey of the United Provinces, 1941:

Table 8. Top 11 cited papers which received minimum 100 citations

Rank	Title of the article	Authors	Journal/conference (place of publication)	Year of publication	Times cited
1	On the generalised distance in statistics	P. C. Mahalanobis	Conference paper (India)	1936	6412
2	On test and measures of group divergence, Part I: Theoretical formulae	P. C. Mahalanobis	Journal article (India)	1930	353
3	Approach of operational research to planning in India	P. C. Mahalanobis	Journal article (India)	1955	294
4	Recent experiments in statistical sampling in the Indian Statistical Institute	P. C. Mahalanobis	Journal article (UK)	1946	279
5	Anthropometric survey of the United Provinces, 1941: a statistical study	P. C. Mahalanobis, D. N. Majumdar, C. R. Rao	Journal article (India)	1949	269
6	Some observations on the process of growth of national income	P. C. Mahalanobis	Journal article (India)	1953	252
7	Statistical study of the Chinese head	P. C. Mahalanobis	Journal article (India)	1928	227
8	On large-scale sample surveys	P. C. Mahalanobis	Journal article (UK)	1944	209
9	Analysis of race-mixture in Bengal	P. C. Mahalanobis	Journal article (India)	1925	136
10	Method of fractile graphical analysis	P. C. Mahalanobis	Journal article (UK)	1960	134
11	A sample survey of the acreage under jute in Bengal	P. C. Mahalanobis	Journal article (India)	1940	132

Table 9. Citation history of top 11 cited papers during 1990–2017

Year	Rank of top 11 cited papers as shown in Table 7											Total citations	Annual % growth rate	Cumulative citations
	1	2	3	4	5	6	7	8	9	10	11			
1990–91	45	2	9	7	5	16	–	3	3	5	3	98	–	98
1992–93	71	14	13	2	4	18	–	4	4	4	3	137	19.9	235
1994–95	59	4	10	5	10	11	2	4	3	7	1	116	–7.66	351
1996–97	80	2	8	12	6	5	1	5	3	6	2	130	6.03	481
1998–99	104	7	7	8	11	13	3	5	3	2	1	164	13.07	645
2000–01	119	9	7	11	6	3	2	2	4	1	–	164	–	809
2002–03	139	32	12	11	8	8	4	2	–	1	3	220	17.07	1029
2004–05	201	21	15	14	13	10	8	5	2	8	5	302	18.63	1331
2006–07	327	26	6	13	13	4	9	6	4	8	4	420	19.53	1751
2008–09	562	23	11	16	11	7	15	3	4	6	5	663	28.93	2414
2010–11	799	26	12	25	9	8	41	11	7	11	14	963	22.62	3377
2012–13	1023	43	18	14	13	17	45	6	11	17	13	1220	13.34	4597
2014–15	1198	26	15	17	13	13	43	10	27	3	11	1376	6.4	5973
2016–17	1115	32	17	22	13	11	38	9	14	6	12	1289	–3.16	7262
Total	5842	267	160	177	135	144	211	75	89	85	77	7262	43.40	

a statistical study' which was co-authored by D. N. Majumdar and C. R. Rao.

Citations history of top 11 cited papers from 1990 to 2017

The study of citation history of the work identifies importance and application of Mahalanobis theory in present-day research. It also shows how relevant his work is, even in the 21st century. Table 9 portrays the citation history of top 11 cited papers during 1990 to 2017. They received a total of 7262 citations with an average annual growth rate of 43.4%. Out of total cumulative citations, the first ranked conference paper cited 5842 times followed by the second ranked journal article with 267 times and seventh ranked journal article with 211 times. The graph of citations and cumulative citations (Figure 2) for the last 28 years shows an increasing trend of using his theory and applications in the present-day statistics.

The mathematical formula for calculation of Annual Percentage Growth Rate is mentioned below:

Percentage growth rate (PGR)

$$= \frac{\text{Present value} - \text{past value}}{\text{Past value}} \times 100,$$

Annual percentage growth rate (APGR)

$$= \frac{\text{PGR}}{\text{Number of years}}.$$

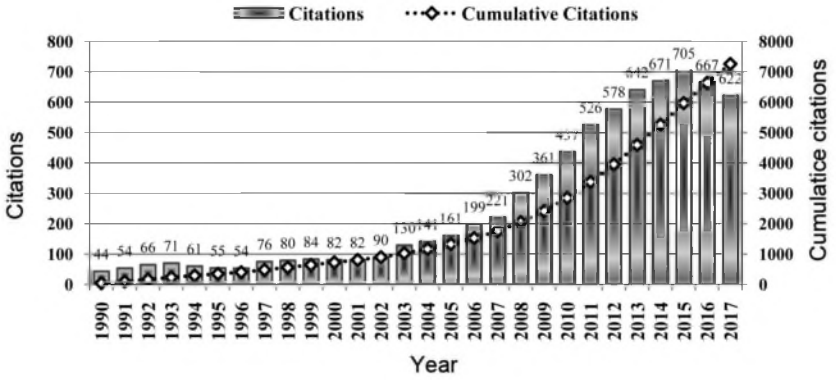

Figure 2. Citation history of top 11 cited papers during 1990–2017.

Table 10. Citation impact of research papers of Mahalanobis

Citation details	Total
Scientific work	273
Research papers (conference and journal)	229
Total cited	9612
Cited articles	98 (42.8%)
Uncited articles	131 (57.20%)
Average citations per paper	41.97
h-Index	23
g-Index	98
i-10 index	34

Citation source: Google Scholar as on November 2017.

Citation impact

Table 10 presents the citation impact of Mahalanobis's research papers. The 229 scientific research papers including both conference papers and journal articles were cited 9612 times with an average citations of 41.97 per paper. Out of all research papers, 98 papers (42.8%) have been cited and the remaining 131 papers (57.20%) remain uncited. The *h*-index, *g*-index and *i*-10 index of Mahalanobis publications are 23, 98 and 34 respectively.

Conclusion

Ronald Aylmer Fisher (1890–1962) shaped the foundations of modern statistical science and Mahalanobis (1893–1972) developed the foundations of statistical science in India. Statistical science was practically unknown in India before the 1920s and until the mid-1930s, nearly all the statistical work in India, was done singlehandedly by Mahalanobis. In spite of principally being a physicist, Mahalanobis' fascination towards statistics came from his interest in the theory of probability. His first scientific paper came out in the *Record of Indian Museum* in 1922. He coined D^2-statistics, which is also known as Mahalanobis Distance Measure. His scientific work and research publications have not only enriched Indian statistical science but are also acclaimed globally. He published his first scientific article at the age of 26 and continued publishing till he breathed last at the age of 78. Mahalanobis died on 29 June 1972, one day before his 79th birthday.

Mahanalobis has shown that statistics can be prudently applied in diversified areas of human knowledge leading to future planning, better livelihood and economic development of the country. The citation impact and citations history show that his idea, theory and principle are being used in statistical applications even today. His unique scientific work is still relevant and shows the path to the present-day statisticians, economists and scholars of the world. His devotion and love to statistics will be remembered for ever.

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