Highly Cited Publications Output by India in Computer Science 1996-2015: A Scientometric Assessment

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ABSTRACT

The study identified highly cited papers in India's computer science research during 1996-2015 and analyzed their publication and citation distributions to understand what role contributing authors, research organizations as well as international collaborative countries have played in Indian computer science research. Highly cited paper were defined as papers that received at least 100 citations since publication. Based on this criteria, it was found that India published a total of 406 highly cited articles in computer science, constituting 0.32% world share during 1996-15. In recent years, top-cited articles have reached their citation peak in the early years of their citation life cycle, but have shown a more-rapid decreasing trend compared to top-cited articles from past decades. These 406 highly articles have an average citation per paper of around 258. The institutional distribution was highly skewed with only a few reputed institutions contributing to highly cited papers. International collaboration mainly happened with the USA. One observes from this study that India's productivity of highly cited papers in computer scienceby authors is abysmally low and theslow growth rate of high quality papers in computer science is a matter of concern. The article argues that challenge before the top leadership in science in the country is how to encourage team-based/multi-institutional collaborative research in order to produce and publish high quality and high impact research work in computer science.
Keywords: Computer Science, India, Highly Cited Papers, Major Contributed Organizations, Authors, International Collaboration, Bibliometrics, Scientometrics.

INTRODUCTION

India is making a strong commitment for ICT based digital economy and emerging as a global player in providing world class technology solutions and business services. As one of global top ranking IT hubs, India is aggressively focusing on IT exports, foreign direct investment in IT industry. As of 2015 India's IT exports accounted for 4.26 per cent of the global market. India's core competencies and strengths in IT software and hardware have attracted significant Foreign Direct Investment (FDI) worth US$ 21.02 billion between April 2000 and March 2016.[1] The Digital India initiative has given IT a key position inside and outside the country. The adoption of key technologies across sectors spurred by the 'Digital India Initiative' could help boost India's Gross Domestic Product (GDP) by US$ 550 billion to US$ 1 trillion by 2025.[1] The Digital India program seeks to transform India into a digitally empowered society with emphasis on e-governance, e-retail, e-utility, e-education, telemedicine and mobile healthcare services and making the governance more participative.

India's internet economy is expected to touch Rs 10 trillion (US$ 146.72 billion) by 2018, accounting for 5 percent of the country's GDP. India's internet user base has reached over 400 million by May 2016, the third largest in the world, while the number of social media users grew to 143 million by April 2015 and smartphones grew to 160 million. Both large and small and medium scale enterprises in IT industry are finding lucrative opportunities for investment. Given these developments, the IT industry has created significant demand and growth in the Indian academic and government sector, especially for engineering and computer science.[1] In a time of change towards digital economy, the country needs to restructure

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and reshape its R&D research base in ICT sector covering critical areas such as cyber security, computing systems and architectures, network infrastructures, software engineering and data management, digital content technologies,and human-technology interfaces.Keeping this in context, it is important to examine Indian research in computer sciences and its global impact. The paper attempts to address this issue by examining India's highly cited papers in computer science.

Literature Review

Singh, Pramanik and Chakraborty examined comparative research trends in computer science and noted that Indian researchers tend to collaborate with researchers outside of India whereas Chinese tend to work among themselves. They also studied temporal evolution of the collaborative pattern in computer science and shift in research topics defining computer science (CS) research domain.[2] Das and Karanjaianalyzed 1408 research papers contributed by the Indian scientists during 1991-2000on computer science. They reported that a few institutions, like IITs (located at Kharagpur, Kanpur, Delhi, Chennai and Mumbai), Indian Statistical Institute at Kolkata and Indian Institute of Science (IISc) at Bangalore dominate in computer science research field and accounted for the largest publication share in the country. They concluded that India has potential of carrying out computer science research of international standard.[3] Gupta, Kshitij and Vermaanalyzedcomputer science research published by India during 1999-2008 to understand the comparative status of the country in computer science vis-à-vis countries like China, South Korea, Taiwan and Brazil.[4] Gupta, Kshitij, Singh analyzed computer science research published by India during 1999-2008 to discover most productive institutions, authors, and high-cited papers in the country in computer science.[5] Singh, Uddin and Pinto in a scientometric and text based analysis of computer science research output data indexed in Scopus during the last 25 years period (1989-2013) sought to identify characteristic similarities and differences in CS research landscape of Indian institutions vis-à-vis world institutions. Uddin and Singh conducted a scientometric and keyword-based analysis of computer science research published by SAARC countries during the last 25 years. The study mapped publications trends to demographic and economic indicators of the SAARC countries, and presented inferences useful for determining guidelines for funding patterns and policy formulation for scientific research in CS domain. Singhal, Banshal, Uddin, and Singhconducted a scientometrics and text-based analysis of computer science research published by India during the last 25 years. The study presented the status of computer science research in India and identified thematic trends in CS domain. Gupta, Bala and Sharma analyzed publications output of India in computer science published during 1999-2008. The study ranked the most productive Indian institutions covering institutes of national importance, universities/ deemed universities, industrial enterprises, research institutes, Indian Institute(s) of Information Technology (IIIT(s)), select engineering colleges, and regional engineering colleges(RECs)/ National Institutes of Technology (NITs) in computer science research by using a series of publications and citation indicators.

It is evident from above that studies that have so far been undertaken so far have sought to focus their attention mainly on quantitative and qualitative analysis of computer science research in India, and not as much on high cited qualitative research. This study instead would seek to address the qualitative dimension of computer science research in the country, analyze highly cited papers in computer science published by India during 1996-2015 on a series of bibliometric indicators with the aim to understand the shift in the quality of research output in computer science over time.

METHODOLOGY

The study derived data on highly-cited papers from the Scopus, an international multidisciplinary bibliographical and citation database as on August 2016 and covered the period from 1996-2015. A highly-cited article (TC2015 ≥ 100) was defined as an article registering at least 100 citations since its publication up to August 2016. In all a total of 406 India's highly cited articles in computer science received at least 100 citations since publication. The journal impact factor (IF) data used in this study based on the JCR 2013.

The study organized publication and citation data into various groups such as (i) first author publications (FP), (ii) corresponding author publications (RP), (iii) the number of citations since publication to 2015 referred to as TC2015, (iv) citations received in the year of publications (C0), (v) citations in the first year after publication (C1), (viii) the number of citations received in year 2015 is referred as C2015, (vi) national and international collaborative publications, and (vii) most productive journals etc.The data was tabulated to determine the quantum of research by publication year, global share of research, research quality, life cycle of research publications, and contribution of different types of Indian authors and organizations in computer science. Indian organizations have been classified into groups such as; (i) institutes of national importance, (ii) research institutes, (iii) universities, (iv)colleges, (v) engineering colleges, (vi) medical and allied colleges, (vii) industrial enterprises and (viii) non-profitable institutions.

The collaboration type was determined from institutional address data of the authors. An article could be either a

single-country article, in which all authors' addresses are from the same country, or bilateral or multilateral collaborative article, co-authored by researchers from 2 or more countries. In a single author article where authorship is unspecified, the single author is presumed both as first author and corresponding author. Similarly, in an article by authors from a single institution, the institution is classified both as the first author institution and the corresponding author institution. In addition, only the first affiliation of corresponding author was considered when the authorship had multiple affiliations.

At the individual level, a non-alphabetical name order sends a clear signal to the market that the author who is listed first actually contributed more. The first author is the person who contributed most to the work and writing of the article.[6] The corresponding author is perceived as the author contributing significantly to the article independent of the author position.[7] The corresponding author supervised the planning and execution of the study and the writing of the paper.[8] It is generally assumed that the first author and the corresponding author play significant roles, and they are acknowledged as the major contributors to a research paper. Thus, in this research, a newly developed indicator as suggested by Chuang and Ho,[10] the *MCI*, was used to assess the extent to which a researcher or an institution contributed to publishing an article. The *MCI* is calculated as the sum of first-author articles and corresponding articles divided by 2-times the total number of articles. It implies the percentage of instances one takes on the leadership role (first author or corresponding author) out of the total possible available opportunities. The equation is:

$$MCI=(FP=RP)/2TP,$$

Where *FP* is the number of first-author articles, *RP* is the number of corresponding-author articles, and *TP* is the number of total articles. When the *MCI* = 0, there is no first- or corresponding-author article. When the *MCI* = 1, all articles are either first- or corresponding author articles. *MCI* has two implications. First, it probably indicates a higher capability or productivity in conducting independent research. Second, it could, as well, indicate a more prominent role in collaborations. On the contrary, a low *MCI* is probably a sign of heavy reliance on collaboration, as well as relying on others to provide a leadership role in conducting research.[9]

OBJECTIVES

The main objective of this scientometric study is to understand the current status of computer science research in India and to know how has the country changed/improved in its quality and impact of research in IT duringthe past 20 years covering the period between 1996 and 2015. The study will identify highly cited papers in India's computer science research and to analyze them for their publication and citation distributions in order to understand what role contributing authors, research organizations as well as international collaborative countrieshave played in Indian computer science research. In particular, the study will focus on (i)India's world share of highly cited papers, (ii) distribution of highly cited papers by publication year, publication mode, and contributing authors and organizations, (iii) comparative share of highly cited papers from stand-alone single institutions and collaborating institutions; (iv) comparative share of highly cited papers from bilateral or multilateral collaboration, and (v) characteristics of top 10 publications on select bibliometric indicators.

ANALYSIS, RESULTS AND DISCUSSION

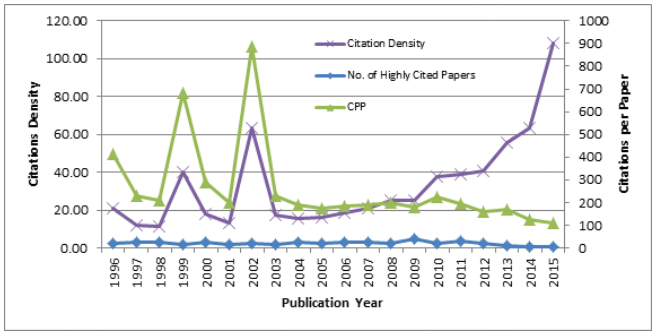
Publications Analysis

India contributed a total of 406 highly cited papers in computer science in a period 20 years during 1996-2015, accounting for0.32% world share (world output =126129 papers).As per data sourced from Scopus database, India's count of highly cited papers in computer science changed on year-to-year basis down from 21 in 1996, the first year of this study period to 3 papers in 2015, the last year of this study period. Papers cited at least 100 times since their publication were considered as highly cited papers (HCPs) in this study.

Highly cited papers by India in computer science were published in bulk as research articles (325, 80.05% share) followed by conference papers 41 (10.10%) paper each as conference papers, 34 (8.37%) as reviews, 3 (0.74%) as books, 2 (0.49%) as letters and 1 (0.25%) as editorial during 1996-2015. As expected, review papers comparatively registered the highest citation impact per paper (363.59), followed by conference papers (323.88), books (294.67%), articles (239.46), letters (124.50) and editorial (117.0) during 1996-2015(Table 1).

Citations Analysis

India's highly cited papers (406) in computer science cumulated 14059 citations in 20 years during 1996-Aug 2016, averaging to 257.92 citations per paper (CPP) in 20 years period, with annual CPP ranging between 108.33 (lowest in 2015) and 884.89 (highest in 2002). In this study, citations to papers have been counted from their publication year till August 2016; hence citation window in this study is not constant but variable varying from 1–20 years since publication. Citations to papers are treated as a proxy for describing the quality of research, to judge how highly cited papers inter-compare on quality and



CPP => Citations per paper

Figure 1: Citation Density of Highly Cited Papers in Computer Science: 1996-2015.

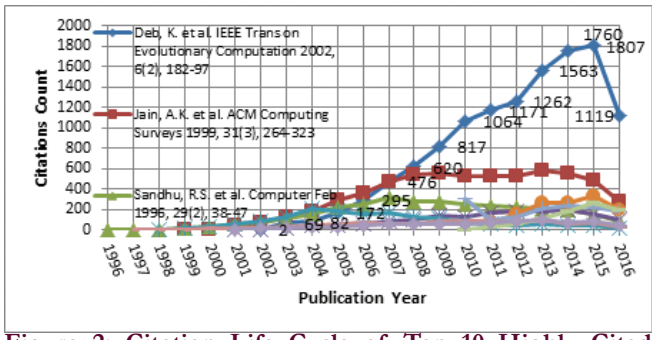


Figure 2: Citation Life Cycle of Top 10 Highly Cited Papers in Computer Science by Publication Year: 1996-2015

impact. CPP as such is not a valid indicator for comparing highly cited paperssince their citation window periodsare variable, varying from 1-20 years since publication. For comparative citation performance this study used another indicator - 'citation density'. It computes citation density as a ratio: 'citations per paper in a given year' divided by 'corresponding citation window period as # of years'. For example, 'citation density'of 19 highly cited papers - published in the year 2002–comes as 63.21 citations per paper per citation year (16813/19/14) = 63.21. The citation density of 406 highly cited papers averaged to 12.90 citations per paper per citation year.

Citation density of highly cited papers in computer science research in India registered high rise during 2003-15 up from 17.66 in 2003 to 108.33 CPP/CPYin 2015. Comparatively, citation density during the first six years of this study, 1996-2002 registered moderate rise up from 20.79 in 1996 to 62.21 in 2002. Citation density was the highest with 108.33 CPP/PCY in the year 2015, the smallest with 11.59 CPP/PCY in the year 1998. High citation density data during 2010-15 implies that computer science research in India has indeed gained significant jump in quality and impact. Keeping in view the variability of citation window, we need to interpret the results with caution.(Figure 1)

The citation spectrum of highly cited papers is wide spreading across from 100 to 884.89 citations per paper on one end and 3148-12244 citations per paper on the other. The bulk of highly cited papers (71.43% share) correspond to papers in citation range 100-198 per paper. Only less than 3% highly cited papers correspond to top end citation range 841-12244 citations per paper. This shows that distribution of highly cited papers is highly skewed (Table2).

Distribution of Highly Cited Papers Output by Contributing Authors

Authorship to 406 highly cited papers varied widely from 1 to 150 authors per paper with an average of 3.86 authors per paper. Sole authorship was limited to 7.14% outputs, joint authorship to 36.45% output, and multiple authorship to 56.40% output. Multiple-authorship (3 -150 authors per paper) in computer science research is increasingly becoming the mode. Of the total of 1567 authors to 406 highly cited papers, 29 contributed one paper each in 20 years, 296 contributed two papers each,330 contributed three papers each, 240 contributed 4 papers each, 22contributed5 papers each, 72 contributed 6 papers each, 49 contributed 7 papers each, and 32 contributed 8 papers each. It shows that frequency distribution of authors of highly cited papers in computer science is not significant. (Table 3).

Top 25 Contributing Authors in Computer Science Research

The major contribution index MCI index varied from 0.0 to 1.0 for the top 25 highly cited authors, authors having citation of atleast 3 citations per paper. MCI greater than 0.5 indicates that the author has high potential to conduct research independently, contribute to research productivity significantly, or play more prominent role in research collaboration. On the contrary low MCI is a sign of heavy reliance on others to play leadership role in conducting research or in research collaboration. In this study no correlation was found between their rank order and MCI index. In other words MCI is independent of size of

Table 1: Distribution of Highly Cited Papers by India across Publication Types: 1996-2015

Type of Publication	TP	TC	CPP
Articles	325	77824	239.46
Reviews	34	12362	363.59
Conference Paper	41	13279	323.88
Books	3	884	294.67
Letter	2	249	124.50
Editorial	1	117	117.00
Total	406	104715	257.92

TP=Total papers; TC=Total citations; CPP = Average citation per paper

Table 2: India's Highly Cited Papers in Computer Science by Citation Frequency Range: 1996-2015

Citation Range	No of Highly Cited Papers	Total Citations	Publications Share	Citations Share
100-198	290	38098	71.43	36.38
200-297	48	11734	11.82	11.21
307-369	26	8573	6.40	8.19
402-589	23	10858	5.67	10.37
607-774	10	6658	2.46	6.36
841-944	2	1785	0.49	1.70
1079-1596	4	5530	0.99	5.28
3148-12244	3	21479	0.74	20.51
Total	406	104715		

contributions by authors. *Table 4 is further subset of top 12 authors with at least 5 citations per paper.*

Of the top 25 authors, only three authors, namely P.Sarasu, A.Kumar and B.Singh registered the highest MCI value of 1 despite ranking low in publication count rank at 9, 19 and 20. The other significant authors with high MCI values were S. Vaidyanathan (MCI=0.952, Publication Rank=1), S.Mitra (MCI=0.875, Publication Rank=7), K.Deb (MCI=0.727, Publication Rank=2), N. Garg (MCI=0.667, Publication Rank=2), H. Singh (MCI=0.667, Publication Rank=22), A. Jain (MCI=0.667, Publication Rank=23), etc. The contributing authors high impact included K. Deb (CPP = of 1528 Publication Rank=2), followed by C. Bhattacharyya and K R K Murthy (CPP=431.33 each and Publication Ranks= 24 and 25).

Top 10 Organizations in Computer Science Research

In all 898 organizations (148 Indian and 750 foreign) had contributed to 406 highly cited papers in computer science research in India during 1996-2015. Of the 148 Indian research organizations, only 44 were comparatively more productive, with each contributing 2 to 46 highly cited papers in computer science during 1996-2015. The other 104 were not so good productivity organizations, contributing just one publication each during the same period.

Institutes of National Importance dominated the publications output of highly cited papers in computer science with largest share (60.10%, 244 papers). Also in terms of citations per paper, institute of national importance registered the highest citation impact of 302.65, followed by non-profit and others (301.45) and engineering colleges (161.09) (Table 5).

In terms of citation per paper, Indian Institute of Technology, Kanpur registered the highest citation impact of

Table 3: Author Productivity in Computer Science in India: 1996-2015

Authors per publication	No. of Publication	Total Authorship
1	29	29
2	148	296
3	110	330
4	60	240
5	22	110
6	12	72
7	7	49
8	4	32
9	3	27
11	1	11
12	2	24
13	1	13
15	2	30
18	1	18
24	1	24
32	1	32
80	1	80
150	1	150
Total	406	1567

734.15 (with Publication rank of 6), followed by Indian Institute of Science, Bangalore (CPP=383.48 and Publication Rank=3). In terms of MCI, Mepco Schlent Engineering College, Sivasaki and Dr S.R.University, Chennai registered the highest value of 1.0 each with publication rank 19 and 5 , followed by Jadavpur University and Kolkata (MCI=0.96 and Publication Rank=9).

Of the 148 Indian organizations contributing to computer science research, 39 were industrial enterprises, 33 universities & colleges, 32 engineering colleges, 27 research institutes, 12 institutes of national importance and 5 non-profit and other organizations. Among the 406 highly cited papers, 67 resulted from contribution with single organization each, 129 papers with 2 organizations each, 58 papers with 3 organizations each, 30 papers with 4 organizations each, 5, 6, 7 and 8 papers each with 11, 7, 4, 6 and 5 organizations, and more than 9 papers by 1, 2 and 3 organizations respectively (Table 6).

Collaboration in Highly Cited Papers

Of all the 406 highly cited publications in computer science, 130 resulted from co-authors from the same single parent organization (no-collaboration), 67 from national collaboration with co-authors/multiple authors from Indian organizations (national collaborative publications), and 209 from international collaboration with co-authors/multiple authors from Indian and foreign organizations (international collaborative publications). Contrary to

Table 4: Highly Cited Authors in Computer Science Research in India: 1996-2015

S.No	Name of the Author	Affiliation	TP	TC	CPP	FP-RP	FP	RP	MCI
1	S. Vaidyanathan	Dr S.R.University, Chennai	21	2591	123.38	19	2		0.952
2	K. Deb	Indian Institute of Technology, Kanpur	11	16808	1528.0	8			0.727
3	S. Bandyopadhyay	Indian Statistical Institute, Kolkata	11	921	83.73	4	2	1	0.500
4	V. Sundarapandian	Dr S.R.University, Chennai	9	1259	139.89	4			0.444
5	S. Das	Jadavpur University, Kolkata	8	2745	343.13	2	1		0.313
6	N.R. Pal	Indian Statistical Institute, Kolkata	8	1995	249.38	2	1		0.313
7	S.K. Pal	Indian Statistical Institute, Kolkata	7	1792	256.00	2			0.286
8	N. Garg	Indian Institute of Technology, New Delhi	6	1002	200.40	4			0.667
9	P. Sarasu	Dr S.R.University, Chennai	5	648	129.60	5			1.000
10	S.R. Murthy	Indian Institute of Technology, Madras	5	641	128.20	1			0.200
11	B.B. Chaudhuri	Indian Statistical Institute, Kolkata	5	721	144.20	2		2	0.600
12	G.P.S. Raghava	Institute of Microbial Technology, Chandigarh	5	949	189.80			3	0.300

FP=Number of papers with first authors; RP=Number of papers with corresponding authors; TP=Total Papers; MCI=Major Contribution Index

Table 5: Distribution of Highly Cited Papers across Types of S&T Research Organizations: 1996-2015

Type of Organization	TP	TC	CPP	%TP	FP-RP	FP	RP	MCI
Institutes of National Importance	244	73847	302.65	60.10	113	1	3	0.47
Universities	81	14648	180.84	19.95	55	1	0	0.69
Industrial Enterprises	56	6560	117.14	13.79	23	0	0	0.41
Engineering Colleges	43	11277	261.09	10.59	21	0	0	0.49
Research Institutes	38	6749	177.61	9.36	21	0	0	0.55
Non-Profit & Others	11	3316	301.45	2.71	1	0	0	0.09
					234	1	3	

FP=Number of papers with organizations affiliating to first authors; RP=Number of papers with organizations affiliating to corresponding authors; TP=Total Papers; MCI=Major Contribution Index

expectations, single institution publications had scored higher citation impact with 281.08 citations per publication compared to International collaborative publications with 257.92citations per publication and national collaborative publications with 185.69citations per publication (Table 7).

Collaborative Profile of Organizations: Authors from Single Institution

In all, 284 authors from 35 organizations collaborated in groups of various sizes (mainly from same parent organization) to publish130highly cited papers (32.02% share) in computer science. Of the 130 single-institution highly cited papers, 69were from 9 institutes of national importance, 34from 8 universities, 13 from 9 research institutes, 6 from 5 engineering colleges, and 6 from 4 industrial enterprises.

The detail of these organizations are as follows:(i) Institutes of National Importance – ISI-Kolkata (18 papers), IIT-Kharagpur and IIT-Delhi (11 papers each), IISc-Bangalore (8 papers), IIT-Madras (7 papers), IIT-Kanpur and IIT-Bombay (6 papers each), IIT-Roorkee (3 papers) and IIT-Guwahati (1 paper); Universities - Dr. S R University & Vel Tech University, Chennai (11 papers), University of Hyderabad (9 papers), Jadavpur University, Kolkata (7 papers).

The distribution of 130 papers by authorship per publications was as follows: 29papers resulted from contribution by 1 author each, 63by 2 authors each, 29by 3 authors each, 5by4 authors each, 2 by 5 authors each, and2by 6 authors in all. The authorship to130 papers averaged to 2.18authors per publication.

Table 6: Top 10 Organizations in Computer Science Research: 1996-2015

S.No	Name of the Organization	TP	TC	CPP	TP	(FP, RP)	FP	RP	MCI
1	Indian Statistical Institute, Kolkata	46	10218	222.13	46	32	1	3	0.74
2	Indian Institute of Technology, New Delhi	46	8123	176.59	46	20		1	0.45
3	Indian Institute of Science, Bangalore	42	16106	383.48	42	16	2	2	0.43
4	Indian Institute of Technology, Kharagpur	33	6836	207.15	33	12	1		0.38
5	Dr S.R.University, Chennai	28	3140	112.14	28	28			1.00
6	Indian Institute of Technology, Madras	26	5934	228.23	26	8			0.31
7	Indian Institute of Technology, Kanpur	26	19088	734.15	26	13		1	0.52
8	Indian Institute of Technology, Bombay	23	5299	230.39	23	10	1		0.46
9	Jadavpur University, Kolkata	23	5952	258.78	23	20	2	2	0.96
10	Microsoft Research, Bangalore	13	2113	162.54	13	7			0.54

TP=Total Papers; FP=Number of first-author top cited articles; RP=Number of corresponding top-cited articles

Table 7: Citation Performance of Highly Cited Publications by Collaboration Type: 1996-2015

Type of Collaboration	Total Publications	Total Citations	Average Citations per Publication
Co-authors with their affiliation to same single Institution	130	36541	281.08
National collaborative Publications	67	12441	185.69
International collaborative Publications	209	55733	266.67
	406	104715	257.92

Of the 130 single institution publications, 100 papers resulted from single authors (serving both as first author and corresponding author), 40from authors serving only as first author, and 20 from authors serving only as corresponding author.

Collaborative Profile of Organizations: National Collaborative institutions

In all, 178 authors from 141 Indian organizations collaborated in groups of various sizes (coming from 2 or more organizations) to publish 67 national collaborative highly cited papers (16.50% share) in computer science (Table 8). Of the 67 national collaborative highly cited papers, 42 were from 9 institutes of national importance, 26 from 23 universities, 9 from 9 research institutes, 20 from 17 engineering colleges, and 10 from 10 industrial enterprises; and 6 from 4 other organizations.

The organizations which collaborated in these 67 highly cited papers include: : (i) Institutes of National Importance- ISI-Kolkata (16 papers), IIT-Delhi (8 papers), IIT-Kanpur and IISc-Bangalore (6 papers each), and IIT-Bombay (3 papers).-The distribution of 67 papers by participating institution was as follows:61 papers each with 2 participating organizations, 5 papers each with 3 participating organizations and 1 paper with 4 participating organizations. The institutional authorship to 67 national collaborative papers averaged to 2.10 collaborating organizations per paper.

The distribution of 67 papers by authorship per publications was as follows: 33 papers were contributed by 2 authors each, 25 publications each by 3 authors each, 8 publications contributed by 4 authors each and1 paper contributed by 5 authors. The authorship to 67 papers averaged to 2.66 collaborating authors per publication.

Of the 67 national collaborative publications, 50 papers resulted from authors serving both as first author and corresponding author, 24 from authors serving only as first author, and 10 from authors serving only as corresponding author.

Collaborative Profile of Organization: International Collaborative Institutions

In all, 1105 authors from 1107 Indian and foreign organizations representing 45 countries collaborated in groups of various sizes (from Indian and foreign organizations) to publish 209 international collaborative highly cited papers (51.48% share) in computer science. Of the 209 international collaborative highly cited papers, 116 were from 11 institutes of national importance, 18 from13 engineering colleges, 23 from 11 universities, 13 from 13 research institutes, and 42 from 30 industrial enterprises.

Indian Institute of Science, Bangalore and Indian Institute of Technology, New Delhi contributed the largest number of papers (29 each), followed by Indian Institute of Technology, Bombay and Indian Institute of Technology, Madras (19 papers each).

The distribution of 209 international collaborative highly cited papersby participating organizations was as follows:

68 papers resulted from 2 participating organizations in each, 53 from 3 participating organizations in each, 29 from 4 participating organizations in each, 11 with 5 participating organizations in each, 7with 6 participating organizations in each, 4 with 7 participating organizations in each, 6 with 8 participating organizations in each, 5 with 9 participating organizations in each, and 3with 10 participating organizations in each. The average number of participating organizations per paper was 5.30.

Medium of Communication

Journals play an important role in the communication structure of science. Of the 406 highly cited papers in computer science research from India, 370were published in 150 peer-reviewed journals (Impact Factor information was available for 143 journals only). No significant correlation was found between citations to highly cited papers and impact factor of their reporting journals (Table 9-10).

Of 150 journals, 85 reported one highly cited publication each, 23 (13.33%) reported two publications each, 11 (11.11%) reported three publications each, 9, 6 and 2 journals reported four, five and six publication respectively and 2, 1 and 6 journals reported seven, eight and nine publications respectively and 3, 1 and 1 journals reported 10, 11 and 14 publications respectively. Table 11 (given at the end) lists the top 32 journals which published 4 or more highly cited publications. *IEEE Transactions on Evolutionary Computation*published largest number of the highly cited publications (14 papers), followed by *Pattern Recognition* (11 publications), *IEEE Transactions on Systems, Man & Cybernetics. Part B, IEEE Journal on Selected Areas in Communication* and *IEEE Transactions on Information Theory* (10 papers each), *IEEE Transactions on Image Processing, IEEE Transactions on Wireless Communication, Applied Soft Computing Journal, Fuzzy Sets & Systems, Pattern Recognition Letters* and *Computer* (9 papers each*), IEEE Transaction on Industrial Electronics* (8 papers), *Bioinformatics* and *IEEE Communication Magazine* (7 papers each),*Expert Systems with applications* and *International Journal of Control Theory & Applications* (6 papers each), etc.

Top 10 Highly Cited Papers

Of the top 10 highly cited papers, 8were published during 1996-2002 and other 2 during 2010-2011. Two papers were published in *IEEE Transaction on Evolutionary Computation* [IF=5.905], and 1 each in *ACM Computer Surveys* [IF=5.243*], Computer*[IF=1.115], *Computer Methods in Applied Mechanics & Engineering* [IF=2.203], *IEEE Communication Magazine*[IF=5.125], *IEEE Transaction on Industrial Electronics* [IF=6.383], *IEEE Transaction on Image Processing* [IF=3.73], and *Neural Computation* [IF =1.626]. One paper was published in conference proceedings. Both citation numbers and ranking for the TC2015 are displayed. The top ranking paper - "A fast and elitist multiobjective genetic algorithm: NSGA-II"was published by Deb, K., Pratap, A., Agarwal, S., Meyarivan, T.in IEEE Transactions on Evolutionary Computation in 2002 and had TC2015 of 12279.

The study organized publication and citation data into seven groups such as (i) first author publications (FP), (ii) corresponding author publications (RP), (iii) the number of citations since publication to 2014 is referred as TC2014, (iv) citations received in the year of publications (C0), (v) citations in the first year after publication (C1), (viii) the number of citations received in year 2014 is referred as C2014, (vi) national and international collaborative publications, and (vii) most productive journals etc (Table 8).

Effect of Time Period on Citations Output

Citation life cycle of highly cited papers published in the time period 1996-2015 exhibit two trends i) papers that exhibit typical early peak, reaching their citation peak in 5 years since publication (Thakkar, K.N. et al. Nanomedicine 2010, 276 citations) (Rahman. I et al. Biochemical Pharmacology 2006, 488 citations), ii) papers that exhibit delayed recognition, delayed citation peak, reaching their citation peak in 13-14 years since publication. In overall, life cycle of highly cited papers (TC2015> 100) lasted from 6 to 14 years and that they all enter decline in their citation after reaching their peak. As can be seen, highly cited papers effectively have dated life cycle but they differ significantly in their cumulative citations output (TC2015) varying from 774 to 12279 citations. It is significant to note that effective from 2010 papers a more-rapid rise in citation numbers, and needed relatively fewer years to reach their citation peak. If such a trend continues to stay, high percentile articles will certainly reach their citation peaks even faster and would need relatively fewer years since their publication (Figure 2).

DISCUSSION

India published a total of 406 highly cited articles in computer science, constituting 0.32% world share during 1996-15. Only such papers that received at least 100 citations since their publication till August 2015 were covered in this study. The publications and citations data for the study was sourced from Scopus database. Though citation in research evaluation is viewed as an acknowledgement of intellectual debt and scientific progress but highly cited papers illustrate high quality performance in science and a useful tool for quality assessment of key (most influential) contributors to a given research field.

Table 8: Collaborating Countries in Highly Cited Papers in Computer Science: 1996-2015

Country	TP	TC	CPP	Number of publications with			
				Total	Both FP and RP	FP	RP
USA	138	38568	279.48	138	88	1	1
U.K.	22	3889	176.77	22	10		
Canada	18	3323	184.61	18	7		
Singapore	15	4956	330.40	15	7		2
France	14	2569	183.50	14	3		
Japan	12	3947	328.92	12	3	1	
Switzerland	10	2512	251.20	10	2	1	

TP=Total Papers; FP=Number of first-author top cited articles; RP=Number of corresponding top-cited articles

Table 9: Distribution of 370 Highly Cited Papers in Indian Computer Science by Citation and Impact Factor

IF Range 2015	Range of Citations						
	100-199	200-299	300-399	400-499	500-599	600 & More	Total
6.0 & More	15	5	2	2	1	3	28
5.0 – 5.99	20	4	1	2	1	5	33
4.0 – 4.99	12	6	2	0	0	0	20
3.0 – 3.99	36	5	7	2	2	3	55
2.0 – 2.99	83	12	4	2	1	3	105
1.0 – 1.99	66	12	8	5	0	4	95
0.00 – 0.99	31	2	0	1	0	0	34
Total	262	46	24	14	6	18	370

A total of 406 highly cited papers in computer science were published across 150 Indian and foreign journals with IF 6.0 and above. *IEEE Transactions on Evolutionary Computation*published largest number of the highly cited publications (14 papers, 3.49%), followed by *Pattern Recognition* (11 publications, 2.70%), *IEEE Transactions on Systems*(10 papers, 2.46%), *Man & Cybernetics Part B*(10 papers, 2.46%), *IEEE Journal on Selected Areas in Communication*(10 papers, 2.46%)and *IEEE Transactions on Information Theory* (10 papers, 2.46%), etc.

These 406 highly articles have received 104715 citationstheir citation impact averaged to 257.92 citations per paper, with annual CPP ranging between 108.33 (lowest in 2015) and 884.89 (highest in 2002). Quality and impact of highly cited papers was compared on a citation density metric. It was highest with 108.33 CPP/PCY in the year 2015, the smallest with 11.59 CPP/PCY in the year 1998. High surge in citation density data of highly cited papers over time in particular during 2010-15 up from 37.52 to 108.33 CPP/PCY implies that computer science research in India has significantly improved in its quality and impact.

Citation life cycle of highly cited papers published in the time period 1996-2015 exhibit two trends i) papers that exhibit typical early peak, reaching their citation peak in 5 years since publication (Thakkar, K.N. et al. *Nanomedicine* 2010, 276 citations) (Rahman. I et al. *Biochemical Pharmacology* 2006, 488 citations), ii) papers that exhibit delayed recognition, delayed citation peak, reaching their citation peak in 13-14 years since publication. It is significant to note that effective from 2010 papers a more-rapid rise in citation numbers, and needed relatively fewer years to reach their citation peak. If such a trend continues to stay, high percentile articles will certainly reach their citation peaks even faster and would need relatively fewer years since their publication.

Of the 148 Indian organizations which contributed to computer science research during 1996-2015, 39 were industrial enterprises, 33 universities & colleges, 32 engineering colleges, 27 research institutes, 12 institutes of national importance and 5 non-profit and other organizations. Institutes of National Importance dominated the publications output of highly cited papers in computer science with largest share (60.10%, 244 papers), followed

Table 10: Citations to Top 10 Most Highly Cited Papers in Computer Science from India, 1996-2015

		TC	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
1	Deb, K. et al. IEEE Trans on Evolutionary Computation,6(2), 182-97	12279							2	69	82	172	295	476	620
2	Jain, A.K. et al. ACM Computing Surveys 1999;31(3):264-323	6048				2	2	38	68	122	182	288	362	476	539
3	Sandhu, R.S. et al. Computer1996;29(2):38-47	3040	3	6	7	18	27	56	72	116	148	224	250	324	283
4	Deb, K. Computer Methods in Applied Mechanics & Engineering 2000, 186(2-4):311-38	1597						3	8	20	44	44	54	80	105
5	Hara, S et al. IEEE Communication Magazine1997;35(12):126-33	1480			3	16	24	62	88	121	208	175	151	163	123
6	Das, S. et al. IEEE Trans on Evolutionary Computation feB 2011;15(1):4-31	1273													
7	Kouro, S. et al. IEEE Trans on IndustriXal Electronics Aug 2010;57(8):2555-80	1389													
8	Srinivasan Reddy, B. et al. IEEE Trans on Image Processing 1996;5(8):1266-71	904		6	4	6	9	17	22	23	39	52	65	53	64
9	Yang, X. S. et al. 2009 World Congress on Nature and Biologically Inspired Computing Controlled Release	846													
10	Keerthi, S.S. et al. Neural Computation March 20011;3(3):637-49	774						2	9	13	24	29	46	56	51

		2009	2010	2011	2012	2013	2014	2015	2016
1	Deb, K. et al. IEEE Trans on Evolutionary Computation 2002; 6(2):182-97	817	1064	1171	1262	1563	1760	1807	1119
2	Jain, A.K. et al. ACM Computing Surveys 1999;31(3):264-323	554	520	521	525	578	549	489	275
3	Sandhu, R.S. et al. Computer 1996; 29(2):38-47	273	254	237	224	203	192	160	80
4	Deb, K. Computer Methods in Applied Mechanics & Engineering 2000; 186(2-4):311-38	135	130	162	186	175	201	157	96
5	Hara, S et al. IEEE Communication Magazine Dec 1997;35(12):126-33	117	76	53	50	57	38	41	19
6	Das, S. et al. IEEE Trans on Evolutionary Computation feB 2011;15(1):4-31			73	151	262	263	327	197
7	Kouro, S. et al. IEEE Trans on Industrial Electronics 2010;57(8):2555-80		311	105	127	211	239	217	179
8	Srinivasan Reddy, B. et al. IEEE Trans on Image Processing 1996;5(8):1266-71	86	88	83	76	94	55	71	33
9	Yang, X. S. et al. 2009 World Congress on Nature and Biologically Inspired Computing Controlled Release		4	26	59	117	188	262	190
10	Keerthi, S.S. et al. Neural Computation 2001;13(3):637-49	53	62	66	78	96	69	82	40

by universities (19.95% share, 81 papers), industrial enterprises (13.79% share, 56 papers each), engineering colleges (10.59% share, 43 papers), research institutes (9.36% share, 38 papers), non-profit & others (2.71% share, 11 papers) during 1996-2015.

The top 10 most productive institutes in computer science research include Indian Statistical Institute, Kolkata (Output = 46, CPP = 222.13), Indian Institute of Technology, New Delhi (Output = 46, CPP = 176.59), Indian Institute of Science, Bangalore (Output = 42, CPP = 383.48), Indian Institute of Technology, Kharagpur (Output = 33, CPP = 207.15), Dr S.R.University, Chennai (Output = 28, CPP = 112.14), Indian Institute of Technology, Madras (Output = 26, CPP = 228.23), Indian Institute of Technology, Kanpur (Output = 26, CPP = 734.15), Indian Institute of Technology, Bombay (Output = 23, CPP = 230.39), Jadavpur University, Kolkata (Output = 23, CPP = 258.78), and Microsoft Research, Bangalore (Output = 13 CPP = 162.54).

In terms of MCI, Mepco Schlent Engineering College, Sivasaki and Dr S.R.University, Chennai registered the highest value of 1.0 each with publication rank 19 and 5, followed by Jadavpur University, Kolkata (MCI=0.96 and Publication Rank=9), Indian Statistical Institute, Kolkata(MCI=0.74 and Publication Rank=1), Institute of Microbial Technology, Chandigarh, Indian Institute of Technology, Roorkee and Defense R&D Organization(MCI=0.67 each and Publication Rank=12, 13 and 18 respectively), etc. MCI varies from 0.0 to 1.0. MCI greater than 0.500 indicates that the author has high potential to conduct research independently, contribute to research productivity significantly, or play more prominent role in research collaboration. On the contrary low MCI is a sign of heavy reliance on others to play leadership role in conducting research or in research collaboration.

Authorship to 406 highly cited papers varied widely from 1 to 150 authors per paper with an average of 3.86 authors per paper. Sole authorship was limited to 7.14% share in output, joint authorship to 36.45% output, and multiple authorship to 56.40% output. Multiple-authorship (3 -150 authors per paper) in computer science research is increasingly becoming the mode. It signals the onset a trend towards team based/ multi-institutional collaborative research to produce high quality research in computer science.

This study observed that internationally collaborated papers averaged higher citation rate per paper (204.1) relative to nationally collaborated papers (140.1). International collaboration is an indispensable to quality of computer science research. Of 406 highly cited papers, 229 resulted from international collaboration across 45 countries. United States participated in the largest number of publications (138), followed by U.K. (22), Canada (18), Singapore (15), Japan (12), Switzerland (10), China (8), Norway (8), Taiwan (7), South Korea (7),Australia (7), Germany (7), Italy (6), Israel (5), Denmark, Hong Kong, Poland, Spain, And Egypt (4 each), and Netherlands, Chile, and Greece (3 each).

CONCLUSION

India's productivity of highly cited papers in computer scienceby authors is still not as significant as expected given the fact that as many as 208 authors were able to contribute justone paper each once in a long span of 15 years, and more so because India's world share of highly cited papers in computer science has been abysmally low just at 0.32%. Besides, the country didn't show a promising rising trend in its rate of growth in its output of highly cited papers over time. It remained range bound between 2 to 11 papers per year. The slow growth rate of high quality papers in computer scienceis indicative of dearth of high profile/high productivity scientists and of high-productivity scientific institutions in computer science in the country; it is a matter of great concern. Notably, bulk of the output of high quality and high impact research in computer science in India has resulted from select top academic and research organizations/institutions working in isolation and not in collaboration. Team based/multi-institutional research in computer science was limited to select few highly cited papers. The challenge before the top leadership in science in the country is how to encourage team-based/multi-institutional collaborative research in order to produce and publish high quality and high impact research work in computer science.

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APPENDIX

Table 11: List of journals publishing 4 or more high cited papers

S.No	Name of the Journal	IF	NP	Papers Citations
1	IEEE Transactions on Evolutionary Computation	5.905	14	12279, 1273, 663, 509, 313, 278, 223, 188, 182, 159, 142, 129, 124, 109
2	Pattern Recognition	3.399	11	612,554, 354, 307, 231, 196, 169, 134, 119, 116, 102
3	IEEE Transactions on Systems, Man & Cybernetics. Part B	6.22	10	619, 447, 201, 183, 168, 149, 142, 127, 121, 106
4	IEEE Journal on Selected Areas in Communication	3.672	10	500, 442, 359, 319, 317, 293, 114, 105, 101, 101
5	IEEE Transactions on Information Theory	1.737	10	315, 309, 201, 197, 184, 177, 144, 131, 124, 105
6	IEEE Transactions on Image Processing	3.73	9	946, 322, 152, 142, 125, 124, 110, 101, 100
7	IEEE Transactions on Wireless Communication	2.925	9	466, 347, 298, 234, 186, 151, 133, 132, 120
8	Applied Soft Computing Journal	2.857	9	247, 167, 167, 157, 138, 125, 122, 119, 107
9	Fuzzy Sets & Systems	2.098	9	328, 194, 153, 130, 120, 115, 107, 101, 101
10	Pattern Recognition Letters	1.586	9	308, 248,195, 153, 143, 135, 121, 113, 110
11	Computer	1.115	9	3160, 419, 407, 370, 324, 313, 265, 248, 102
12	IEEE Transaction on Industrial Electronics	6.383	8	1081, 697, 293, 179, 157, 126, 125, 107
13	Bioinformatics	5.766	7	414, 217, 178, 153, 139, 117, 110
14	IEEE Communication Magazine	5.125	7	1585, 437, 165, 153, 140, 135, 132
15	Expert Systems with applications	2.981	6	264, 192, 114, 111, 103, 103
16	International Journal of Control Theory & Applications	0.95	6	142, 135, 129, 123, 119, 107
17	IEEE Transactions on Fuzzy Systems	6.701	5	447, 321, 210, 119, 103
18	Information Sciences	4.95	5	280, 272, 208, 143, 123
19	IEEE Transactions on Neural Networks	4.854	5	368, 325, 208, 191, 110
20	Journal Of Chemical Information & Modeling	2.88	5	266, 167, 135, 114, 108
21	IEEE/ACM Transactions on Networking	2.186	5	182, 181, 161, 158, 135
22	IEEE Micro	1.091	5	342, 146, 141, 123, 107
23	Wireless Networks	1.006	5	663, 284, 249, 119, 106
24	Evolutionary Computation	3.6	4	610, 338, 237, 139
25	Mechanical Systems & Signal Processing	2.771	4	174, 149, 108, 105
26	Information & Management	2.163	4	256, 152, 130, 110
27	IEEE Signal Processing Letters	1.661	4	272, 226, 146, 101
28	International Journal of Modeling, Identification & Control	1.57	4	139, 124, 110, 104
29	Mobile Networks & Applications	1.538	4	231, 120, 118, 108
30	Journal of Chemical Information & Computer Science	1.33	4	266, 198, 167, 102
31	IEEE Software	0.82	4	194, 159, 138, 117
32	International Journal of Soft Computing	0.26	4	146, 143, 137, 131

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