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Application of Bradford's Law of Scattering in the Field of Production Engineering Literature: A Bibliometric Analysis of Ph.D.Theses

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ABSTRACT

Application of Bradford's Law of Scattering is one of the bibliometric laws, which is used commonly in bibliometric research. The study carried out on the data of journals cited in the Ph.D. theses submitted to Jawaharlal Nehru Technological University, Hyderabad, Telangana. The study examine the applicability of Bradford's Law of Scattering it include 564 journal titles and 2043 journals citations containing 3947 references collected from 41 doctoral theses. Rank list was prepared and 'Journal of Materials Processing Technology' took first place with 135 citations followed by 'International Journal of Production Research' with 108 citations and 'International Journal of Machine Tools and Manufacautre' with 98 citations was the most preferred journals. The Bradford's Law of Scattering and Leimkuhler model was tested to verify the dataset and it was found to fits the present dataset

Keywords: Citation analysis, Bradford's Law, Leimkuhler model, Production Engineering, Mechanical Engineering, Ranking of journals.

1. INTRODUCTION

Production engineering is also known as Manufacturing engineering is that branch of professional engineering requiring such education and experience as is necessary to understand and apply engineering procedures in manufacturing processes and methods of production of industrial products. It requires the ability to plan the practices of manufacturing; to research and develop tools, processes, machines, and equipment; and to integrate the facilities and systems for producing quality products with the optimal expenditure of capital.

The technical information comes through number of publications such as periodicals, journals, theses etc. Journals are a key information source to the researchers, however the large number of journals and their high subscription costs make it difficult for libraries to subscribe all required journals. Citation analysis can be carried out to identify core journals in the field. The ranked list of highly cited journals is a practical tool for a librarian to select the journals of maximum utility. Citation analysis is one of the ways through which one can identify the most important journals for the library collection. Bradford's Law states that articles on a given field are distributed over journals according to specific mathematical function, where a large number of articles are scattered in fewer highly productive journals. The purpose of this study was to apply the accepted formulations of Bradford's Law to journal publications of production engineering research.

2. REVIEW OF LITERATURE

Number of studies have been undertaken to test the Bradford's Law of Scattering. Venkatanarayana and Doraswamy (2020) used Braddofr's law to the evaluation of civil engineering book collection through circulation data. Gyan and Singh (2019) applied Bradford's Law of Scattering and obsolescence in the literature of Chemistry Ph.D. theses submitted to Tripura University. The study revealed that the journal entitled 'Phytochemistry' is the most cited journal. The present study dataset did not follow the Bradford's Law; however, the Leimkuhler model is valid for the dataset. Wagh, Gawande and Wadalkar (2018) analysed Ph.D. theses of Home Sciences submitted to Marathwada Agricultural University, Parbhani. The study revealed that the journals are most preferred source of information and the Bradford's Law fits to the dataset. Satish Kumar and Senthilkumar (2018) examining the application of Bradford's Law of Scattering on research articles published in the field of Astronomy and Astrophysics by Indian scientists during 1988-2017. The study revealed that the scattering of research publication was failed to prove the law of scattering as well as Leimkuhler model. Wardikar (2013) analysed Ph.D. theses of Library and Information Science submitted to the universities of Maharashtra, India. The study revealed that the journal distribution patter of library and information science theses does not fit into the Bradford's distribution. Further, the Leimkuhler model is employed for the verification of Bradford's law, it was found that the law find valid for the dataset.

3. OBJECTIVES OF THE STUDY

The objectives of the present study are:

- To find out the bibliographical form wise distribution of citations
- To prepare the rank list of journals in production engineering research publications
- To examine the applicability of Bradford's Law of Scattering in the field of production engineering.

4. METHODOLOGY

A total of 2043 journals containing 3947 citations collected from 41 doctoral theses submitted to Jawaharlal Nehru Technological University, Hyderabad, Telangana, India. The authors studied all the appended citations as appearing in the submitted theses in the specialization of Production Engineering. The authors examined the citations and recorded findings on significant aspects like author pattern, bibliographic forms, publication time, publisher credentials, name of the journals, country etc. The verbal formulation was tested by three separate parameters for carrying the different number of periodicals, while for testing the appropriateness of graphical formulation, the value of the cumulative number of journals and citations was calculated for plotting the graph.

5. Bradford's Law of Scattering

Bradford's Law of Scattering describes a quantitative relation between journals and the papers these publish. Samuel Clement Bradford, Chief Librarian at the London Science Museum, made statistical analysis of two geophysics bibliographies, the Current Bibliography of Applied Geophysics (1928-1931) and the Quarterly Bibliography of Lubrication (1931-1933). He tested the journals containing references to these fields in their descending order of productivity and then divided the articles into three approximately equal zones or groups. He termed the first one as the nuclear zone, which is highly productive; the second zone as moderately productive zone; and the third zone as peripheral zone or low productive zone. Bradford discovered regularity in calculating the number of titles in each of the three zones. On the basis of the observations, Bradford concluded that the ratio of the titles of journals in successive zones followed a common pattern. Bradford's verbal formulation stated that if scientific journals are arranged in order of their decreasing productivity of articles on a given subject, they may be divided into a nucleus of periodicals more particularly devoted to the subject, and several 'groups' or 'zones' containing the same number of articles as the nucleus, where the number of periodicals in the nucleus and succeeding zones will be 1: n: n2, where 'n' is a multiplier.

Based on Bradford's observations, Brookes suggested the following linear relation to describe the scattering phenomenon as:

$$F(x) = a + b \log x$$

where $F(x)$ is the cumulative number of references contained in the first x most productive journals, and a and b are constants. This is the most widely used formulation of Bradford's Law.

Vickery extended the verbal formulation to show that it can be applied to any number of zones of equal yield. Leimkuhler issued the following simple function for Bradford' distribution, which was named after him:

$$R(r) = a \log (1 + br)$$

where $R(r)$ is the cumulative number of articles contributed by journals ranked 1 through r, and a and b *are* parameters. Similarly, Brooke's derivation for journal productivity takes the form:

$$R(r) = a \log (b/r)$$

Further, Wilkinson noticed that the formulae provided by Leimkuhler and Brookes did not really describe the same phenomenon. Starting from the late 1960s, several mathematical formulations, models, and syntheses of previous statements related to Bradford's Law have been put forth, but very little agreement exists about which model is the best. Brooke's expression of the Bradford distribution has however gained wide acceptance.

6. THEORETICAL ASPECTS OF BRADFORD'S LAW

Bradford's Law of Scattering describes a quantitative relationship between journals and the papers they publish. It explains that, only a small number of core journals will supply the nucleus of papers on a given topic which accounts for a substantial percentage (1/3) of the articles, to be followed by a second larger group of journals that accounts for another third, while a much larger group of journals picked up the last third3. There are two most widely recognized formulations of the so called Bradford's Law: the verbal formulation which is derived from the verbal statement of Bradford's conclusion, and the graphical formulation, which is an empirical expression derived from the graphical survey of a distribution of periodicals. Bradford did not give a mathematical model for his law. Models were suggested later by Brookes, Vickery and Leimkuhler. Several authors, while explaining the scattering of articles in journals, have formulated many different models of Bradford's Law. Leimkuhler developed a model based on Bradford's verbal formulation as:

$R(r) = a \log(1+br)$ --------------------------------------(1)

$r = 1, 2, 3 \ldots$

while explaining Leimkuhler's Law, Egghe shows that

$a = Y_0/\log k$ ---(2)

$b = k\text{-}1/r_0$ ---(3)

where r_0 is the number of sources in the first Bradford group, Y_0 the number of items in every Bradford group (all these group of item being of equal sizes), and k the Bradford multiplier.

$R(r)$ is the cumulative number of items produced by the sources of rank 1, 2, 3…r and a and b are constants appearing in the law of Leimkuhler. In forming Bradford groups, it is shown that the number of group's p is a parameter that can be chosen freely.

Egghe has shown the mathematical formula for calculating the Bradford Multiplier k as

$k = (e^{\gamma}\, y_m)^{1/p}$ --(4)

where e^{γ} is Euler's number ($e^{\gamma} = 1.781$).

If the sources are ranked in decreasing order of productivity, then y_m is the number of items in the most productivity sources.

Then y_0 and r_0 are:

$Y_0 = y^2_m \log k$ -------------------------------------- (5) and

$r_0 = (k\text{-}1)Y_m$-- (6)

Once p is chosen, the value of k can be calculated

by using

$k = (1.781\text{x}\, y_m)^{1/p}$ ------------------------------------(7) and

$$Y_0 = A/P$$

where *A* denotes the total number of articles.

Let T denote the total number of journals in Bradford group, there are

$r_0k^i\text{-}1$ sources (i = 1, 2, 3……p)

$$T = r_0 + r_0k + r_0k2 + \dots\dots\dots + r_0k^p\text{-}2 \text{-----------------} (8)$$

$$\text{So, } r0 = T/1+k+k2+\dots\dots\dots\dots+kp\text{-}1 = T(k\text{-}1)/(k^p\text{-}1)\text{--}(9)$$

Since *A* and *T* are known from the data set, r_0 and Y_0 are calculated, once *p* is calculated by the formula (7)

7. DATA ANALYSIS

7.1 Bibliographic Forms

Table 1 shows the distribution of cited literature in different bibliographic forms

Table 1: Distribution of cited literature in different bibliographic forms

Bibliographic forms	Number of Citations	Percentage
Journals	2043	51.76
Databases	695	17.61
Conferences/seminars/ workshops/ Conventions etc.	533	13.50
Books	427	10.82
Reports	129	3.27
Theses/Dissertations	43	1.09
Others	44	1.11
Websites	24	0.61
Patents	9	0.23
TOTAL	**3947**	**100.00**

(Others: newsletters, newspapers, reviews, meetings etc.)

It is evident from the Table 1 that journals contribute the highest number of citations, accounting for 51.76 percent of the total citations. Databases secured the second highest number of citations, accounting for 17.61 percent of the total citations, followed by proceedings of conference/seminars/workshops/symposiums etc. (13.50%), books (10.82%), reports (3.27%), theses/dissertations (1.09%), websites (0.61%), and patents (0.23%). The remaining 1.11 percent of citations is found in other bibliographic forms. Hence, it can be concluded that journals are the information sources/literature mostly cited by researchers in Production Engineering field.

7.2 Rank List of Journals in Production Engineering

The ranking of journals as per the distribution of citations of articles in production engineering is exhibited in Table 2.

Table 2: Ranks list of journals in Production Engineering

S.No	Name of the journal	Citations			Cumulative	
		Rank	No	%	No	%
1	Journal of Materials Processing Technology	1	135	6.60793	135	6.60793
2	International Journal of Production Research	2	109	5.335291	244	11.94322
3	Journal of Annals of the CIRP	3	98	4.796867	342	16.74009
4	International Journal of Machine Tools and Manufacture	4	47	2.300538	389	19.04063
5	Journal of Power Sources	5	39	1.908957	428	20.94958
6	International Journal of Advanced Manufacturing Technology	6	36	1.762115	464	22.7117
7	International Journal of Machining Tools and Manufacturing	7	36	1.762115	500	24.47381
8	Journal of Expert Systems with Applications	8	35	1.713167	535	26.18698
9	Journal of Composites Science and Technology	9	32	1.566324	567	27.7533
10	International Journal of Thin-Walled Structures	10	30	1.468429	597	29.22173
11	Journal of European Operations Research	11	28	1.370534	625	30.59227
12	Journal of Computer and Structures	12	26	1.272638	651	31.86491
13	Journal of Sound and Vibration	13	23	1.125795	674	32.9907
14	International Journal of Flexible Manufacturing Systems	14	22	1.076848	696	34.06755
15	Journal of Composite Structures	14	22	1.076848	718	35.1444
16	Journal of Welding	15	21	1.0279	739	36.1723
17	ASME Journal of Fuel Cell Science Technology	16	18	0.881057	757	37.05335
18	Journal of Material Science and Technology	16	18	0.881057	775	37.93441
19	Transactions of the American Foundrymen's Society	16	18	0.881057	793	38.81547
20	International Journal of Numerical	17	16	0.783162	809	39.59863

	Methods in Engineering					
21	Journal of Applied Mechanics	17	16	0.783162	825	40.38179
22	Journal of Material Science	18	15	0.734214	840	41.11601
23	Journal of Operational Research	18	15	0.734214	855	41.85022
24	Journal of Scripta Materialia	18	15	0.734214	870	42.58444
25	Wear Journal	18	15	0.734214	885	43.31865
26	Journal of Composite Materials	19	14	0.685267	899	44.00392
27	Journal of Precision Engineering	20	13	0.636319	912	44.64024
28	Journal of Wear	20	13	0.636319	925	45.27655
29	IEEE Transactions on Engineering Management	21	12	0.587372	937	45.86393
30	Journal of AIAA	21	12	0.587372	949	46.4513
31	Journal of Computer and Industrial Engineering	22	11	0.538424	960	46.98972
32	Journal of Fuzzy Sets and Systems	22	11	0.538424	971	47.52815
33	Journal of Material Science	22	11	0.538424	982	48.06657
34	International Journal of Machine and Tooling	23	10	0.489476	992	48.55605
35	Journal of American Ceramic Society	23	10	0.489476	1002	49.04552
36	Journal of Automatic Welding	23	10	0.489476	1012	49.535
37	Journal of Engineering for Gas Turbines and Power	23	10	0.489476	1022	50.02447
38	Journal of Experimental Mechanics	23	10	0.489476	1032	50.51395
39	Journal of Management Science	23	10	0.489476	1042	51.00343
40	Journal of Naval Research Logistics Quarterly	23	10	0.489476	1052	51.4929
41	International Journal of Materials and Design	24	9	0.440529	1061	51.93343
42	Journal of European Ceramic Society	24	9	0.440529	1070	52.37396
43	Journal of Manufacturing Systems	24	9	0.440529	1079	52.81449
44	Journal of Welding Production	24	9	0.440529	1088	53.25502
45	Journal of Optics	25	8	0.391581	1096	53.6466
46	AFS Transaction	26	7	0.342633	1103	53.98923
47	IEEE Transactions on Neural Networks	26	7	0.342633	1110	54.33187

48	International Journal of Mechanical Sciences	26	7	0.342633	1117	54.6745
49	Journal of AFS Transactions	26	7	0.342633	1124	55.01713
50	Journal of Regional Science	26	7	0.342633	1131	55.35977
51	Journal of the American Ceramic Society	26	7	0.342633	1138	55.7024
52	ASME Journal of Engineering for Industry	27	6	0.293686	1144	55.99608
53	International Journal of Cybernetics and Systems	27	6	0.293686	1150	56.28977
54	International Journal of Product Research	27	6	0.293686	1156	56.58346
55	Journal of American Ceramic Society Bulletin	27	6	0.293686	1162	56.87714
56	Journal of Ceramic Engineering Science Processing	27	6	0.293686	1168	57.17083
57	Journal of Energy Resources Technology	27	6	0.293686	1174	57.46451
58	Journal of Industrial Engineering	27	6	0.293686	1180	57.7582
59	Journal of Materials and Manufacturing Processes	27	6	0.293686	1186	58.05189
60	Journal of Operation Research Society	27	6	0.293686	1192	58.34557
61	Journal of Russian Engineering	27	6	0.293686	1198	58.63926
62	Journal of Solid Structures	27	6	0.293686	1204	58.93294
63	Transactions of the Institute of Indian Foundry men	27	6	0.293686	1210	59.22663
64	AIIE Trans	28	5	0.244738	1215	59.47137
65	IEEE Transactions on Energy Conversion	28	5	0.244738	1220	59.71611
66	International Journal of Hydrogen Energy	28	5	0.244738	1225	59.96084
67	International Journal of Impact Engineering	28	5	0.244738	1230	60.20558
68	International Journal of Powder Metallurgy	28	5	0.244738	1235	60.45032
69	International Journal of Production	28	5	0.244738	1240	60.69506

	Economics					
70	Journal of Automobile Engineering	28	5	0.244738	1245	60.9398
71	Journal of Ceramic Institute	28	5	0.244738	1250	61.18453
72	Journal of Computers and Industrial Engineering	28	5	0.244738	1255	61.42927
73	Journal of Engineering for Industry	28	5	0.244738	1260	61.67401
74	Journal of Indian Foundry	28	5	0.244738	1265	61.91875
75	Journal of Intelligent Manufacturing	28	5	0.244738	1270	62.16349
76	Journal of Manufacturing Science and Engineering	28	5	0.244738	1275	62.40822
77	Journal of Material Science Engineering	28	5	0.244738	1280	62.65296
78	Journal of Materials Engineering and Performance	28	5	0.244738	1285	62.8977
79	Journal of Metallurgy	28	5	0.244738	1290	63.14244
80	Journal of Reinforced Plastics and Composites	28	5	0.244738	1295	63.38718
81	Journal of Science	28	5	0.244738	1300	63.63191
82	Journal of the Minerals	28	5	0.244738	1305	63.87665
83	Journal of Transportation Science	28	5	0.244738	1310	64.12139
84	Production and Inventory Management	28	5	0.244738	1315	64.36613
85	Transactions of National Research Institute for Metals	28	5	0.244738	1320	64.61087
111	26 Journals with 4 citations	29	104	5.090553	1424	69.70142
149	38 Journals with 3 citations	30	114	5.580029	1538	75.28145
239	90 Journals with 2 citations	31	180	8.810573	1718	84.09202
564	325 journals with 1 citation	32	325	15.90798	2043	100

It is evident from the Table 2 that the journal citations cited by researchers in Production Engineering are scattered in 564 journal titles. Among them 'Journal of Materials Processing Technology' occupies first rank for being cited more number of times with 6.61 percent of total citations, followed by 'International Journal of Production Research' (5.34%), 'Journal of Annals of the CIRP' (4.80%), 'International Journal of Machine Tools and Manufacture' (2.30%), and 'Journal of Power Sources' (1.91%).

7.3 Implementation of Bradford's Law

To observe the appropriateness of the distribution of journals using the verbal formulation of Bradford Law, the following explanations were made and the results were presented. The first part deals with the verbal formulation of the theory based on data consisting of whole journal references arranged by their decreasing frequency of citations, while the second part examines the graphical representations based on the same data.

7.4 Verbal Formulation

The number of cited journals has been arranged by decreasing number of citations. To test the verbal formulation of Bradford's Law, the rank number of journals, number of citations, cumulative citations were given. For testing the algebraic interpretation of the law, the 564 journals were divided into three zones. The Bradford's multiplier factor was arrived at by dividing journals of a zone by its preceding zone. Bradford's multiplier was expressed as the ratio of the number of journals in any group to the number of journals in any immediately preceding group. The basis for choosing the three zones was that the percentage error in distribution of citations, among the three zones should be minimum. The distribution of journals and corresponding number of citations in the three zones are shown in Table No. 3.

Table 3: Scattering of journals and citations over Bradford Zone

Zones	Number of Journals	Number of Citations	Percentage of Journals
I (Core)	13	674	2.30
II	72	646	12.77
III	479	723	84.93
TOTAL	**564**	**2043**	**100.00**

In the present data set (Table 3) it was observed that, 13 journals covered 674 articles, next 72 journals covered 646 articles and next 479 journals covered 723 articles. In other words, one third of the total citations have been covered by each group of the journals.

According to Bradford's, the zones, thus identifies will form an approximately geometric series in the form $1:n:n^2$. But it was found that the relationship of each zone in the present study is 13:72:479.

$13 : 72 : 479 : : 1 : n : n^2$

Here 13 represent the number of periodicals in the

$$n = \frac{\frac{72}{13} + \frac{479}{72}}{2} = \frac{5.54 + 6.65}{2} = \frac{12.19}{2} = 6.095$$

n = 6.095 is a multiplier

Therefore, 1 x 13: 13 x 6.095: 13x $(6.095)^2$ = 13: 79.235:482.94

$$Percentage\ of\ error = \frac{575.175 - 564}{591564} X\ 100$$

$$= \frac{11.175}{564} X\ 100$$

$$= 0.0198\ X\ 100 = 1.98$$

Here the percentage of error is negligible. It is also observed that, the number of journals contributing citations to each zone increases by a multiplier of 6.095. So it can be said that the distribution in present study follow Bradford's law for more confirmation of this law we can apply one more law i.e. Leimkuhler model.

7.5 Application of Leimkuhler model

For application of Bradford's law, the citations distribution was divided in three zones (p). Bradford assumes that there should be minimum three zones, here also 'p' is assumed to be 3. Then by using the mathematical formula, the value of the Bradford's multiplier 'k' is calculated as

$k = (e^y \text{ x } y_m)^{1/p}$

Where e^y = 1.781 Eulers number

y_m = first rank Journal citations

p = p is number of zone

$k = (1.781 \times 135)^{1/3}$

$= (240.435)^{1/3}$

$= \sqrt[3]{240.435}$

= 6.22

$$yo = \frac{A}{P}$$

Where y_0 = No of citations in each zone

A = No. of Citations

P = 3

$$yo = \frac{2043}{3} = 681$$

The nucleus zone r_0 can be defined as:

$$ro = \frac{T(k-1)}{k^p - 1}$$

$$= \frac{564(6.22-1)}{6.22^3 - 1}$$

$$= 564\, X \frac{5.22}{(240.642 - 1)}$$

$$= \frac{2944.08}{239.642}$$

$$ro = 12.29$$

Different Bradford's zone can be obtained using the value of k and r_0.

Nucleus zone $r_0 = r_0 \times 1 = 12.29$

First zone $r_1 = r_0 \times k = 12.29 \times 6.2 = 76.44$

Second zone $r_2 = r_0 \times k^2 = 12.29 \times 6.22 \times 6.22 = 475.48$

13.43: 81.61: 495.98 = 591.02

$$Percentage\ of\ error = \frac{564.21 - 564}{564} X100 = \frac{0.21}{564} X100$$

$$= 0.000037\ X100 = 0.04$$

The Bradford groups thus formed were shown in the table no. 3A

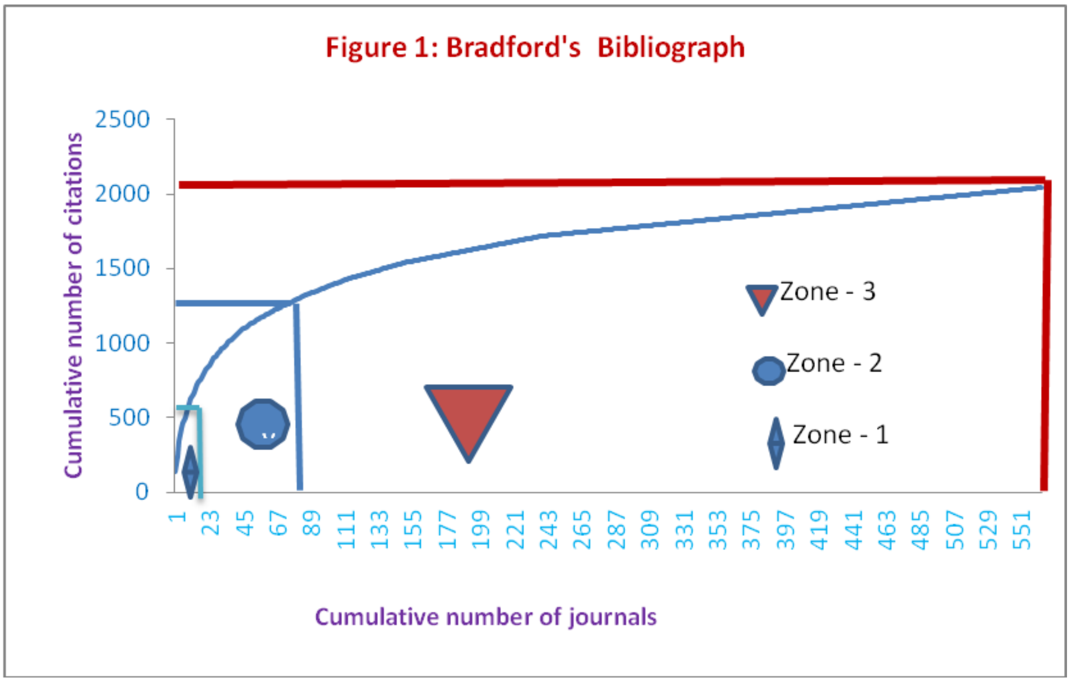
Table 3A : Using Leimkuhler Model, Bradford's Zone and Number of Journals

Zones	Number of Journals	Number of Citations	Percentage of Journals
I (Core)	12	651	2.13
II	73	669	12.94
III	479	723	84.93
TOTAL	**564**	**2043**	**100.00**

Here the percentage of error is very much negligible. It was observed that, the number of journals contributing citation to each zone is increased by multiplier of 6.22. The data of zonal analysis also shows that there is almost equal 1/3rd of total citations in each zone. Journal in nucleus zone are highly productive and productivity of journals decreases in next subsequent zones. This theoretical presentation of Bradford's law proves that Bradford's law of Scattering is valid in present study.

7.6 Graphical Formulation

Bradford's Bibliograph for present study have been plotted taking the cumulative number of journal titles on the X-axis and cumulative number of citations on the Y-axis. From the figure 1 it is found that data in present study have an initial raising curve and followed by linearity. From the figure it is also confirms that Bradford's law of Scattering is suitable for the present study.



CONCLUSION

The study revealed that journals contribute the highest number of citations, accounting for 51.76 percent of the total citations. Databases secured the second highest number of citations, accounting for 17.61 percent of the total citations. The rank list of journals in the field of production engineering indicates that 2043 citations were scattered in 564 journal titles. It is evident from rank list that out of these 564 journals first 13 journals contribute 674 (32.99%) citations i.e. 1/3rd citations and these 13 journals are core journals in the field of production engineering. To test the Bradford's Law, 564 journals and 2043 citations were divided in three zones of equal number of citations. After dividing citations in three zones the number journals in each zones is in the ratio of '13: 72: 479'. Hence it is evident from analysis of data that scattering of journal titles in the field of production engineering is follows Bradford's Law. The Method based on the Leimkuhler model was used for the verification of Bradford's Law. From the study it is found that Law is fit for the present data set.

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