



Contents lists available at ScienceDirect

Socio-Economic Planning Sciences

journal homepage: www.elsevier.com/locate/seps

Invited paper

A survey and analysis of the first 40 years of scholarly literature in DEA: 1978–2016

Ali Emrouznejad ^{a,*}, Guo-liang Yang ^{b,**}^a Aston Business School, Aston University, Birmingham, UK^b Institute of Policy and Management, Chinese Academy of Sciences, Beijing 100190, China

ARTICLE INFO

Article history:

Received 22 January 2017

Accepted 23 January 2017

Available online xxx

Keywords:

Data envelopment analysis

Efficiency and productivity

Bibliography

Survey

ABSTRACT

In recent years there has been an exponential growth in the number of publications related to theory and applications of Data Envelopment Analysis (DEA). Charnes, Cooper, and Rhodes (1978) introduced DEA as a tool for measuring efficiency and productivity of decision making units. DEA has immediately been recognized as a modern tool for performance measurement. Since then, a large and considerable amount of articles has been appeared, including significant breakthroughs in theory and a great portion of works on DEA applications, both public and private sectors, to assess the efficiency and productivity of their activities. Although there have been several bibliographic collections reported, a comprehensive analysis and listing of DEA-related articles covering its first four decades of history is still missing. This paper, thus, aims to report an extensive listing of DEA-related articles including theory and methodology developments and "real" applications in diversified scenarios from 1978 to end of 2016. Some summary statistics of the publications' growth, the most utilized academic journals, authorship analysis, as well as keywords analysis are also provided.

© 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

There has been continuous and rapid growth in the field of Data Envelopment Analysis (DEA)-related studies since the original work of Charnes, Cooper, and Rhodes [Measuring the efficiency of decision-making units. *European Journal of Operational Research* 1978, 2(6): 429–44] (referred to CCR) [1]. This paper aims to provide full list of DEA publications since 1978. To the best of our knowledge, this listing of DEA-related articles is the most complete source of references on DEA theory and its applications in measuring the efficiency, productivity, or performance of decision-making units (DMUs). Authors hope that this new updated bibliography on DEA-related articles will be helpful to researchers and practitioners in this field when exploring the new frontiers in DEA in both theory and applications. Although we tried to include all articles, however, due to large number of publications it is not possible to guarantee a complete and accurate list with no omission of the data. Should readers happen to find any error(s) in this paper,

please feel free to report them to the authors, see details at <http://DEAzone.com/biblio/>.

2. Bibliography of DEA

There are already several other bibliographies in the area of DEA which have been reported in the existing literature, e.g. Emrouznejad and Thanassoulis [4–6], Seiford [9,10], Tavares [2], Gattoufi et al. [7,8], and Emrouznejad et al. [3]. In this study we searched related articles on SCOPUS (<http://www.scopus.com/>) and merged them into authors' dataset that is mainly gathered from the website of www.DEAzone.com. We considered publications until end of 2016. It should be noted that we only included DEA-related articles published in journals. There are about 2,200 articles published as working paper, book chapter or conference proceedings which we did not include them in this study. In total, there are 10,300 DEA-related journal articles reported in this study. List of these articles are available in the supplement to this paper (see Appendix A).

As a worldwide accepted management science and operations research (MS/OR) tool, the evolution of DEA has been tracked here in terms of the increase of numbers of both articles and authors. First, it is obvious from our analysis that DEA is an emerging topic and an essential mathematical tool for measuring efficiency or

* Corresponding author.

** Corresponding author.

E-mail addresses: a.emrouznejad@aston.ac.uk (A. Emrouznejad), glyang@casipm.ac.cn (G.-l. Yang).

performance which has received a great number attentions in diversified fields of management science. Second, three stages of the development status of DEA-related articles are detected in our study to demonstrate the tendency of DEA as an “exponential” growth. Third, several traditional MS/OR journals including *European Journal of Operational Research*, *Journal of the Operational Research Society*, *Journal of Productivity Analysis*, *Omega* and *Annals of Operations Research* are the most utilized journals for DEA publications, while journal of *Socio-Economic Planning Sciences* has been identified first choice for DEA papers with applications in the public sector. In total, there are 94% of DEA-related articles have less than 4 authors and about 34% were published by two authors. Energy, industry, banking, educations and healthcare including hospital are found to be the most popular application areas. We detected approximately 11,961 distinct DEA authors and 25,137 distinct keywords in all DEA-related articles in our database, which has also been grown significantly in recent years.

The next section lists a series of selected descriptive statistics involving the numbers and distributions of papers, journals, authors, keywords, as well as pages within our database of DEA-related articles.

3. Statistics on DEA publications

3.1. Statistics based on different years

Fig. 1 demonstrates the rapid increase of DEA-related articles by year. It should be noted that there was “exponential” growth in the number of journal articles since the seminal work of CCR in 1978.

In recent four decades (1978–2016), there are totally 10,300 DEA-related articles in the literature. In particular, in the last three years (2014, 2015 and 2016), the numbers of journal articles reached to just about 1000 published works in each year. In general, we can roughly classify the development status of DEA-related articles into three stages : (1) 1978–1994: in this stage the growth of DEA-related articles is relatively slow in the sense of the article numbers ; (2) 1995–2003: in the second stage the growth of DEA-related articles is relatively stable and the average number of published articles is about 134 per year ; (3) 2004-present: in the third stage the number of DEA-related articles show the “exponential” growth and the average number reaches about 680 per year. The latest trend of publications show about 1000 papers in each year.

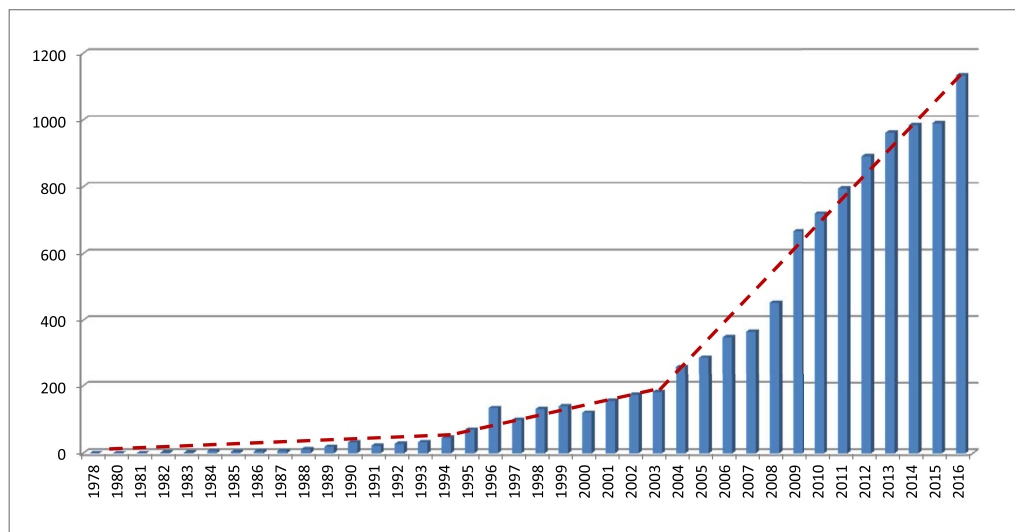


Fig. 1. Distribution of DEA-related articles by year (1978–2016).

Table 1

The 21 journals that have published the greatest number of DEA articles.

No.	Journal	Numbers	% of papers
1	European Journal of Operational Research	691	23.23%
2	Journal of the Operational Research Society	281	9.45%
3	Journal of Productivity Analysis	255	8.57%
4	Omega (United Kingdom)	237	7.97%
5	Expert Systems with Applications	181	6.09%
6	Annals of Operations Research	177	5.95%
7	Applied Economics	134	4.51%
8	Socio-Economic Planning Sciences	115	3.87%
9	Computers and Industrial Engineering	96	3.23%
10	Applied Mathematics and Computation	94	3.16%
10	Energy Policy	94	3.16%
12	International Journal of Production Economics	89	2.99%
13	Computers and Operations Research	74	2.49%
14	Journal of Cleaner Production	71	2.39%
15	Energy Economics	69	2.32%
15	International Journal of Production Research	69	2.32%
17	Benchmarking	68	2.29%
18	Applied Mathematical Sciences	61	2.05%
18	Applied Economics Letters	61	2.05%
20	Applied Mathematical Modelling	57	1.92%
Total		2974	100.00%

3.2. Statistics based on different journals

Table 1 intends to show the top 20 journals that have published the greatest number of DEA-related articles in the last 40 years.

From Table 1, *European Journal of Operational Research*, *Journal of the Operational Research Society*, *Journal of Productivity Analysis*, and *Omega* are the most utilized journals. It is reasonable since DEA theory and most applications fall within the fields of management science and operations research (MS/OR), which are exactly the scopes covered by these journals.

3.3. Statistics based on different authors

In this study 11,975 distinct DEA authors were identified in total, with an average of 2.6 authors per publication. About 17% of all DEA-related articles were written by a single/sole author, while about 34% were published by two authors. Most of all DEA-related articles, about 94%, have four or less than four authors. The article with most authors has 30 distinct names. The following Fig. 2 shows the distribution of DEA-related articles by number of authors.

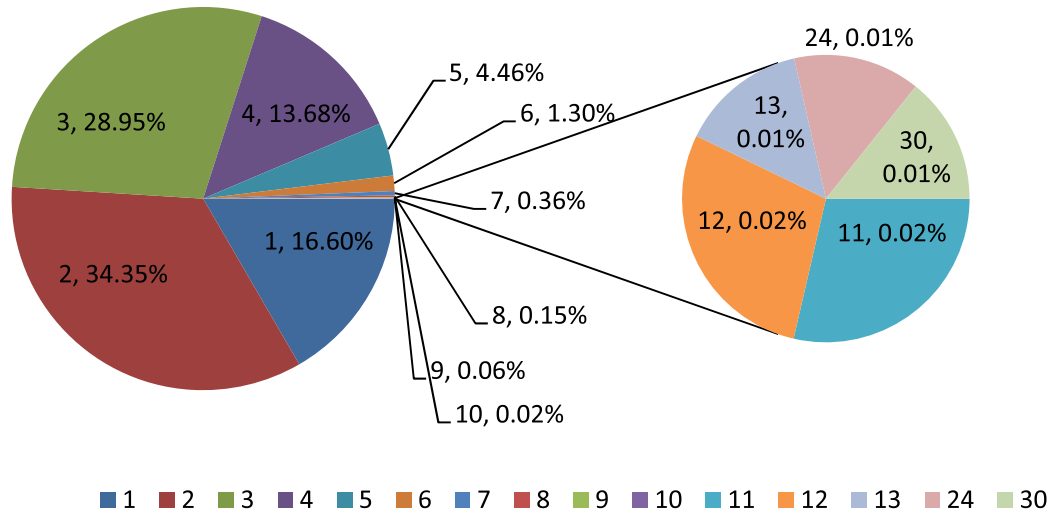


Fig. 2. Distributions of DEA-related articles by number of authors (1978–2016).

Table 2
The 50 most used keywords by number of DEA-related articles.

No.	Keywords	No. of publications
1	Data Envelopment Analysis, Data Envelopment Analysis (DEA), DEA, or DEA models	9989
2	Efficiency	2382
3	Decision making	1048
4	Technical efficiency	876
5	Linear programming	722
5	Productivity	722
7	Mathematical models	574
8	Data reduction	535
9	Benchmarking	502
10	Decision making unit, Decision-making units	479
11	Human, Humans	477
12	Efficiency measurement	440
13	Optimization	368
14	Malmquist index, Malmquist Productivity Index	359
15	Operations Research	337
16	Data handling	308
17	China	298
18	Energy efficiency	286
19	performance assessment	276
20	Regression analysis	275
21	Economics	272
21	Performance	272
21	Bootstrapping, bootstrap	272
24	Efficiency, Organizational	265
25	Returns to scale	253
26	Data analysis	244
27	Eurasia	224
27	United States	224
29	Industry	208
29	Performance evaluation	208
31	Relative efficiency	207
32	Banking	193
32	Ranking	193
34	Problem solving	184
35	Data envelopment	183
36	Costs	177
37	Resource allocation	176
38	Efficiency analysis	173
39	Europe	169
40	Decision theory	168
41	Competition	163
42	Performance measurement	157
43	Mathematical Programming	154
44	Sustainable development	151
45	Total factor productivity	149
46	Organization and management	148
47	Profitability	141
48	Numerical model	138
49	Sensitivity analysis	136
50	Methodology	130

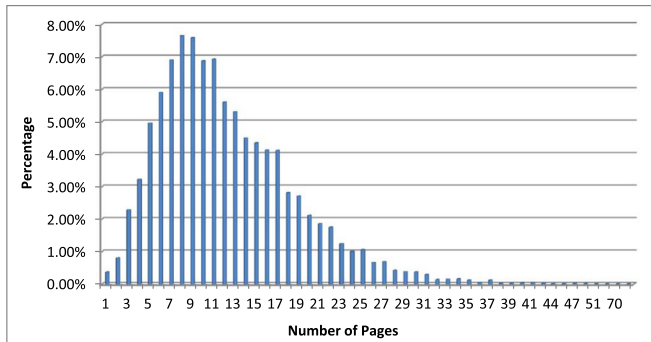


Fig. 3. Distribution of DEA articles by number of pages (1978–2016).

3.4. Statistics based on keywords used

According to our dataset most DEA-related journal papers have identified keywords, and so approximately 25,137 distinct keywords were used. The following Table 2 shows the first 50 most used keywords. There is no doubt that Data Envelopment Analysis, DEA, or DEA models are the most used keywords with number of article of 9989. Moreover, efficiency, decision-making, technical efficiency, linear programming, and productivity are also most popular keywords in the existing DEA-related articles.

3.5. Statistics based on page numbers (size)

In excess of 120,000 pages of scholarly DEA-related articles have been published over the past four decades in scientific journals, with an average of 12.3 pages per article. Nearly 22% of the DEA-related articles are between 9 and 11 pages in length, with approximately 42% being between 7–12 pages. About 73% of the DEA-related articles are between 6 and 18 pages in length. The following Fig. 3 shows the distribution of DEA-related articles by number of pages. After all, DEA-related articles appear to have a distribution by page numbers similar to those found in most other MS/OR fields of study.

4. Current studies and future trends

In order to discover the current studies and future trends of DEA

Table 3
Top 5 most popular research keywords in 2015 and 2016.

No	Research keywords
1	Eco-efficiency, undesirable outputs, directional distance function (DDF), environmental efficiency, carbon dioxide emissions, pollution, sustainable development, sustainability, environmental protection
2	Network DEA, two-stage DEA, efficiency Decomposition
3	Benchmarking
4	Bootstrap, bootstrapping
5	Returns to scale, scale efficiency

Table 4
Application fields of DEA methodology in 2015 and 2016.

No.	Application field
1	Agriculture
2	Banking
3	Supply chain
4	Transportation
5	Public policy

research, we further investigated the keywords of journal articles published in the last two years (2015 and 2016). To reflect the current studies we list, in Table 3, the top 5 most popular research keywords appeared in the DEA-related articles published in the last two years.

Next, we further list, in Table 4, the top 5 latest application fields of DEA with the greatest numbers of journal articles, including Agriculture, Banking, Supply Chain, Transportation, as well as public policy.

5. Conclusions and discussions

Since the seminal work of Charnes, Cooper, and Rhodes [1] in DEA, there has been an “exponential” growth in the number of journal articles in recent four decades (1978–2016). Until end of 2016, the total number of journal articles reaches 10,300 and the distinct authors reach 11,975 in total. Based on the statistics of journal articles, we found that (1) *European Journal of Operational Research*, *Journal of the Operational Research Society*, *Journal of Productivity Analysis*, *Omega* and *Annals of Operations Research* are the most utilized journals in this field while journal of *Socio-Economic Planning Sciences* has been recognized as the first choice journal for DEA papers with applications in the public sector ; (2) Most of all DEA-related articles have less than 4 authors and the percentage is 94% ; (3) Data Envelopment Analysis (including DEA, or DEA models) are the most used keywords, and Efficiency, decision-making, technical efficiency, linear programming, as well as productivity are second most popular keywords in the existing DEA-related articles ; (4) Environmental efficiency and DDF (including eco-efficiency, undesirable outputs, directional distance function (DDF), environmental efficiency, carbon dioxide emissions, pollution, sustainable development, sustainability, environmental protection), network DEA (including two-stage DEA, efficiency decomposition), benchmarking, bootstrap or bootstrapping, as well as returns to scale (including scale efficiency) are the main fields of current studies. Moreover, we detect agriculture, banking, supply chain, transportation, as well as public policy are the top 5 application fields of DEA with the greatest numbers of journal articles in 2015 and 2016.

Acknowledgements

The second author acknowledges the supports from the National Natural Science Foundation of China (NSFC, Nos. 71201158, 71671181) and Ministry of Science and Technology of China (MOST, No. 2016YFC0503407).

Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.seps.2017.01.008>.

References

- [1] Charnes A, Cooper WW, Rhodes E. Measuring the efficiency of decision-making units. *Eur J Operat. Res* 1978;2(6):429–44.
- [2] Tavares G. A bibliography of data envelopment analysis (1978–2001). RUT-COR, Rutgers University; 2002. also available at: http://rutcor.rutgers.edu/pub/rrr/reports2002/1_2002.pdf.
- [3] Emrouznejad A, Parker BR, Tavates G. Evaluation of research in efficiency and productivity: a survey and analysis of the first 30 years of scholarly literature in DEA. *Socio-Economic Plan Sci* 2008;42:151–7.
- [4] Emrouznejad A, Thanassoulis E. An extensive bibliography of data envelopment analysis (DEA), vol. III: supplement vol. 1; 1997. p. 1–24. Working Paper 258.
- [5] Emrouznejad A, Thanassoulis E. An extensive bibliography of data envelopment analysis (DEA), vol. I: working papers; 1996. p. 1–55. Working Paper.
- [6] Emrouznejad A, Thanassoulis E. An extensive bibliography of data

- envelopment analysis (DEA), vol. II: journals papers; 1996. p. 1–21. Working Paper.
- [7] Gattoufi S, Oral M, Reisman A. A taxonomy for data envelopment analysis. *Socio-Economic Plan Sci* 2004a;38(2–3):141–58.
- [8] Gattoufi S, Oral M, Reisman A. Data envelopment analysis literature: a bibliography update (1996–2001). *Socio-Economic Plan Sci* 2004b;38(2–3):122–59.
- [9] Seiford LM. A DEA bibliography (1978–1992). In: Charnes A, Cooper WW, Lewin AY, Seiford LM, editors. *Data envelopment analysis: theory, methodology and applications*. Boston, USA: Kluwer; 1994. p. 437–69.
- [10] Seiford LM. A bibliography for data envelopment analysis (1978–1996). *Ann Operations Res* 1997;73:393–438.

Ali Emrouznejad is a Professor and Chair in Business Analytics at Aston Business School, UK. His areas of research interest include performance measurement and management, efficiency and productivity analysis as well as data mining. Dr Emrouznejad is *Editor of Annals of Operations Research*, *Associate Editor of RAJOR-Operations Research*, *Associate Editor of Socio-Economic Planning Sciences*, *Associate*

Editor of IMA journal of Management Mathematics, *Senior Editor of Data Envelopment Analysis journal*, and member of editorial boards or guest editor in several other scientific journals. **He has published over 100 articles in top ranked journals**; he is author of the book on “*Applied Operational Research with SAS*”, editor of the books on “*Big Data Optimization*”, (Springer “*Performance Measurement with Fuzzy Data Envelopment Analysis*” (Springer), “*Managing Service Productivity*” (Springer), and “*Handbook of Research on Strategic Performance Management and Measurement*” (IGI Global). He is also co-founder of Performance Improvement Management Software (PIM-DEA), see <http://www.DEAzone.com> and <http://www.Emrouznejad.com>.

Guoliang Yang obtained his Ph.D. in Management Science from Chinese Academy of Sciences in 2013. He is currently an associate professor at the Institute of Policy and Management, Chinese Academy of Sciences. His research interests are performance measurement, science and technology policy, and decision theory and methods. In recent years he published a couple of papers on top-ranked journals including *European Journal of Operational Research*, *Journal of the Operational Research Society*, *Omega*, *Computers & Operations Research*, and etc. His main area of current research is on CO₂ emissions reduction. See https://www.researchgate.net/profile/Guoliang_Yang.