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Celebrating 50-years of OR in South Africa – a bibliometric analysis of contributions to international OR literature

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Abstract

The Operations Research Society of South Africa (ORSSA), the first Operations Research (OR) society in Africa, celebrated its 50$^{\text{th}}$ anniversary at its annual conference in 2019. To commemorate the occasion a book, covering the history of the society, was launched at the conference. One area that was not covered in this book was the contribution of South Africans to the international OR literature. This paper endeavors to fill that void through a bibliographic analysis of papers published by South Africans over the 50-year period. A list of over 100 journals were used for this analysis. General empirical results are derived while a visual analysis of top author research networks is presented. The analysis demonstrates the contribution to the international Operations Research/ Management Science (OR/MS) knowledge base of a small but vibrant national OR society at the most southern point of Africa.

Key words: Operations Research; Management Science; Bibliographic Analysis; South Africa; National Society; History.

1 Introduction

The Operations Research Society of South Africa (ORSSA) celebrated its 50$^{\text{th}}$ anniversary in 2019 at the annual conference of the society held in Cape Town. As part of the 50-year anniversary the society published a book *"Operations Research in South Africa – The First 50 Years"* [15]. It is a comprehensive and detailed history of the society. Included

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is an in depth analysis of papers published, in total 237, over the period 1985 to 2018 in ORiON the journal of ORSSA [30]. There is, however, one aspect that was not covered and captured in the book namely the contribution of South Africans to the international OR knowledge base and specifically journal articles published in international OR/MS journals. The focus of this paper is on a bibliometric analysis of these contributions by South Africans.

South Africans have been involved in OR right from its inception during World War II. Basil Schonland, director of the Bernard Price Institute of Geophysics at the University of the Witwatersrand (WITS), was appointed head of the Air Defense Research Development Establishment (Operational Research Group) (ADRDE(ORG)) in July 1941 [2]. Subsequently, in January 1944, Schonland became Superintendent of the newly established Army Operational Research Group (AORG). After the war Schonland established and became the first president of the Council for Scientific and Industrial Research (CSIR). A British mathematical physicist Frank Nabarro, one of the original members of the Blackett's Circus [4], later joined Schonland's ADRDE (ORG) and after the war he was offered a chair in physics at WITS, accepted the offer and became a South African.

The first OR applications in South Africa were in the mining industry. These applications were conducted mainly by the "Operational Research Bureau" that was established in 1952 by Herbert Sichel [25]. Fiore & Rozwadowski [9] were the authors of the first publication of an OR nature from Africa that was published in 1968 in the journal, Management Science published by the then Operations Research Society of America (ORSA). On 21 November 1969, ORSSA was founded at WITS in Johannesburg during a two-day conference. Approximately 150 delegates from South Africa, Zambia and Lesotho were in attendance. Rozwadowski was one of the main founding members of the society. Tragically in October 1970 Rozwadowski, his wife and their two young kids were asphyxiated while on a visit to Annadale, Minnesota in the USA. ORSSA honoured him by instituting the Tom Rozwadowski medal, awarded annually for the best paper published by a member of ORSSA in the preceding year.

What follows is an analysis of the contributions of South Africans to the international OR literature over the 50-year period from 1969 to 2019. For a relatively small OR society the achievements in this regard testify to a high standard of the practice of OR.

The structure of the paper is as follows. A literature review on bibliographic analysis is presented in Section 2. Section 3 provides a bibliographic analysis of publications by South Africans in the international OR/MS literature. What is presented in this Section is the number of papers published in international journals, papers published annually, the number of citations, papers with the highest number of citations and the top authors. A visual analysis of the top author networks constitutes Section 4 together with the citations of these researcher communities. Then in Section 5 the institutional representation of the authors is presented. Section 6 covers the research, technique, and application areas of all the papers. International recognition is the topic of Section 7. In the last two sections there is a brief general discussion and then a short conclusion.

2 Literature review - Bibliometric analysis

Bibliometric and scientometric analysis provides a view of research in a specific field that can be classified by papers, authors, and journals. Bibliometric analysis is the quantitative study of bibliographic material where statistical methods are used in the analysis with the objective of determining, inter alia, the academic quality of a journal as well as the performance of authors using quantitative assessments of the number of citations, etc. [29]. Several papers focusing on OR related topics have been published recently.

Merigó & Yang [18] completed a bibliometric analysis of all operations research and management science (OR/MS) publications published in 81 journals in the OR/MS category of the Web of Science (WoS). The top 30 journals were ranked based on the journal's H-index, the top 200 most cited papers were listed as well as the authors with the most publications and those most cited. Finally, the 8 most reputable OR/MS journals are listed. Laengle *et al.* [17] analyzed the contributions to OR/MS by universities across the world. From this, the most productive and influential universities over the period 1991 to 2015 were determined.

With the 40^{th} anniversary of the European Journal of Operational Research (EJOR), Laengle *et al.* [16] performed a bibliometric overview of all papers published in EJOR. With the 50^{th} anniversary of the Journal of the Operational Research Society (JORS), Ranyard [22], presented metrics pertaining to the most cited articles and the most cited authors in the history of JORS. With the profiling of Katsaliaki *et al.* [14], published at the 60^{th} anniversary of JORS, the objective was to review and profile publications in JORS over the decade, 2000 to 2009, to assist in identifying under-explored research issues, to select and suggest theories and methods that would be appropriate to address these issues through research in future.

Smith [27] presented a bibliography of papers relating to applications of OR in 18 West African countries. Subsequently this was extended to sub-Saharan countries in Africa with the exclusion of South Africa [26]. There is a detailed outline of the sources of where the information was obtained for both papers and how the data was collated. Some 275 papers were identified for West Africa and 300 for sub-Saharan Africa. In a study to determine the contribution of African countries to OR, a scientometric analysis was performed by Argoubi *et al.* [1]. The WoS was used as the source and 3186 OR/MS papers, indexed between 1990 and 2018, published by African authors from 54 countries were found. A detailed analysis using these papers are presented.

Very little has been published in the international literature that focus on OR in South Africa. The first view on OR in the country is given in Fatti [8] with an emphasis on OR in mining and OR in wildlife management. Hearne [12] gives a very interesting overview of the concern for the environment in the country as well as the preservation and management of the exceptional variety of wildlife present in South Africa. A different perspective on OR in South Africa is given by Stewart [28] through the analysis of papers presented over a 20-year period at local conferences. All three of these are personal views of the respective authors of the state of OR in South Africa.

3 Bibliographic analysis of contributions to the international OR/MS literature from South Africa

To address the main objective of this article a list, or set, of OR/MS journals needed to be identified and these journals can then be sourced to create a publication database of South African contributions. The methodology followed to identify the set of journals, how the data was extracted and analyzed using this data is outlined below.

3.1 Methodology

The question of how to determine the contribution of operations researchers from South Africa's to the international OR literature, over a period of 50 years, is a contentious and difficult one, almost impossible! The issue becomes even more complex since OR penetrates all aspects of society. Furthermore, the OR approaches and techniques are nowadays used and applied by individuals from various disciplines, many of these individuals are unaware that OR is being used to solve a problem. It was decided to focus on journals, specifically OR/MS journals, as used internationally. Furthermore, since the focus is on ORSSA, the local OR society, the tendency is to include contributions from members of this society.

Two potential lists of journals were considered as the data source for the bibliographic analysis. First there is the SCImago country and journal list used for ranking scientific performance. SCImago, a research group based in Spain, developed, inter alia, a portal where the ranking of scientific journals is captured and presented annually [23]. The latest SCImago international scientific journal ranking is for 2020. Selecting the subject area "Decision Sciences" and the subject category "Management Science and Operations Research" a total of 233 journals are listed as of April 2021. Although the subject category is specific, it is difficult to classify some, quite a number, of these as OR/MS journals.

A second source is produced by Clarivate Analytics using data obtained from the WoS. The subject category "Operations Research and Management Science" is used to identify and select the relevant OR/MS journals [5]. This approach lists a total of 83 OR/MS journals. The International Transactions of Operational Research (ITOR) journal ranked 23$^{\text{rd}}$ in 2019 out of 83 journals that were identified in this manner [13]. JORS quotes its ranking, obtained from the Clarivate analysis, as being 34$^{\text{th}}$. Even though there are journals on this list, where the relevance to OR can be questioned, it was nevertheless decided to use the 83 journals as the main source for this bibliographic analysis. A few OR journals that are not on this list, as they do not meet the WoS requirements, were also used in the analysis as it gives a more complete picture of international OR/MS contributions of South Africans, with the emphasis on ORSSA members.

An exhaustive search, perusing each of the 83 journals, was performed to find papers published by South African authors. The data was collected for the 50-year period from 1969 to 2019 that matches the 50-year anniversary of ORSSA. Two early articles[1], one published in 1963 (Botha & Adendorff [3]) and the other in 1968 (Fiore & Rozwadowski [9]) were however also included. The one by Fiore and Rozwadowski was the first paper

[1]Journal publications are referred too interchangeably as articles or papers throughout this article.

published by South Africans in an international OR journal. The exhaustive search used the search term "South Africa" for "Author Affiliation". If any author had an affiliation that showed "South Africa" then the paper was included, implying that the author was attached, in whatever way, to a South African university or organization at the date of publication of the article. It does, therefore, imply that authors identified in this way may not have been residents or citizens of South Africa.

There are a whole range of sources that can be used to obtain the number of citations for each paper. Google Scholar which 'is not a human-curated database but a search engine of the whole internet which narrows the results to "scholarly" ones based on machine automated criteria' [20], was used as the citation source. As a search engine, Google Scholar, considers "scholarly" material for inclusion and these include books, journal articles, reports, theses, preprints, and other types of sources. As is acknowledged by the WoS [34], Google Scholar is more liberal in the way it attributes citations to a paper. Using Google Scholar also ensures that all papers are treated equally. Here too an exhaustive process, conducted during August 2021, was followed to obtain the number of citations for the papers used in this analysis.

3.2 Number of papers and citations

In total 699 papers were published in the 83 journals obtained from Clarivate Analytics, over the 50-year period 1969 to 2019, with the total number of citations being 26 312 when the analysis was conducted. The journals, with their respective rankings, are listed in Table 1. What is shown in the two righthand columns is the number of papers and the total citations for all the articles published over the 50-year period in that specific journal. In 20 of the journals no papers were published by someone affiliated with an entity in South Africa.

The five journals with the highest number of papers are presented in Table 2. Just over one third of the papers by South Africans published in the 83 journals were published in these five journals. Three of the journals, Journal of Optimization Theory and Applications, EJOR and JORS are completely devoted to the practice of OR which shows the preference of South African operations researchers. The most citations are for papers published in EJOR.

The objective of this article is to provide as comprehensive a compilation of papers published by operations researchers from South Africa as possible. To enhance the search, a few "obvious" OR journals that are missing from the list of 83 were added. In addition, using Google Scholar, CVs of some ORSSA members and knowledge of the South African OR community[2] it was possible to increase the number of articles by 78 with an additional 3 469 citations. Table 3 gives a list of the additional journals, identified in this way, with the number of articles and citations. The articles in a few of these journals (marked with an * in Table 3) were also found through an exhaustive search.

[2]The author has been involved with ORSSA since 1973, served the society in various capacities and attended all the society conferences since joining the society.

Table 1: *List of OR/MS journals with number of articles and citations.*

Rank	Full journal title	Number of papers	Citations
1	Technovation	18	806
2	Expert Systems with Applications	28	1 287
3	Omega-International Journal of Management Science	27	1 860
4	International Journal of Production Economics	9	1 494
5	Journal of Manufacturing Systems	4	96
6	Reliability Engineering & System Safety	36	1 323
7	Transportation Research Part B-Methodological	2	32
8	Decision Support Systems	7	314
9	Transportation Research Part E-Logistics and Transportation Review	1	212
10	Journal of Operations Management	1	93
11	International Journal of Production Research	16	410
12	Fuzzy Optimization and Decision Making	-	-
13	M&SOM-Manufacturing & Service Operations Management	-	-
14	European Journal of Operational Research	62	3 648
15	Socio-Economic Planning Sciences	2	15
16	Safety Science	16	532
17	IEEE Systems Journal	-	-
18	Management Science	7	241
19	Memetic Computing	-	-
20	Production Planning & Control	-	-
21	Computers & Operations Research	15	1 084
22	Transportation Science	-	-
23	International Transactions in Operational Research	7	114
24	International Journal of Computer Integrated Manufacturing	8	62
25	Mathematical Programming	8	247
26	Systems & Control Letters	19	1 126
27	Networks	12	208
28	Production and Operations Management	-	-
29	Annals of Operations Research	16	707
30	Operations Research	4	251
31	Networks & Spatial Economics	3	36
32	Flexible Services and Manufacturing Journal	1	5
33	Quality Technology and Quantitative Management	4	46
34	Journal of the Operational Research Society	31	1 335
35	Engineering Optimization	28	414
36	International Journal of Systems Science	29	146
37	Studies In Informatics and Control	-	-
38	Journal of Quality Technology	4	288
39	Central European Journal of Operations Research	1	6
40	International Journal of Information Technology & Decision Making	-	-

Table 1: *List of OR/MS journals with number of articles and citations. (Continued.)*

Rank	Full journal title	Number of papers	Citations
41	Optimization and Engineering	2	22
42	Journal of Global Optimization	16	1 524
43	Mathematics of Operations Research	4	115
44	Journal of Scheduling	3	123
45	Operational Research	6	32
46	Computational Optimization and Applications	7	290
47	Quality And Reliability Engineering International	27	570
48	Proceedings of the Institution of Mechanical Engineers Part O-Journal of Risk and Reliability	13	134
49	IISE Transactions	3	99
50	Informs Journal on Computing	3	22
51	IMA Journal of Management Mathematics	-	-
52	Optimization	4	27
53	Optimization Letters	5	46
54	TOP	1	3
55	Optimization Methods & Software	4	55
56	Journal of Optimization Theory and Applications	83	3 280
57	Journal of Industrial and Management Optimization	-	-
58	International Journal of Technology Management	2	75
59	Journal of Systems Science and Systems Engineering	1	13
60	OR Spectrum	1	23
61	Optimal Control Applications & Methods	23	228
62	Journal of Simulation	-	-
63	Applied Stochastic Models in Business and Industry	22	365
64	4OR-A Quarterly Journal of Operations Research	1	6
65	European Journal of Industrial Engineering	1	5
66	Queueing Systems	3	145
67	RAIRO-Operations Research	1	5
68	Mathematical Methods of Operations Research	1	23
68	Systems Engineering	1	4
70	Engineering Economist	-	-
70	INFOR	-	-
72	Discrete Event Dynamic Systems-Theory and Applications	-	-
73	Journal of Systems Engineering and Electronics	-	-
74	Concurrent Engineering-Research and Applications	-	-
75	Discrete Optimization	5	142
76	Probability in the Engineering and Informational Sciences	-	-
77	SORT-Statistics and Operations Research Transactions	-	-
78	Interfaces	4	82
79	Asia-Pacific Journal of Operational Research	6	121
80	Operations Research Letters	13	170
81	Naval Research Logistics	6	117
82	Pacific Journal of Optimization	-	-
83	Military Operations Research	1	8
	Total	699	26 312

Table 2: *The top five journals with the highest number of papers.*

Journal full title	Number of papers	Citations
Journal of Optimization Theory and Applications	83	3 280
European Journal of Operational Research (EJOR)	62	3 648
Reliability Engineering & System Safety	36	1 323
Journal of the Operational Research Society (JORS)	31	1 335
International Journal of Systems Science	29	148
Total	241	9 724

Table 3: *Additional journals as further sources for articles.*

Nr	Additional Journals - Full Journal Title	Nr of articles	Citations
1	*Decision Analysis	2	21
2	Ecological Modelling	22	850
3	*Journal of Heuristics	1	4
4	*Multi-Criteria Decision Analysis	6	478
5	*Group Decisions and Negotiation	4	196
6	*OPSEARCH	3	10
7	*Annals of Discrete Mathematics	4	215
8	Discrete Applied Mathematics	3	36
9	Applied Mathematical Modelling	7	428
10	International Journal of Electrical power	3	110
11	Computers and Electronics in Agriculture	1	66
12	Journal of Water Resource Planning and Management	1	37
13	Fuzzy Sets and Systems	2	147
14	Health Systems	1	13
15	*Operations Research Perspectives	3	51
16	Swarm and Evolutionary Computation	1	9
17	Geographical Analysis	2	261
18	Computers Environment and Urban Systems	2	99
19	Annals of Nuclear Energy	1	9
20	Water Resources Research	1	104
21	IEEE Transactions on Systems Man and Cybernetics	2	40
22	Water Resources Research	1	124
23	Journal of Environmental Planning and Management	1	91
24	Landscape and Urban Planning	1	22
25	Journal of Business Economics	1	11
26	International Journal of Performance Analysis in Sport	1	19
27	Climate and Development	1	18
	Total	78	3 469

The entire analysis from here onwards considers articles from both data sources, thus, in total 777 articles with 29 781 citations.

In their bibliographic analysis of the OR/MS field Merigó & Yang [18] identified various aspects related to OR/MS including an analysis of the most influential journals. The thirty top OR/MS journals with the highest H-index where identified. They qualify this by stating that the H-index gives an approximation of the quality of a journal, as perceived by researchers, which is a better indicator of quality than the impact factor according to them. In total 463 articles were published by South Africans in these 30 journals over the 50-year period (see Table 4). This represents just under 60% of the total number of articles and is an indication of the quality and standard of the work originating from South Africa.

3.3 Number of articles published annually

Figure 1 shows the number of articles published annually over the 50-year period considered. It shows an article published in 1963 in the International Journal of Production Research [3]. The other article published before 1969 is the one by Fiore & Rozwadowski [9], published in Management Science.

The number of articles published since the start of the 21st century shows an almost exponential growth. Before this the number of papers published annually was low and fluctuated between 5 and 20 per annum except for 1981. In the first 40 years since the formation of ORSSA there was no real pressure on especially academics to published academic articles. It was around the start of the 21st century that substantial funding was made available for each article published in an "accredited" journal. Annually the government Department of Higher Education in South Africa compiles a list of "accredited" academic journals and if an article is published in such a journal the institution of the author received a substantial amount of funding. This played a big role in increasing the output especially from academics. Furthermore, one of the measurements of the performance of academics include the number of articles published in international journals.

3.4 Articles with the highest number of citations

Citations are an indication of the impact of an article. As stated in the methodology followed in this analysis all citations were obtained using Google Scholar. In Table 5 the articles with 200 or more citations are presented. There are 24 such articles with only 5 articles having over 500 citations. There are 50 odd authors in total spread amongst the 24 articles, although some authors are not South Africa citizens. However, the name of only one author appears more than once and that is Prof T.J. Stewart who features as an author in 7 articles, all related to "multi-criteria decision analysis". The rest of the titles of the articles cover a wide range of topics and techniques. Four articles each appear in the Journal of Optimization Theory and Applications, and EJOR respectively, both amongst the top 30 ranked journals according to their H-index [18].

Further analysis of the 777 articles, shows that 25 articles have 0 citations and 35 have only 1 citation. This represents 3,2% and 4,5% of the total, respectively. There are 314 articles (40,4%) with 10 or fewer citations. The average number of citations for all articles is 38,3.

Table 4: *OR/MS Journal ranking, according to the H-index [18] - number of publications by South African authors in the 30 highest ranked journals*

Nr	Journal	Nr of papers
1	Management Science	7
2	Operations Research	4
3	European Journal of Operational Research	62
4	Mathematical Programming	8
5	Systems & Control Letters	-
6	International Journal of Production Research	-
7	Mathematics of Operations Research	4
8	Journal of the Operational Research Society	31
9	Journal Optimization Theory and Applications	83
10	Transportation Research Part B: Methodological	2
11	Journal of Operations Management	1
12	Journal of Quality Technology	4
13	Computers & Operations Research	15
14	Transportation Science	-
15	Networks	12
16	International Journal of Production Economics	9
17	IIE Transactions	3
18	Omega – International Journal of Management Science	27
19	Naval Research Logistics	6
20	Expert Systems with Applications	28
21	Decision Support Systems	7
22	Reliability Engineering & System Safety	36
23	Interfaces	4
24	Operations Research Letters	13
25	Annals of Operations Research	16
26	Journal of Global Optimization	16
27	Production and Operations Management	-
28	International Journal of Systems Science	31
29	Technovation	18
30	Safety Science	16
	Total	463

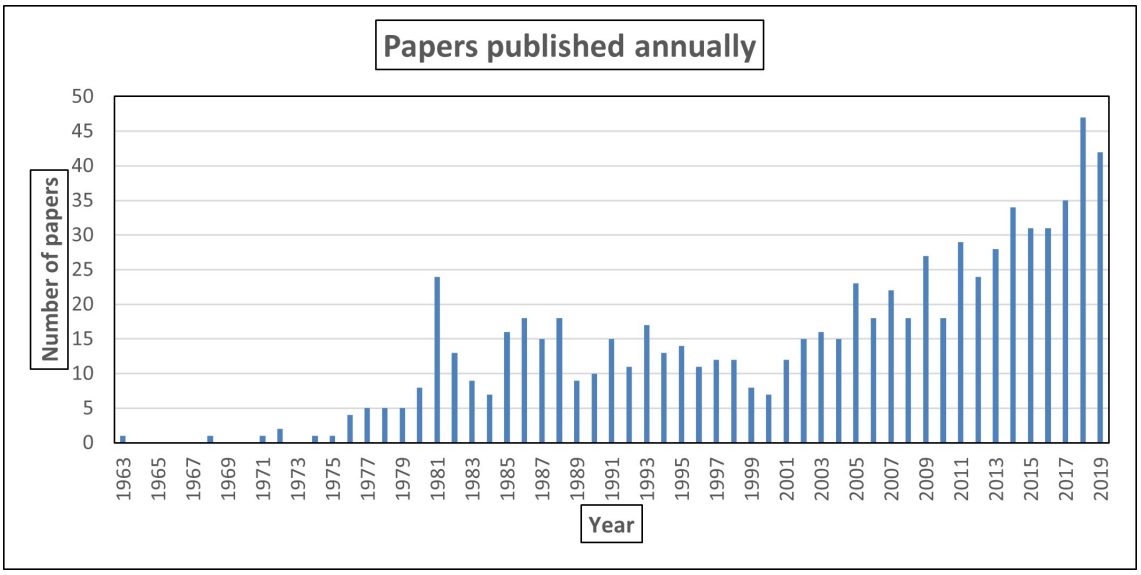

Figure 1: *Number of articles published annually by South African OR researchers in international journals over the 50-years, 1969 to 2019.*

To compare this with other countries internationally is almost impossible. Nevertheless, in the SCImago Journal and Country Rank 1996–2019 bibliometric indicators database [23], countries are ranked according to the number of publications in all journals, over a 20-year period. South Africa ranks 35 out of 240 countries, territories, etc. The average citations per article published by South Africans are also included in this analysis and this is given as 14,59. The SCImago database sources its data from Scopus, the world's largest abstract and citation database [24], which in turn uses citations based on peer-reviewed research literature only. A comparison is thus not compatible between the SCImago and this analysis, both from the number of years covered as well as the source of the citations. However, it still gives an indication that the publications of the OR community, in terms of the average citations per publication, are not totally out of line with that of the South African average.

3.5 Top authors

The authors with the highest number of publications are shown in Table 6. All ten are, or were, researchers and academics. Most of them have also published articles in local journals such as the ORSSA journal ORiON, the local industrial engineering journal as well as the journal of the Statistical Association of South Africa (SASA). It is interesting to note that of the ten authors listed in Table 6 only four published articles in the ORSSA journal, ORION. These are Van Vuuren (19), Yadavalli (10), Stewart (4) and Finkelstein (2) – the number of articles each one authored or co-authored is given in brackets [30]. Furthermore, the ten authors have all also published in other international journals not listed amongst the 110 journals used in this analysis. These articles cover topics in disciplines such as Statistics, Mathematics, Applied Mathematics as well as Industrial Engineering.

Table 5: *Articles with 200 or more citations - authors, article title, journal name and year of publication listed.*

	Author(s)	Year	Article Title	Journal	Citations
1	Wamba SF, Akter S, Edwards A, Chopin G & Gnanzou, D	2015	How 'big data' can make big impact: Findings from a systematic review and a longitudinal case study.	International Journal of Production Economics	1333
2	Stewart TJ	1992	A critical survey on the status of multiple criteria decision-making theory and practice.	Omega	908
3	Xu H	2003	An iterative approach to quadratic optimization.	Journal of Optimization Theory and Applications	751
4	Ali MM & Khompatraporn C	2005	A numerical evaluation of several stochastic algorithms on selected continuous global optimization test problems.	Journal of Global Optimization	611
5	Guo B-Z & Zhao Z-L	2011	On the convergence of an extended state observer for nonlinear systems with uncertainty.	Systems & Control Letters	573
6	Stewart TJ, Janssen R & Van Herwijnen M	2004	A genetic algorithm approach to multiobjective land use planning.	Computers & Operations Research	375
7	Schutte JF & Groenwold AA	2005	A study of global optimization using particle swarms.	Journal of Global Optimization	372
8	Stewart TJ	1996	Relationships between data envelopment analysis and multicriteria decision analysis.	Journal of the Operational Research Society	352
9	Kaelo P & Ali MM	2006	A numerical study of some modified differential evolution algorithms.	European Journal of Operational Research	346
10	Shapiro A	1990	On concepts of directional differentiability.	Journal of Optimization Theory and Applications	332
11	Xu HK & Kim TH	2003	Convergence of hybrid steepest-descent methods for variational inequalities.	Journal of Optimization Theory and Applications	325
12	Martin DH	1985	The essence of invexity.	Journal of Optimization Theory and Applications	317

Table 5: *Articles with 200 or more citations - authors, article title, journal name and year of publication listed. (Continued.)*

	Author(s)	Year	Article Title	Journal	Citations
13	Dekker S, Cilliers P & Hofmeyr J-H	2011	The complexity of failure: Implications of complexity theory for safety investigations.	Safety Science	307
14	Durbach I. & Stewart TJ	2012	Modeling uncertainty in multi-criteria decision analysis.	European Journal of Operational Research	306
15	Shapiro A	1991	Asymptotic analysis of stochastic programs.	Annals of Operations Research	289
16	Aerts JCJH, Eisinger E, Heuvelink GBM & Stewart TJ	2003	Using linear integer programming for multi-site land-use allocation.	Geographical Analysis	245
17	Omran MGH, Engelbrecht AP & Salman A	2009	Bare bones differential evolution.	European Journal of Operational Research	230
18	Lotfi V, Stewart TJ & Zionts S	1992	An aspiration-level interactive model for multiple criteria decision making.	Computers & Operations Research.	227
19	Hawkins DM	1981	A cusum for a scale parameter.	Journal of Quality Technology	216
20	Arentze T, Borgers A, Timmermans H & DelMistro R	2003	Transport stated choice responses: effects of task complexity, presentation format and literacy.	Transportation Research Part E: Logistics and Transportation Review	212
21	Stewart TJ	1996	Robustness of additive value function methods in MCDM.	Journal of Multi-Criteria Decision Analysis	209
22	Berjak SG & Hearne JW	2002	An improved cellular automaton model for simulating fire in a spatially heterogeneous Savanna system.	Ecological Modelling	205
23	White L & Lee GL	2009	Operational research and sustainable development: Tackling the social dimension.	European Journal of Operational Research	202
24	Oerlemans LAG, Knoben SJ. & Pretorius MW	2013	Alliance portfolio diversity, radical and incremental innovation: The moderating role of technology management.	Technovation.	200

Table 6: *Ten top authors in terms of articles published.*

Rank	Author	Number of Articles	Citations
1	MS Finkelstein – Univ. of the Free State (UFS)	78	1 718
2	TJ Stewart – CSIR & Univ. of Cape Town (UCT)	57	5 040
3	YYavin – CSIR & Univ. of Pretoria (UP)	50	328
4	MM Ali - WITS	35	1 957
5	JH van Vuuren – Stellenbosch Univ. (SU)	25	811
6	B-Z Guo - WITS	18	955
7	S Adali – CSIR & Univ. of Natal (UN)	18	207
8	M Sniedovich - CSIR	17	431
9	VSS Yadavalli - UP	14	303
10	C Frangos - UP	14	71

Amongst these five are, or were, well-known and active members within ORSSA, namely, Stewart, Ali, Van Vuuren, Sniedovich and Yadavalli. Stewart and Sniedovich were both at the CSIR after which Stewart took a chair at UCT and Sniedovich moved to Australia. Ali is from WITS, Van Vuuren from SU with Yadavalli from UP. Yavin (deceased) and Adali were mathematicians at the CSIR during the 70's and 80's, and then joined universities, UP and UN respectively. It may be reasonable to assume that they both would not have considered themselves operations researchers. The same holds for Frangos, from the UP, who was Yavin's co-author in many articles. Guo is a Professor in Control Theory at WITS while Finkelstein's (University of the Free State (UFS)) research is focused on reliability theory and stochastic modelling.

What stands out from Table 6 is the number of citations of Stewart, associated with his 57 articles. The 5040 citations are more than double that of Ali which is the closest, with 1957. It suggests that Stewart may be considered as one of the foremost researchers ("first amongst equals") in the OR/MS field in South Africa based on this analysis covering the first 50-years of ORSSA. Stewart is also one of the leading international researchers over the last 35 to 40 years in MCDM.

4 Top author networks

One of the aspects of bibliographic analysis is to determine networks of authors. In this case the five top authors are considered, and specialized software is used to visually represent these author networks. The focus here is on the five top author networks, co-authorship, and citations. A software tool, VOSviewer, was used to graphically visualize some of the relevant data. VOSviewer was developed at the University of Leiden in the Netherlands and is used for constructing and visualizing bibliometric networks [32]. Data sources can include journals, researchers, or individual publications. Networks, in a visual form, from these sources can be constructed based on citations, bibliographic coupling, co-citations, or co-authorship relations.

A bibliographic database needed to be constructed containing all the articles of the five top authors. For this purpose, WoS, Scopus, PubMed or any similar database can be used. However, not all journals are indexed in WoS, Scopus or PubMed for the past 50-year period. There is an alternative, Dimensions, that contain almost all the required articles. Since VOSviewer also caters for data files, created using Dimensions[3], the decision was to use this 'research knowledge system'. Of the 245 articles, published by the 5 top authors, it was possible to include 237 in the database by limiting the search for the period 1969 to 2019. Almost 97% of the articles are thus included in the bibliographic analysis. This database can now be used with Dimensions to, inter alia, create a visual representation in the form of clusters of the research networks of the five authors, their co-authors, and their joint publications. A representation based on citations, as determined via Dimensions, is also included. The functionality of VOSviewer is outlined in [33].

4.1 Network visualization of co-authorship

The network of co-authorship between the top five authors and all their co-authors are shown in Figure 2. The 'bubbles', or circles, represent the five authors. The size of the 'bubble' gives an indication of the number of articles by the author in question. The largest bubble is clearly that of Finkelstein followed, in size, by those of Stewart, Yavin, Ali and Van Vuuren. The lines (which are not that clear in Figure 2 as they are small), or links, show the relationship between authors and co-authors. Thus, where there is a line between two authors, they have co-authored one or more articles. There are five colors representing the clusters of the five authors. The clusters of authors, who are relatively strongly connected by co-authorship links indicated in Figure 2 by the smaller bubbles, represent research networks or research communities. In total there are 34 clusters with the largest 3 clusters consisting of 10 items (authors) each. There are 19 clusters with only 2 items.

Some observations from Figure 2:

1. There is no link between the five top authors except for the link between Stewart and Fatti, and Ali and Fatti. This seems to indicate that the top researchers in South Africa tend to collaborate with colleagues at their own university, international researchers, or students. This is one of the characteristics of the South African OR scene – a researcher works in a specialized field but there are no others working in that field at other universities or organizations in the country. A possible reason being the size of the OR community that is relatively small.

2. Finkelstein, Stewart, and Ali have research networks both with South Africans and international researchers. The smaller clusters, around the larger ones, indicate stronger research networks for all three of these. In the case of Stewart, the bubble

[3]Dimensions is a linked research knowledge system that re-imagines discovery and access to research. Developed by Digital Science in collaboration with over 100 leading research organisations around the world, Dimensions brings together grants, publications, citations, alternative metrics, clinical trials, patents, and policy documents to deliver a platform that enables users to find and access the most relevant information faster, analyse the academic and broader outcomes of research and gather insights to inform future strategy. For more information about the product, visit https://dimensions.ai [6].

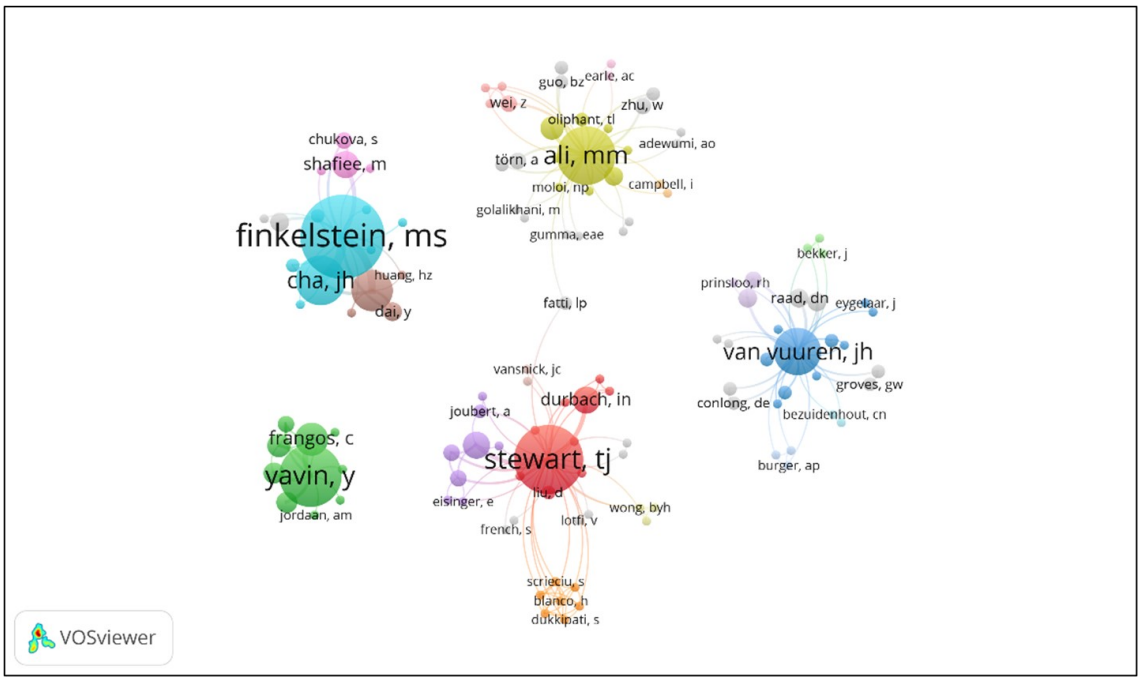

Figure 2: *Network visualization of the five top authors with co-authors.*

with the name Durbach, shows collaboration with colleagues from the same university, UCT.

3. Yavin worked closely with Frangos, a South African researcher, and they published several articles together. Yavin also had a few software programmers as co-authors.

4. In the case of Van Vuuren the majority of his 25 OR related articles were published with a MSc or PhD student. Van Vuuren is Professor of Operations Research in the Department of Industrial Engineering at SU. He is the head of the Stellenbosch Unit for Operations Research in Engineering (SUnORE), a world class unit, aimed at pursuing excellence, in training young scientific minds in the "analysis of support of effective decisions" (https://sunore.co.za/).

4.2 Citation visualization

A further visualization is that for citations (see Figure 3). The figure is very similar to that of Figure 2, the difference here is the size of the bubbles which in this case represents the number of citations for all the articles of the different authors. The largest bubble is that representing Stewart, then Ali and Finkelstein both having similar number of citations. Fourth is Van Vuuren and then Yavin. The work of Yavin was very specialized and focused, published many years ago and that could explain the low number. It should be noted that the citations in Figure 3 is the numbers obtained via Dimensions.

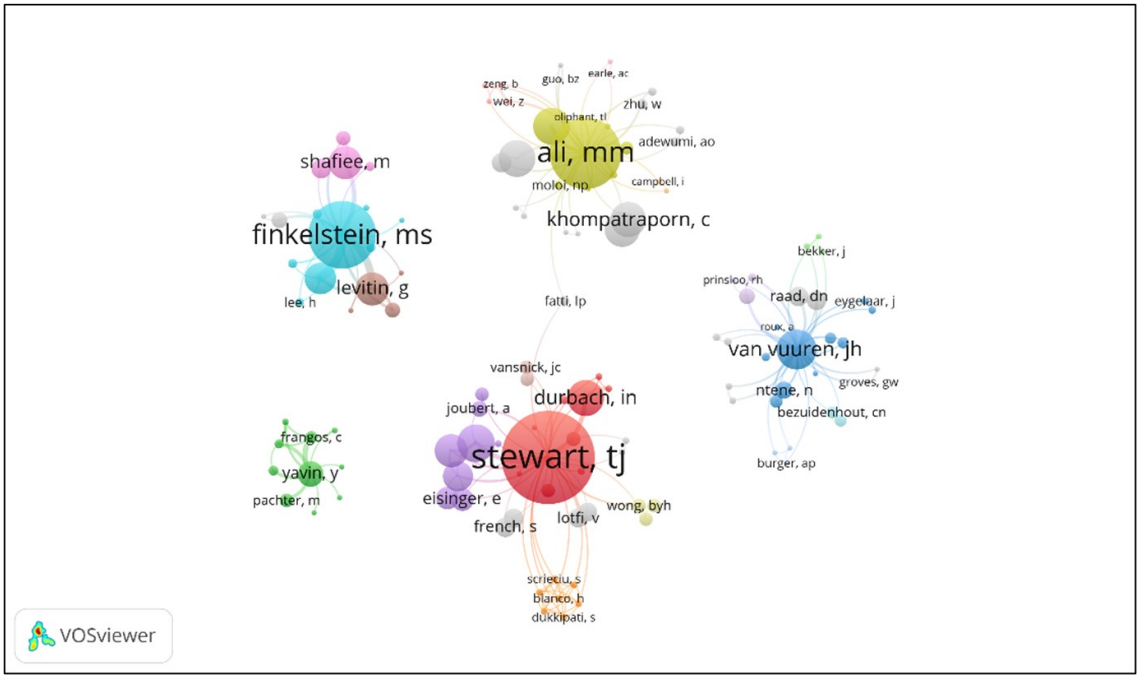

Figure 3: *Citation visualization of the five top authors and their networks.*

5 Author institutional representation

In Figure 4 all South African authors and co-authors for every article are added together to give the number shown against their associated institution as presented in the pie chart. The universities with 20 or more authors are shown separately on the chart. The universities with only a few authors are group together under "Other Univ" while authors from the private sector, government departments and government institutions are all shown under "Non-univ". Data for ten universities appear in the figure together with that of the CSIR. The largest number of authors are from the three larger universities namely UP, UCT and WITS. The high numbers for these universities are mainly due to one or two academics with a high number of articles. This holds true for the UFS with basically one academic that published in the journals used in this analysis. A characteristic of the South African OR/MS scene is the fact that up to around 2009 very few academics, except those that are prolific researchers, published their work. As can be seen from Figure 1 the number of publications is increasing annually indicating that more academics are starting to publish their work.

A few further observations from what is presented in Figure 4 are in order. First the high number of authors for the CSIR is due to a period in the 70's and 80's when the National Research Institute for Mathematical Sciences (NRIMS), CSIR was considered a world class institution in mathematical science. There was a period when NRIMS employed more than 25 international researchers. The CSIR changed its strategy in the first half of the 80's, most of the researchers left and there was then a considerable period where no or very few articles were published by researchers from the CSIR.

Very few practitioners of OR/MS in South Africa publish their work. Firstly, it is not something that forms part of their work performance and thus there is no incentive to publish, they don't have time for writing articles and, possibly the main reason, is confidentiality. The private sector does not encourage their employees to publish results that could affect the competitiveness of a company. Where real world OR is published it is often done by academics. Only a handful of articles have authors from government departments.

There has been a considerable amount of collaboration with international researchers and academics by local colleagues. In total 361 international co-authors contributed to the 777 articles. The number of co-authors per article are: 159 articles with 1 international author, 92 with 2, 31 with 3, 10 with 4, 1 article with 5 and 1 with 6 international co-authors. These international co-authors come from countries across the world.

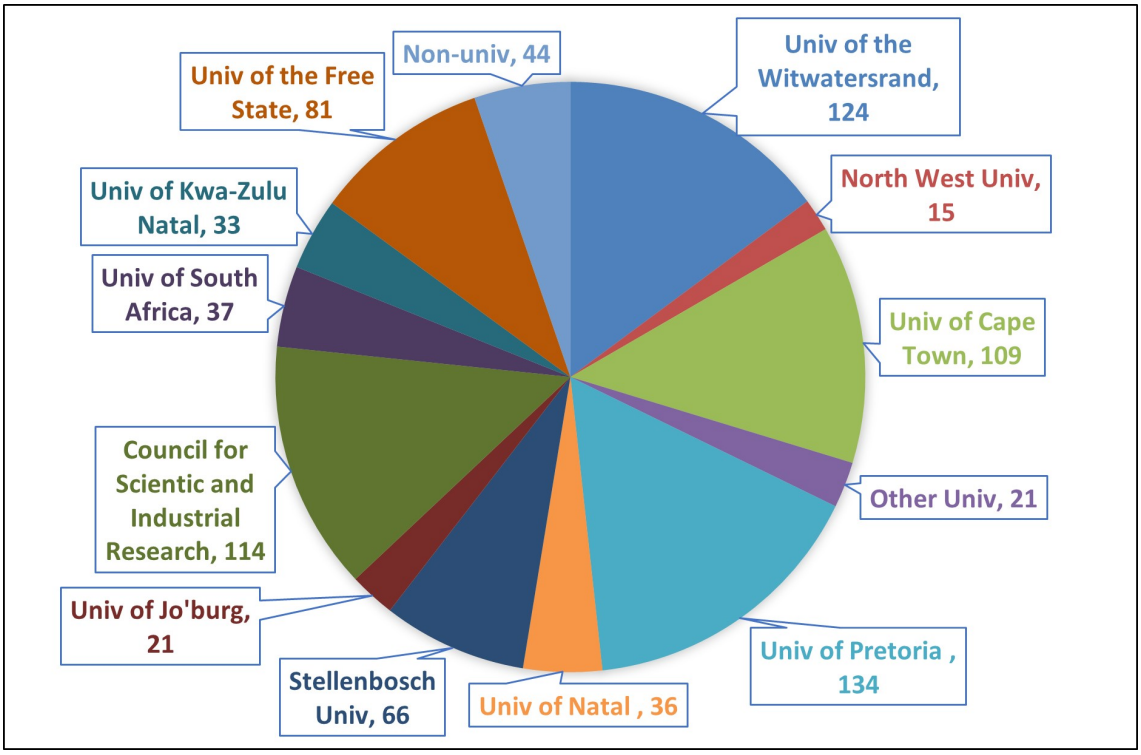

Figure 4: *Number of authors for all articles and their institution.*

6 Research, technique, and application areas

Categorizing 777 articles from a diverse range of journals into a specific OR technique is a substantial challenge and therefore only some general comments on this topic are in order. A wide range of OR techniques are used by the OR community in South Africa. The same applies to application areas. This is one of the characteristics that stand out from the both the research and application of OR in the country. Evidence of this is clear from an analysis of the articles published in the local OR journal, ORiON. The journal classifies the articles that are published in the journal into 21 categories or "topical areas" and the

number of articles in each category range from 7 to 24 [30]. In essence the same holds for what is published internationally. The categories are listed below, and as can been seen, it covers a very wide range of topics:

- Assignment, Allocation, Timetabling,
- Agriculture,
- Decision Support, Decision Making,
- Demand and Supply Chain Analysis,
- Elections, Government and Development,
- Financial Investment, Risk Analysis, Portfolio Optimisation,
- Graph and Network Theory,
- Inventory Management,
- Knapsack, Packing, Cutting Problems,
- Metaheuristics, Neural Networks,
- Military,
- Multi-Criteria Decision Analysis, Multi-Objective Optimisation,
- Mathematical Biology, Natural Resource Management, Conservation, Ecology,
- Optimisation and Mathematical Programming,
- Philosophy, History, Marketing, Teaching of Operations Research,
- Production and Project Scheduling,
- Queuing Theory,
- Reliability, Repairability and Availability,
- Statistical Analysis,
- Theoretical and Computer Simulation,
- Vehicle Routing, Travelling Salesperson Problem.

A brief evaluation of keywords of the 62 articles published in EJOR, one of the journals devoted to OR results in basically the same conclusion, almost all the techniques are used. In addition, there is no application area that stand out or typifies work done in South Africa. There are 22 articles published in the Ecological Modelling journal which could be considered a definite application area characteristic of South Africa. The 22 articles cover a broad spectrum of issues in ecology.

The top ten authors have to a large extend focused research areas and as indicated most of their papers address aspects within the focus area. Table 7 lists their main research areas.

Table 7: *Research areas of the top ten authors.*
a - Google Scholar; b - http://www.stats.uct.ac.za/; c - www.vuuren.co.za; d - www.research.net

Author – Institution	**Research areas**
MS Finkelstein – UFS	Reliability and stochastic modelling[a]
TJ Stewart – CSIR & UCT	Multiple criteria decision analysis, Decision theory, Applications of linear programming and simulation[b]
Y Yavin – CSIR & UP	Control Theory[a]
MM Ali – WITS	Global optimization, OR, Optimal control theory, MINLP, Optimization in big data[a]
JH van Vuuren – US	Graph Ramsey Theory, Graph Colouring Problems, Graph Routing Problems, Graph Domination Theory[c]
B-Z Guo – WITS	Control theory[a]
S Adali – CSIR & UN	Design optimization, Optimal control, Composite structures, Nano Mechanics[a]
M Sniedovich – CSIR	Decision theory, Dynamic programming, OR[d]
VSS Yadavalli – UP	Industrial & system engineering[a]
C Frangos – UP	Control Theory[a]

7 International recognition

Over the 50-year period considered a few papers of ORSSA members received recognition. On three occasions members of ORSSA were the runners-up for the IFORS Prize for OR in Development. These are papers that were presented at IFORS conferences and subsequently published. This was at the IFORS conferences in 1999 [31], 2002 [10] and 2008 [21] respectively. The Goodeve medal for the best paper in JORS, for a specific year, was awarded to Prof L.P. Fatti in 1984 [7]. Two South African organizations featured as finalists in the annual Franz Edelman award competition held by the Institute for Operations Research and the Management Sciences (INFORMS) in the USA. In 1996 a team from the South African National Defence Force (SANDF) won the Edelman award for a decision support model for restructuring the military force structure, a model developed using a mixed integer approach [11]. The Simulation and Modelling team of SASOL, a company that produces liquid fuels from natural gas and coal, was the second South African team to be finalists in this competition [19]. Both papers were subsequently published in Interfaces (now INFORMS Journal of Applied Analytics) published by INFORMS.

8 Discussion

No bibliographical analysis of the outputs from South African operations researchers has been done previously. The choice or collection of journals used for such an analysis can differ as there is no standard or formal guideline indicating which journals should be included in such an analysis. The 83 OR/MS journals from Clarivate Analytics plus several journals not included in this collection, some that can most definitely be considered OR journals, were included in the analysis presented in this paper. In addition, a few

other journals were selected because ORSSA members published in these journals. Their inclusion originated from scrutinizing ORSSA member's CVs as well as Google Scholar.

Most of the contributions to the international research literature originates from universities and research organizations in South Africa. There is very little publications prepared and published by government officials. This applies to all levels of government namely at national, provincial, and local or municipality level. The same holds for the private sector. In this case confidentiality is a major consideration with publishing in international journals, or scientific journals in general, certainly not a priority. Over the 50-year period this phenomenon has not changed.

The OR techniques and methodologies used in the publications by South Africans cover a wide and diverse range. This is typical of the practice of OR in the country. The same goes for research and application areas. In both cases nothing stands out as a research area or application area that is typical and closely associated with South Africa. In the 20th century mining was possibly the biggest industry in South Africa. However, by the start of the 70s mining companies started cutting back on costs and most of the mining OR groups disappeared. This was at the time ORSSA was established.

Argoubi *et al.* [1] conducted a scientometric analysis of OR/MS papers published by African authors indexed in the WoS for the period 1990 to 2018 (see Section 2.2). As an African country South African operations researchers featured in this analysis, but the period used as well as the source of data differs from the results shown in our study. It is thus not feasible to do any comparisons to the study by Argoubi *et al.* [1]. Nevertheless, it is interesting to note that their study showed that South African and Tunisian authors produced just over 40% of all the African papers published in the ten top journals identified by their study while four countries, South Africa, Tunisia, Algeria, and Morocco have published more than 56% of the papers considered in their study. Bibliographic analysis is very data dependent, and this is illustrated by the study of Argoubi *et al.* [1]. In their analysis a South African author is ranked 3rd of the authors from Africa with the most publications. This same author, Prof C. Mbohwa from the University of Johannesburg, does not feature in the bibliographic analysis presented here.

9 Conclusion

ORSSA, the first African OR society, celebrated its 50th anniversary in 2019. To commemorate this occasion the history of the society was captured in detail and comprehensively in a book launched at the conference where the anniversary was celebrated [15]. One aspect of this history was not captured namely the contribution, in the form of journal articles, of South African operations researchers to international OR journals. This article, using a collection of 83 OR journals plus a few additional journals, endeavors to fill this void. In total 777 articles authored by South Africans OR/MS professionals were identified. Of these articles 463 were published in the 30 top international OR/MS journals according to the journal H-index which is an indication of the high standard and quality of South Africa OR/MS publications. Added to the 777 international contributions of South Africans to the OR/MS literature, the 237 articles published in ORiON, the local journal, gives a total of over 1 000 articles published over the 50-year period, a noteworthy achievement!

Over a period of 50-years the contribution from a small but vibrant and active OR society, located at the most southern point of Africa, has been significant. Not only has there been a significant number of journal articles published by members of this society, but members of the society have contributed to all the international OR forums. In addition, the only triennial IFORS conference held on the African continent to date was held in South Africa in 2008. Furthermore, two South African entries, on separate occasions, were amongst the finalists of the INFORMS Edelman award competition with one being the winner in 1995. ORSSA can be proud of its achievements.

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