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Bibliometric approach to "applications of response surface methodology (RSM) publications" and its review as the most widely used optimization tool

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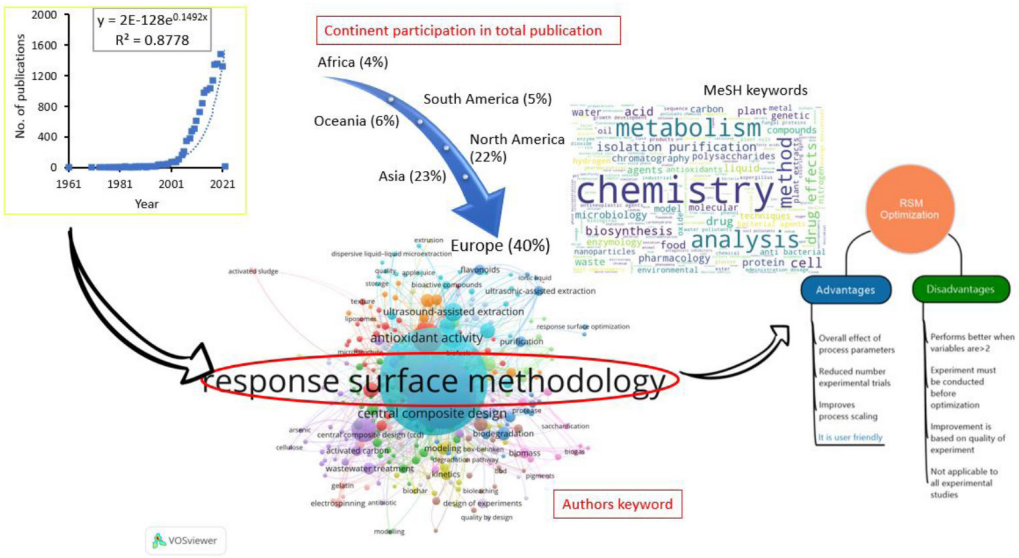
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An increasing number of articles are published in the field of optimization research, and response surface methodology is an interesting optimization tool. As a result, the main goal of this work is to conduct a bibliometric analysis on the distribution of response surface methodology-related articles across the different domains of optimization research, as well as to track the evolution of their interest and identify the nations, publishers, and authors producing the greatest volume of scholarly works. For this investigation, the "LENS" database system was used since it covers a huge number of documents and simplifies the process of downloading and analyzing datasets. VOSviewer and the text mining program Orange Canvas were used to analyze the dataset. The survey indicates that the most prolific countries in this field of study are those in Europe. The most publications are found in iop conference series and materials, whereas the most citations are found in the journal of bioresource technology. Additionally, according to authors, the most used method for experimental optimization is response surface methodology, or RSM. Despite having several benefits over the traditional one parameter at a time strategy, RSM is not appropriate for every modeling and optimization study.

Keywords: *Bibliometric analysis, Response surface methodology, Most widely used, Optimization technique, Benefits and drawbacks.*

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Graphical abstract



1. Introduction

Numerous researchers are known to have used response surface methodology (RSM) [1, 2]. Khuri [3] defines RSM as an amalgam of statistical and mathematical techniques employed to arrange a sequence of experiments with the aim of generating sufficient predictions, fitting an empirical model to data gathered with the chosen design, and determining the optimal conditions for model input parameters that yield the maximum or minimum response within an interest region. Box and Wilson [4] reported that formal work on RSM began with the publication of an article on practical results from optimized conditions. It was originally designed to predict experimental responses [5], but it has since developed to modeling of numerical experiments. However, the predictor's type of mistake is where the difference lies. The work concentrated on setting up a series of tests for adequate predictions, fitting the hypothesized model to data gathered under the selected design, and determining optimal conditions on the model's input variables. Khuri [3] gave a basic summary of response surface approach. But as it is shown to make work much easier than the typical trial and error methods, optimization is becoming more and more accepted in many fields of research [6]. Bas and Boyaci [7] looked at the modeling and optimization applications of response surface methods. They discovered that there are limitations to the application of RSM for the optimization of all chemical and biological processes. For instance, calculating the kinetics of a reaction or assessing kinetic constants. According to Bas and Boyaci [7], it is only applicable to the modifications that can be explained by a second order polynomial equation.

In recent years, bibliometric analysis has sparked significant interest in the scientific community, with the primary goal of providing a retrospective or overview of the major trends published by journals over a given time period [8]. However, the methodological approaches are based on quantitative and qualitative evaluations of scientific literature and can be used to assess and compare the research performance of scholars, journals, institutions, countries, or topic sectors [9]. Bibliometric evaluation describes the qualitative and quantitative effect of journals, institutions, research groups, individual researchers, and countries [10]. It is extremely important since it allows for correct classification. Furthermore, it provides broad overviews of trends in specific disciplines covered by journals [11, 12, 13]. However, bibliometrics has been used in a variety of scientific fields, as well as to rate institutions and universities around the world [14].

However, literature search reveal that there is scarcity of bibliometric studies of response surface methodology in optimization publications as well as its systematic review. Therefore, this study investigates the trend of the application of RSM as the most widely used optimization technique and its significance.

2. Methodology

The following subsection outlines the process used to obtain a dataset of documents for response surface (RSM) optimization study. Our methodology is comparable to that of Cobo et al. [15] and García-Sánchez et al. [16], who conducted quantitative studies on a specific field. To gather the dataset for the current study, we ran a query that included the terms "application of response surface methodology in optimization", "response surface methodology in optimization", and "application of RSM in optimization". The data is gathered from the LENS database using lens.org, an interconnected research information system accessible at https://www.lens.org/lens/search. The LENS was previously known as Patent Lens, an online patent and scholarly literature search engine. It has been described as the "most holistic scholarly literature database, outstripping the width and depth of two leading commercial databases Web of Science (WoS) and Scopus combined" [17]. This approach was selected due to its enormous data delivery capacity, user-friendly interface, free nature, and ability to count the number of citations per article. In addition, obtaining a batch of specified data in CSV file format will make processing and analysis easier. The data was analyzed using VOSviewer, as previously used by numerous researchers, including Gobbo et al. [18], Alkaissy et al. [19], Muritala et al. [20], and Xue et al. [21]. Therefore, the query variables are:

- Date ranging from 1961 – 2021.
- All publication type is used.
- The query was performed on November 25th 2021.

3. Results and Discussion

A total of 50,001 documents were retrieved from the query format. However, it is worth noting that the search only looked at the terms "application of response surface methodology in optimization" and "application of RSM in optimization."

3.1 *The Publication Trends and Distribution of Citations*

The following paragraph provides an overview of the gathered data trend. The scholarly search for "application of response surface methodology in optimization"; out of a total scholarly works of 46,913, works cited by patents showed 3,592, citing patents gave 13,966, patent citations are 14,955, works cited by scholarly is 40,323 and scholarly citations is 1,691,229 from LENS.ORG (https://www.lens.org/lens/search/scholar/structured). As it can be seen in Figure 1, that the application of response surface methodology in optimization has clearly increased from 2001 period, with more than 1000 publications to 2018 it started reducing gradually. In 2021 the interest diminished to less than 50 publications.

The majority of publications are published in journals relating to food science, chemistry, science and technology, and engineering and technology (Fig. 2). There are reportedly only two journals dedicated to computer science. This might be the result of the authors' publication in general scientific and technological journals, such science and technology of food, as opposed to journals focused on optimization. More proof of this can be found in Fig. 3, where the number of citations per journal matches the top 20 journal list in Table 1. The highest citation, 14335, belongs to bioresource technology, which also has the strongest link strength (1746) with 265 publications, or roughly 1.11% of all the publications from the top 20 journal list. The total number of articles in which two keywords occur together is

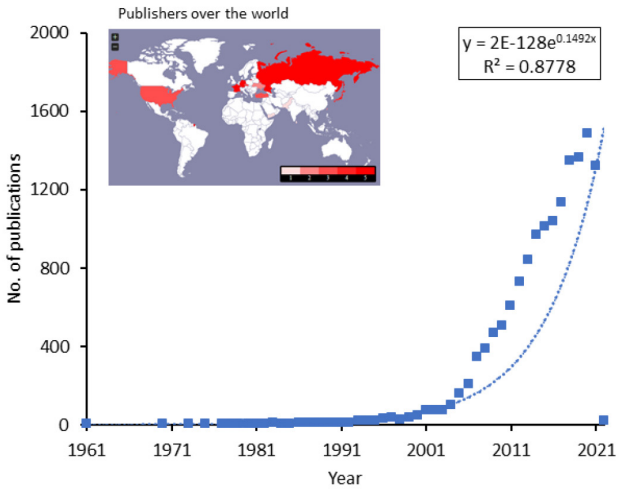


Figure 1

Number of published articles per year

represented by the link strength. The fundamental idea behind citation analysis is that an article's importance increases with its citation count [15]. An overview of average citations per journal is shown in Fig. 3. However, the Journal of Hazardous Materials has the second greatest citation at 11892, with 164 articles (Table 1). The colors classify the range of citations per journal. The dark red colors indicate very high values for both publications and citations, whereas the dark blue colors show the lowest values.

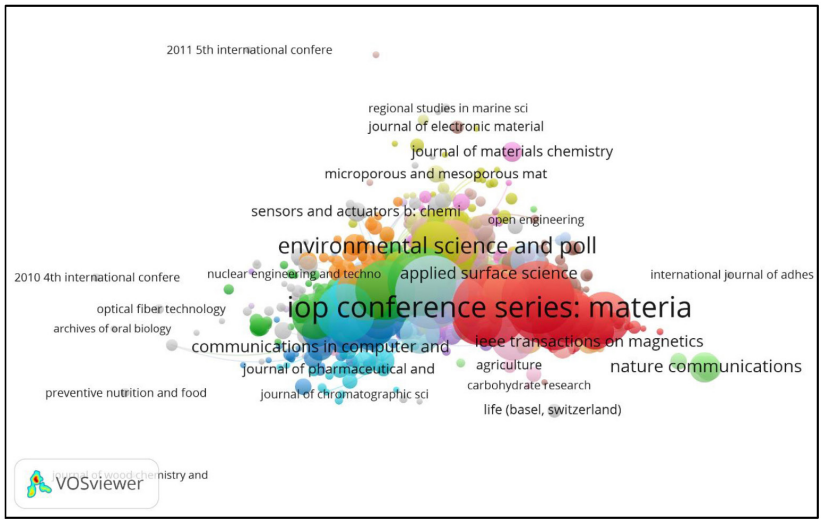


Figure 2

Network visualization map of citation based on journals with minimum of 3 documents per journal

Table 1

The most prominent 20 journals, the quantity of papers released, and the amount of citations received over the time frame.

Journal	Publications	%Total publications	Citations	Total link strength
iop conference series: materials science and engineering	426	1.78	340	195
iop conference series: earth and environmental science	397	1.66	97	49
journal of physics: conference series	386	1.61	73	36
materials today: proceedings	367	1.53	988	380
scientific reports	347	1.45	1422	279
bioresource technology	265	1.11	14335	1746
molecules (Basel, Switzerland)	250	1.04	2364	730

Contd...

plos one	232	0.97	1253	181
the international journal of advanced manufacturing technology	222	0.93	4524	541
international journal of biological macromolecules	217	0.91	5451	914
ssrn electronic journal	203	0.85	289	9
industrial crops and products	183	0.76	5366	1134
advanced materials research	181	0.76	254	148
environmental science and pollution research international	175	0.73	1364	518
international journal of molecular sciences	170	0.71	1255	219
rsc advances	169	0.71	2120	647
journal of hazardous materials	164	0.68	11892	2161
sustainability	163	0.68	467	67
science and technology of food industry	159	0.66	15	2

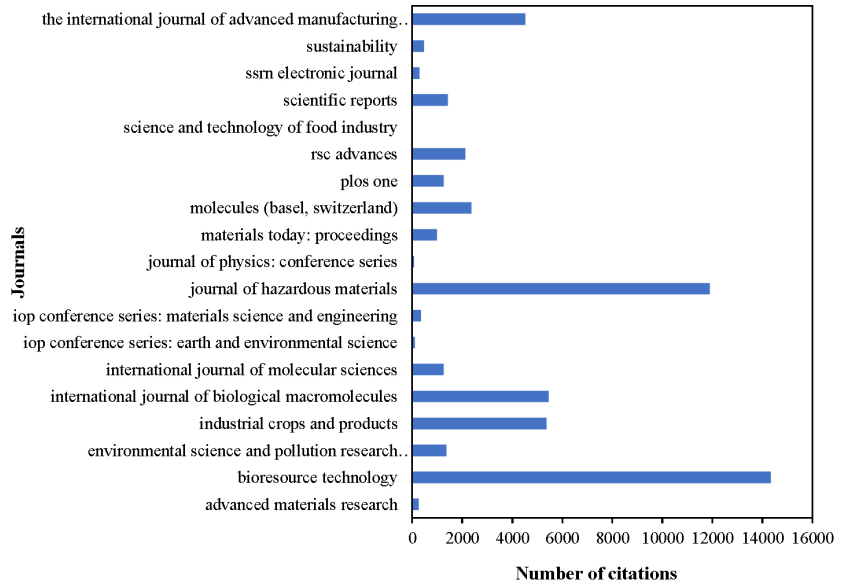


Figure 3

Number of citations according to journals

3.2 *The Leading Authors and their Collaborations*

Authors are in charge of information on "response surface methodology (RSM)" in optimization, and an author's production and cooperation analysis can quickly reveal the field's key scholars as well as the author's social connections. Therefore, the entire

collaboration network of authors is presented in Table 2, Fig. 4 and 5, whereas the author with the most citations of 3398, that is *"Marcos, 2008"* was seen as the lead author in this topic. In Table 2, the listing of leading authors indicates that the leading author has the highest link strength of 103. In order to determine the average citation per year, the total number of citations is also divided by the duration of the author's article publication. It was observed that author "Marcos A. Bezerra" has the highest yearly citation of 243 with the highest citation link of 103.

In Figure 4 the highest level of co-authorship link occurred between 2012 and 2020 showing the blue and yellow group. However, due to the sparsely linked network structure of other groups, only the massively connected component of the authors' collaboration network was chosen to investigate the author's social connections in RSM research. Furthermore, the analysis excluded authors whose publications exclusively contained editorial material. The node size and color signify an author's publication and the number of authors in the same group, respectively, whilst the linkages and their breadth represent author collaboration and its strength. Figure 5 shows that the highest level of collaboration happened between 2007 and 2009, represented by the red color group.

Recent publications from 2012 up to 2021 did not show strong link in collaboration. Figure 6 presents the authors' year of publication and citation count, validating the co-authorship and citations connection analysis.

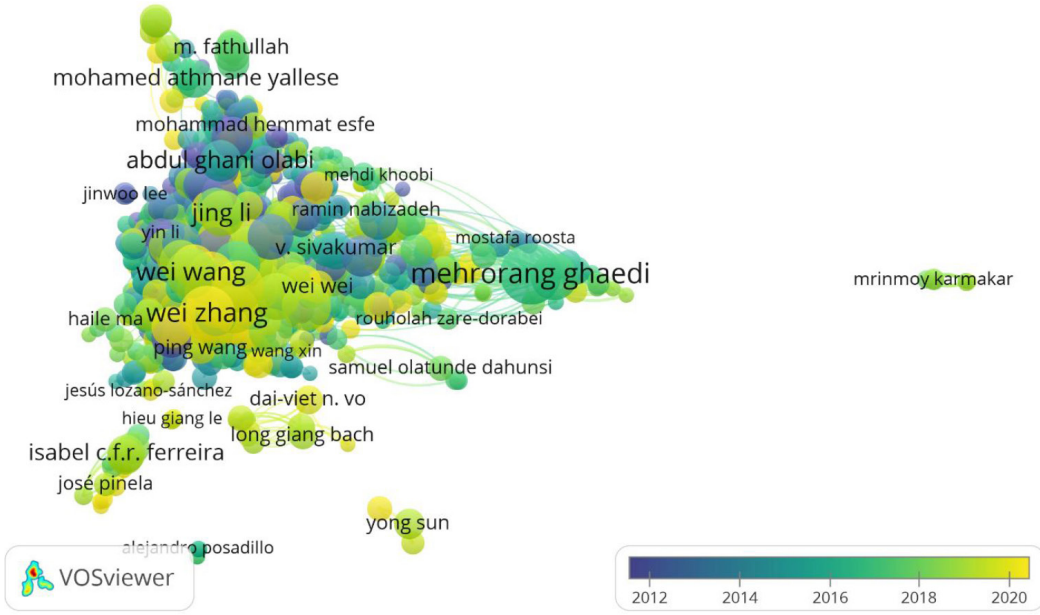


Figure 4

VOSviewer overlay view of bibliographic coupling of co-authorship

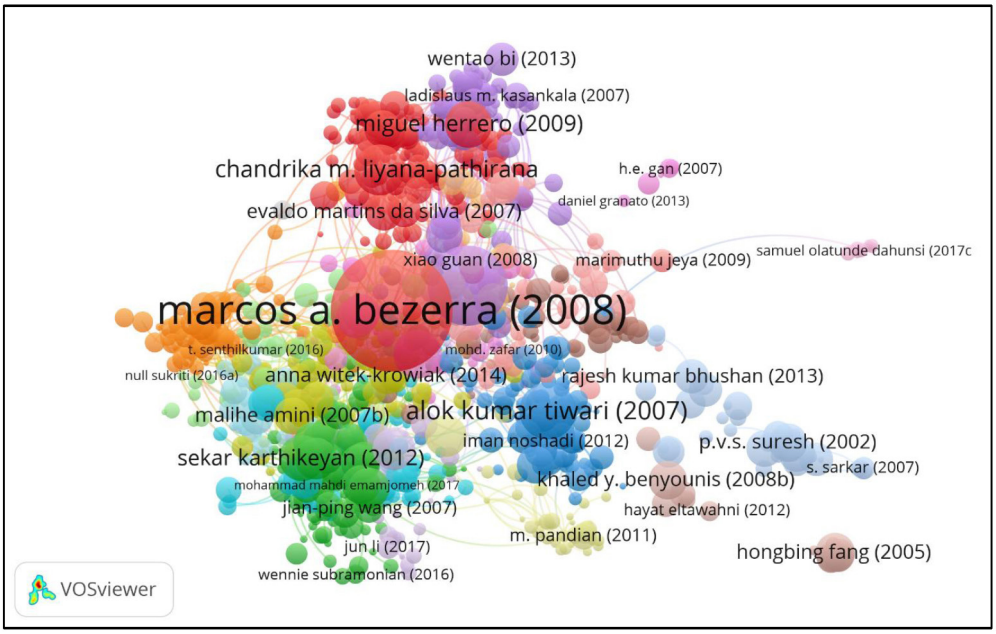


Figure 5

VOSviewer network map of citations based on authorship

Table 2

The top 20 authors, their citations and link strength during the period.

Authors	Citations	Mean citation	Links
Marcos A. Bezerra (2008)	3398	243	103
Deniz Baş (2007b)	1470	98	84
Alok Kumar Tiwari (2007)	737	49	14
Chandrika M. Liyana-Pathirana (2005)	591	35	45
Luciana Vera Candioti (2014)	542	68	10
Miguel Herrero (2009)	500	38	7
Sekar Karthikeyan (2012)	490	49	3
V. Gunaraj (1999)	421	18	15
S. Sadri Moghaddam (2009)	405	31	13
Mark Anderson (2004)	404	22	4
Shahin Ghafari (2008b)	394	28	31
Kaan Yetilmezsoy (2009a)	385	30	13
S Sadri Moghaddam (2009)	384	30	11
Kiran M. Desai (2008)	378	27	49

Contd...

Mojtaba Safari (2014)	361	45	5
Hongbing Fang (2005)	354	21	4
Khaled Y. Benyounis (2008b)	350	25	5
Kaan Yetilmezsoy (2009b)	346	27	12
P.V.S. Suresh (2002)	339	17	7
Shahin Ghafari (2008a)	339	24	27

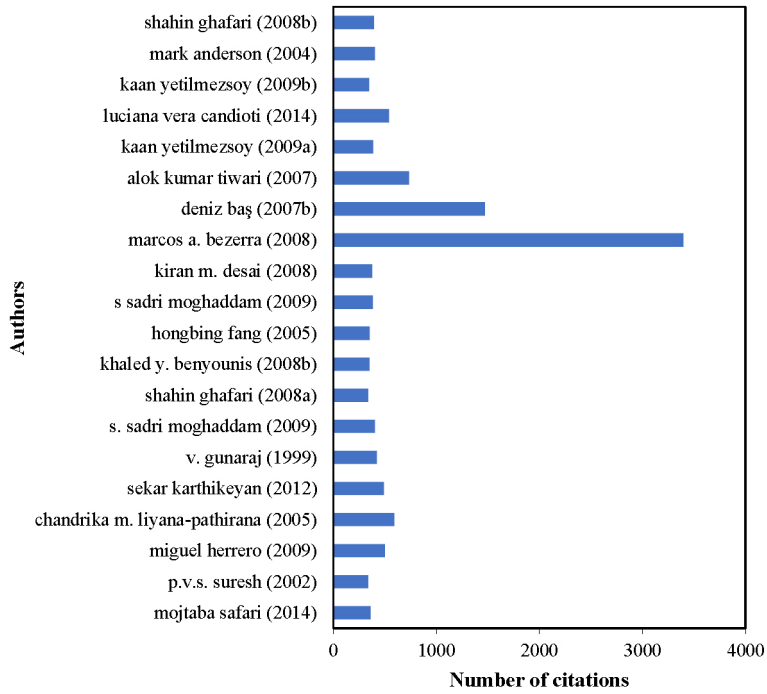


Figure 6

Number of citations by authors and year of publication

3.3 *Leading Continents/Countries and Participation*

The continents/countries cooperation relationship in the subject of discuss was investigated systematically by utilizing the collaboration network analysis to ascertain the connection of countries and institutes via the VOSviewer software, also using the world map to indicate the spread of participation via LENS.org (Fig. 7). Table 3 shows that the network includes six continents: Africa, South America, Oceania, Asia, Europe, and North America. It should be highlighted that authors from Europe have the most publications and participation in the network. However, as seen in Figure 7, the map color represents the density of scientific productions from each country, as indicated by the color index.

The thicker the line between certain countries, the stronger the collaboration between them as shown on the world map in Fig. 7. In addition, it was observed that United Arab Emirates showed highest level of participation (Fig. 8), followed by United States, Netherlands and Greece. However, countries in Europe indicate a very high level of participation in publication of application of response surface methodology in optimization.

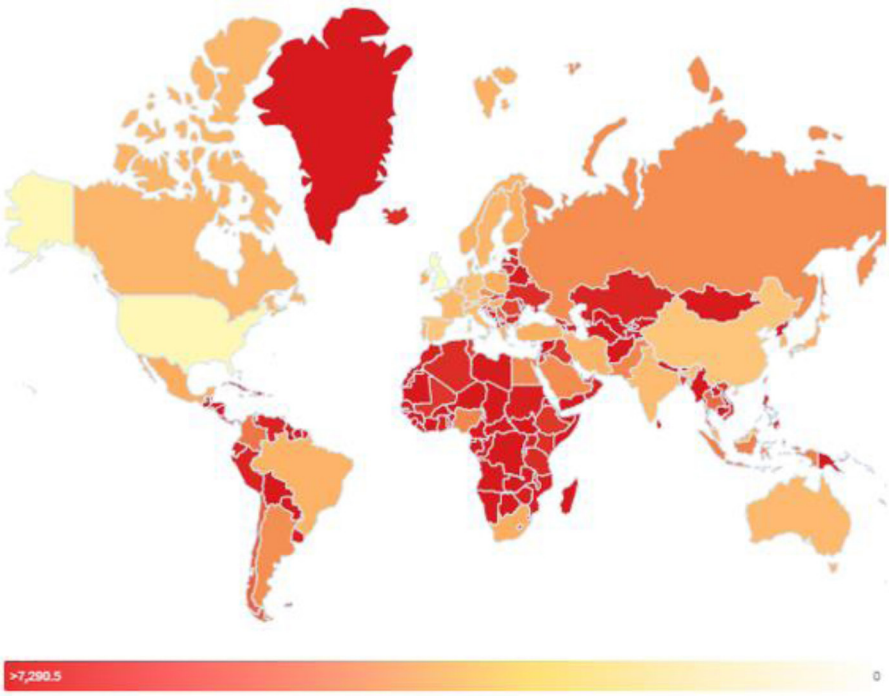


Figure 7

Institution countries/regions of the world collaboration network in RSM optimization publications.

Table 3

Publications on "application of response surface methodology in optimization" by continent

Rank	Continent	No. of publications	Participation in total publication (%)
1	Europe	18891	40
2	Asia	10518	23
3	North America	10292	22
4	Oceania	2854	6
5	South America	2471	5
6	Africa	1887	4

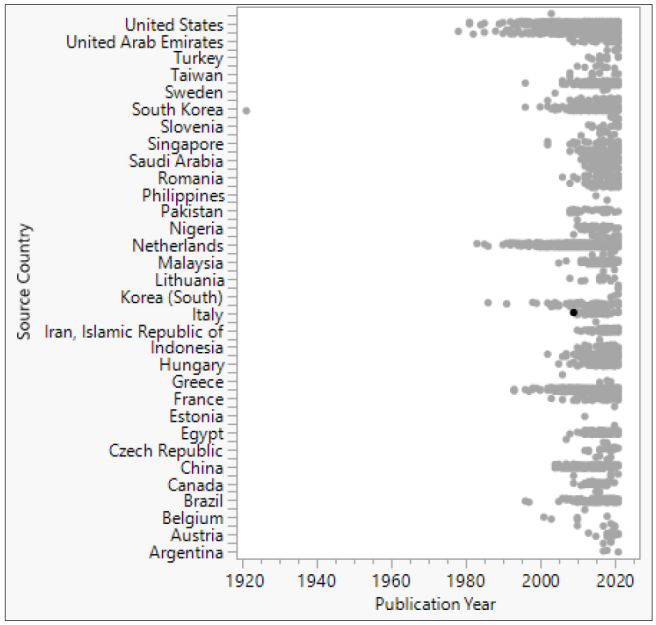


Figure 8

A scatter plot of countries participation across publication year

3.4 *Research Fields Identification*

In scholarly publications, "keywords" are "one of the vital elements supplied by the authors of the articles to show a paper's core content" [21]. Therefore, author's keywords are crucial, as they convey the titles and or are engaged to disseminate information to the scientific community. The author's keyword co-occurrences network highlights a different outlook of themes in RSM application, this shows keywords from the main author that are frequently occurring simultaneously in "response surface methodology". Knowing that some keywords appear only a couple of times, simultaneously occurring keywords would in no little way impact on the main themes of the subject.

As a result, considering main themes, only keywords with more than five appearances were chosen to populate the co-occurrence network map and suggest titles, as reported by Xue et al. [21]. As a result, only 305 of the 8731 keywords were collected due to their frequency. Figure 9 shows the keyword co-occurrence network for the aggregate "RSM application in optimization". It should be noted that the frequency of the keyword is directly related to the size of the node and the fonts used for the symbol.

A technique is here developed for citation analysis using both Medical Subject Headings (MeSH). It is a restricted phrase glossary is used to catalog articles. The 956 MeSH terms and 756 field of study were extracted from the total dataset using Jupiter notebook via python 3.9 software and are plotted using the word cloud feature showing a total of 100 words each (Fig. 10 and 11). A word cloud is a text processing technique that highlights terms that

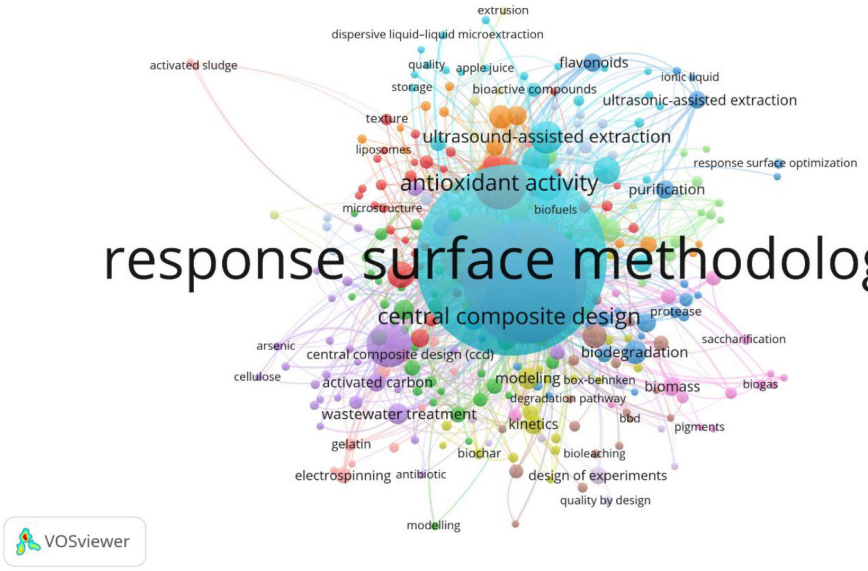


Figure 9

A network map of authors keywords co-occurrence cluster of response surface methodology in optimization publications

occur more frequently in a given text using graphical representations of word frequency. The size of the term in the graphics represents its frequency in the paper. It was found that the majority of the terms are associated with health (*chemistry, analysis, metabolism, method, microbiology, isolation purification, drug effects* etc.) showing conspicuous evidence of the keyword "chemistry" as the most frequent medical subject heading (MeSH). However, "*analysis*" and "*method*" are core words in RSM (Fig. 10). As seen in Fig. 11, the major fields of research in response surface optimization are *"response surface methodology"*, *"material*

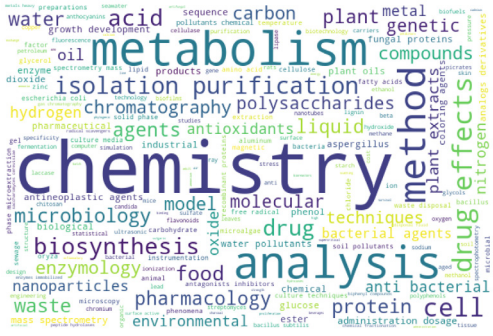


Figure 10

The word cloud representation from MeSH terms

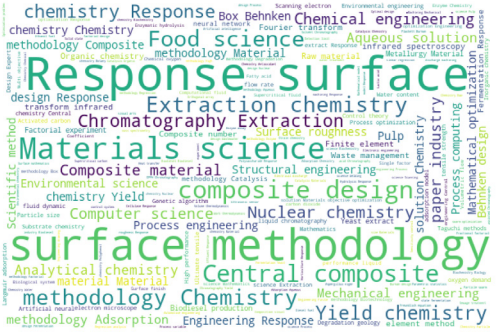


Figure 11

The word cloud visualization based on field of study

science", "extraction chemistry", "food science", "Composite Design", and "Box Behnken" are the most frequent words used. This indicates that RSM optimization has been widely used in "response surface methodology", "material science" and "chemistry related" fields. However, "*Composite Design*" and "*Box Behnken*" are core words in RSM as shown in Fig. 11.

4. The Application of RSM in Optimization Studies

4.1 *RSM as an optimization tool*

RSM is applied in situations where the dependent variable is affected by a number of factors and the goal is to maximize the response [22, 23]. It has since been widely used in a variety of sectors for the design and enhancement of systems where efficient design qualities are desired [24]. It is extremely helpful for both improving the designs of already-existing items and developing, formulating, and introducing novel products [25]. Assuming that the response's variance is homogeneous, this methodology performs well [26]. However, such an assertion may not necessarily apply when faced with actual problems. In RSM implementation, "Central Composite Design (CCD) is the most widely used design technique in second order response surface models. Response surface method consists of the following steps" [4, 27]:

- Development of an experimental framework
- Creation of response functions
- Optimization of process parameters

One of the major assumptions of response surface technique is that the experimental error is constant and uncontrollable by investigators when it comes to the system under study [28]. Many response surface designs, such as Central composite, Doehlert, and Box–Behnken, are utilized for optimization [29]. because it is rotatable and requires fewer test runs. As an illustration, the Box-Behnken design is favored above the Doehlert and Central Composite designs (CCD and DD). A design is only rotatable when the tests are roughly positioned on a sphere. It is possible to ensure that the precision of a predicted design's reaction is constant throughout the domain by selecting the appropriate number of center points. Because it lacks any points at the edges of the cubic region created by the two-level factorial level combos, the Box-Behnken design has an advantage [29, 30, 31, 32]. Consequently, determining an appropriate approximation to the true connection is the first stage in RSM. First-order low-order polynomials are the most prevalent kind [3]:

$$y = \beta_o + \sum_{i=1}^{k} \beta_i x_i + \varepsilon r \tag{1}$$

A second-order model may significantly improve the optimization process if a first-order model is unable to fit due to variable interaction or surface curvature. According to Ahmad and Janahiraman [33] and Olatunji et al. [34, 35], a general second-order model is as follows:

$$y = \beta_o + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_i \sum_j \beta_{ij} x_i x_j + \varepsilon r \quad (2)$$

y is the response function, $\beta i, \beta ii$ and βij are the coefficients of the linear, quadratic and interaction terms respectively, x_i and x_j are the independent variables, and εr is the error term.

For the optimum range, a second order polynomial or quadratic equation with a value close to the response region is typically appropriate [33]. Furthermore, the regression coefficients contained in the approximation model are called the independent variables and are estimated by minimizing the sum of squared errors [3, 5]:

$$G(a) = \sum_{p=1}^{P} \{w_p (F_p - \tilde{F}_p(a))^2\} \rightarrow \min \quad (3)$$

where w_p symbolizes the weight coefficient that describes the information's relative contribution from the original function at the position $p, p = 1, \ldots, P$.

The most important aspect of "RSM is the design of experiments (DoE)" [5]. Although, the goal of DoE is to choose the points at which the dependent variable should be evaluated [3].

4.2 *RSM as the most widely used optimization technique*

Recent years have been an increase in interest in RSM [36]. One technique for approximating an unknown function for which only a few values are computed is the design of experiments (DOE) method [37, 38, 39, 40]. It is a popular technique that requires a small number of experiments [41]. This method utilized for high-cost experiments and continuous solution spaces. RSM appears to be heavily utilized in modeling and optimizing food processing operations and product composition, according to Kidane [36]. Hence it is used especially with continuous solution spaces. It is indeed a widely utilized optimization technique across various fields such as chemical, engineering, clinical sciences [42]. RSM has been applied successfully in different studies, including optimizing carbon dioxide absorption processes using artificial neural networks (ANN) [43], maximizing ammonia nitrogen recovery and minimizing chromium loadings in effluent treatment [44], and optimizing process parameters for friction stir welding of AA6063-T6 pipes to achieve superior tensile properties [45]. Additionally, RSM has shown effectiveness in improving processes and achieving optimal solutions even with limited information about the objective function, as demonstrated in the context of cancer screening simulation models [42]. Therefore, RSM stands out as a versatile and powerful tool for modeling, optimizing, and improving processes in various scientific and industrial applications.

The number of publications in each year of application response surface in optimization as shown in Fig. 1 indicates a rapid increase in from 2001 to 2020 (< 1,500 publications). Although, it started since 1961 (Fig. 1), however 2021 showed a decline in publication. RSM optimization, on the other hand, has been extensively utilized in the areas of "response surface methodology," "materials science," and "chemistry related" research.

The fundamental RSM words that appeared frequently were "Composite Design," "Box Behnken," "analysis," and "method," in that order. According to Figures 10 and 11, it can be observed that the Central Composite Design (CCD) and Box Behnken Design (BBD) are the most often utilized RSM designs.

4.3. *The benefits and drawbacks of response surface approach in optimization*

Less trial and error in experimentation, computation of intricate iterations and interactions between independent variables, analysis and optimization, and enhancement of current design are the primary benefits of RSM. Compared to traditional experimental work, it is more applicable because it is based on experimental methodology that considers the interactions between the variables. Furthermore, it illustrates the total impacts of the process variables [5, 46]. In addition to examining how the independent variables affect the process being studied, RSM creates an empirical model that explains it. But the main benefit of RSM is that it may produce a lot of data with fewer experimental runs needed to assess many parameters and their interactions [32]. With the right experimental design, it can be utilized to forecast the optimal performance circumstances. Furthermore, it offers enhancements to augment the potential for process scaling and aids in the interpretation of multivariate phenomena [46, 47]. It has been successfully applied in the optimization of "soil washing condition on Zn removal efficiency," according to Alman-Abad et al. [48]. Figure 12 summarizes the benefits and drawbacks of using RSM in optimization.

Even though RSM offers several advantages over the conventional one parameter at a time technique, not all modeling and optimization studies can take advantage of its application. The main drawback of RSM is that it requires a second-order polynomial to fit the data [7]. A second order polynomial would limit the capacity to explain systems with symmetrical and asymmetrical curves [7, 49]. It cannot operate accurately with fewer than three independent variables.

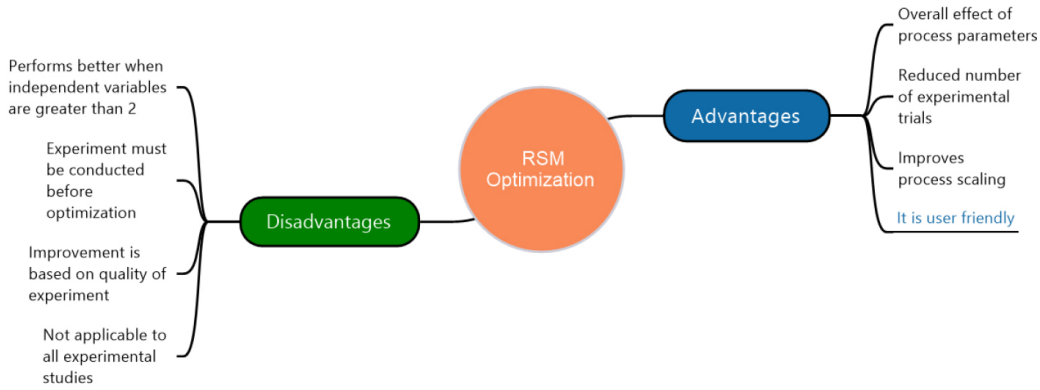


Figure 12

The benefits and drawbacks of using response surface methodology in optimization

5. Conclusion, Research Gap and Future Directions

The bibliometric analysis presented in this work describes the trend in the "application of RSM in optimization," highlighting the disciplines that have produced the greatest publications and citations as well as the advantages and disadvantages of RSM use. The LENS.org database, which collected a corpus of 50,001 papers between 1961 and 2021, has been taken into consideration. The findings indicate that the fields with the highest citation counts in the bioresource technology journal—chemistry, mathematics, computers, health sciences, biology, materials, engineering, and psychology—have the greatest number of publications in the subject. But according to the review, which dates back to 1961, RSM is the most often employed experimental optimization method. Despite it offers a number of benefits over the conventional one parameter at a time approach, not all modeling and optimization investigations are suitable for it. The fact that RSM needs a second-order polynomial to match the data is its most severe feature.

In many different fields, such as carbon dioxide absorption [43], electrochemical discharge machining [50], food formulations [51], and electrochemical grinding [52], RSM is widely used for optimization. There is a research gap in examining the applicability of RSM in a wider range of sectors and processes, despite its effectiveness in modeling and optimizing processes.

Further studies could focus on enhancing RSM's adaptability to different materials and conditions, improving its efficiency in complex systems, and exploring its integration with other optimization techniques to overcome limitations and enhance overall performance. By addressing these gaps, researchers can unlock the full potential of RSM as a versatile and powerful optimization tool in diverse fields.

Highlights

- Research trends on application of RSM in optimization
- RSM is the most widely used optimization technique
- Benefits and drawbacks of RSM in optimization

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Conflict of Interest

Authors declare no conflict of interest.

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Authors Contribution

The idea and design of the study were contributed to by all authors. Daniel Hogan Itam, Ibiba Taiwo Horsfall, Ekwueme Chimeme Martin, and Ibibia James Abam handled the material preparation, first draft, data gathering and analysis, and final editing.

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