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SUPERVISED MACHINE LEARNING FOR BANKRUPTCY PREDICTION: A BIBLIOMETRIC STUDY OF 2002 TO 2022

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Abstract:

The devastating after-effects of bankruptcy include the shutting down of business establishments and the dismissal of employees. This present study examines the use of supervised machine learning to predict bankruptcy between 2002 and 2022 by bibliometrically evaluating 361 scholarly publications from the Scopus database in September, 2022. VOSviewer, Harzing's Publish and Perish, and Microsoft® Excel were used to analyse the data. The outcome of this bibliometric analysis provides a clearer and wider understanding of existing and future trends of using supervised machine learning to forecast bankruptcy.

Keywords:

Bankruptcy, Machine Learning, Bibliometric, Finance

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Introduction

Weak financial administration, unfavourable market conditions, an economic slump, excessive investments, and unmanageable arrears are among the most common causes of bankruptcy. The devastating impact of bankruptcy on an establishment (Popikova & Papik, 2022) is understandably a concern for players in the business domain (Shetty et al., 2022). Multiple approaches have been proposed to assess the sustainability of a company. Studies on conventional approaches tend to depend exclusively on accounting and market statistics (Altman, 1968; Beaver, 1966). Furthermore, the statistical models for bankruptcy prediction lack accuracy. Supervised learning is widely used in various fields, from finance and healthcare to marketing and autonomous systems, providing valuable insights, automation, and decision-making capabilities based on historical examples and predefined outcomes. Artificial intelligence (AI) platforms, however, have facilitated the widespread use of more precise machine learning techniques in the medical and archaeological domains among others (Li & Wang, 2017).

Bankruptcy prediction is a binary classification problem that correlates with the capacity to foresee whether an establishment will evade or succumb to bankruptcy. Accurate predictions require the use of algorithms with which to train datasets; such as the financial statements of an establishment (Qu, 2019).

Considered a subset of computer science, machine learning can be used for a wide variety of issues, including those requiring classification. The application of machine learning techniques for bankruptcy prediction entails the use of algorithms to scrutinise the financial accounts of an establishment to assess the possibility of insolvency. Logistic regression, decision trees, random forests, and neural networks are among the techniques applicable for this task (Devi & Radhika, 2018). Bankruptcy prediction is a classic example of a classification problem, which can be overcome with classifying algorithms (Wang, 2017). Machine learning has been found to yield better accuracy than conventional statistical methods for small datasets. As such, optimisation methods; such as genetic algorithm (GA) and particle swarm optimisation (PSO), have been combined with machine learning to enhance bankruptcy prediction accuracy when relying on enormous datasets (Devi & Radhika, 2018).

The measures used to predict bankruptcy can be divided into two categories: parametric and non-parametric (Clement, 2020). When comparing the accuracy of conventional statistical approaches; such as logistic regression and linear discriminant analysis; and machine learning techniques; such as support vector machines, bagging, boosting, and random forest; to predict bankruptcy in corporations, Barboza et al. (2017) concluded that machine learning techniques were roughly 10% more precise than conventional statistical approaches. Fedorova (2022) developed innovative sets of indicators for bankruptcy models. As such, this present study used machine learning to scrutinise the financial statements of the listed companies and ascertain their likelihood of bankruptcy. The direction of this study aims to contribute to the review in two main focuses. The first focus is to present the research trends and applications of bankruptcy through bibliometric analysis. Second, to summarise specific knowledge for relevant supervised machine learning approaches.

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Methodology

As it is considered among the most extensive databases containing scholarly publications from multiple fields and that have been reviewed by industry peers, this present study gathered the required data from the Scopus database. Apart from providing pertinent and reliable bankruptcy prediction information associated to extant studies, professional viewpoints, verified data, and applicable diagnostic tools, the Scopus database also comprises approximately 36377 titles; more specifically, 13583 inactive titles and 22794 are active titles; from close to 11678 publishers. Of this number, 34346 are peer-appraised chronicles for highly recognised disciplines; such as the life, social, physical, and health sciences.

On 12 September 2022, the Scopus database was searched for scholarly publications containing the term 'bankruptcy' in the title. The search was limited to publications on machine learning and published over a 20-year period between 2002 to 2022 to gather publications that were most significant to this present study. Several adjustments; such as (a) restricting the language of the publication to English only, (b) only publications on business, management and accounting, computer science, economics, mathematics, econometrics and finance, social sciences, and decision sciences, (c) publications such as articles, conference papers, and book chapters, (d) keywords unrelated to supervised machine learning and bankruptcy prediction were disregarded, and (e) manual filtration was performed to dismiss unrelated publications.

As part of the data sets, the data was exported in CSV and RIS formats. To analyse the collected documents, several tools were used, including Microsoft Excel, VOSviewer, and Harzing's Publish and Perish software.

Table 1: Final Query Used For Data Collection

No.	Search Query	Results
1.	**Final query**: (TITLE-ABS-KEY ("bankruptcy")) AND (machine AND learning) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2009) OR LIMIT-TO (PUBYEAR , 2008) OR LIMIT-TO (PUBYEAR , 2007) OR LIMIT-TO (PUBYEAR , 2006) OR LIMIT-TO (PUBYEAR , 2005) OR LIMIT-TO (PUBYEAR , 2004) OR LIMIT-TO (PUBYEAR , 2003) OR LIMIT-TO (PUBYEAR , 2002)) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SUBJAREA , "COMP") OR LIMIT-TO (SUBJAREA , "BUSI") OR LIMIT-TO (SUBJAREA , "MATH") OR LIMIT-TO (SUBJAREA , "ECON") OR LIMIT-TO (SUBJAREA , "DECI") OR LIMIT-TO (SUBJAREA , "SOCI")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "ch")) AND (EXCLUDE (EXACTKEYWORD , "Plant Shutdowns") OR EXCLUDE (EXACTKEYWORD , "Information Management") OR EXCLUDE (EXACTKEYWORD , "Genetic Programming") OR	671

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	EXCLUDE (EXACTKEYWORD , "Information Systems") OR EXCLUDE (EXACTKEYWORD , "Article") OR EXCLUDE (EXACTKEYWORD , "Costs") OR EXCLUDE (EXACTKEYWORD , "Sentiment Analysis") OR EXCLUDE (EXACTKEYWORD , "Priority Journal"))	
2.	Exclude keywords with clustering algorithm and cluster analysis since clustering falls under unsupervised machine learning: [EXCLUDE (EXACTKEYWORD, "Clustering Algorithms") OR EXCLUDE (EXACTKEYWORD, "Cluster Analysis")]	654
3.	Manual filtration to exclude irrelevant articles.	361

Results And Discussions

Several across-the-board indicators from the datasets are depicted to provide an outline of studies on the use of supervised machine learning for the prediction of bankruptcy. Documents and source types, research productivity, subject area, most active source title, keywords, title and abstract analysis, distribution of publications by countries, authorship, most active institutions, and citation analyses were the pre-determined criteria used to evaluate all articles corresponding to the search.

Document and Source Types

Document types refer to the originality of the documents, such as conference proceedings, journal articles, or book series, whereas source type refers to the type of source documents, whether journal, conference paper, book chapter, book, or trade publication (Sweileh et al., 2017). We can see from Table 2 that most documents found are articles with 77.29% followed by conference papers and book chapters with 19.11% and 3.6% respectively. As shown in Table 3, the documents are classified into four different source types, with journals representing the most with 276 documents (76.45 %), followed by conference proceedings with 45 documents (12.47 %) of the total publications.

Table 2: Document Type

Document Type	Total Publication (TP)	Percentage (%)
Article	279	77.29
Conference Paper	69	19.11
Book Chapter	13	3.60
Total	**361**	**100.00**

Table 3: Source Type

Source Type	Total Publication (TP)	Percentage (%)
Journal	276	76.45
Conference Proceeding	45	12.47
Book Series	29	8.03
Book	11	3.05
Total	**361**	**100.00**

Year of Publications - Evolution of Published Studies

Examining documents by year of publication allows the researcher to see the pattern and popularity of the research subject over time (Ahmi & Mohamad, 2019). With only two

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publications, the field of bankruptcy prediction using supervised machine learning began in 1990. Until now, the number of publications has increased significantly.

Table 4: Year of Publications

Year	TP	NCP	TC	C/P	C/CP	*h*	*g*
2002	3	3	502	167.33	167.33	3	3
2003	5	5	262	52.4	52.4	4	5
2004	2	2	129	64.5	64.5	2	2
2005	9	9	1798	199.78	199.78	9	9
2006	5	5	661	132.2	132.2	5	5
2007	7	7	627	89.57	89.57	6	7
2008	7	6	691	98.71	115.17	6	7
2009	18	18	980	54.44	54.44	12	18
2010	15	15	654	43.6	43.6	8	15
2011	21	20	736	35.05	36.8	11	21
2012	24	24	664	27.67	27.67	14	24
2013	14	14	586	41.86	41.86	8	14
2014	8	7	360	45	51.43	6	8
2015	10	10	496	49.6	49.6	7	10
2016	13	11	461	35.46	41.91	7	13
2017	20	20	870	43.5	43.5	13	20
2018	19	13	222	11.68	17.08	8	14
2019	31	28	535	17.26	19.11	13	22
2020	39	33	475	12.18	14.39	13	20
2021	45	34	357	7.93	10.5	8	18
2022	46	14	26	0.57	1.86	3	3
Total	**361**						

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

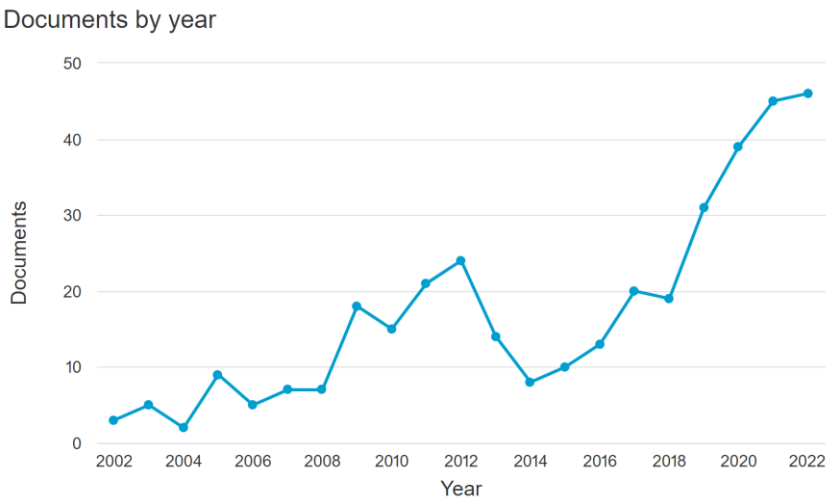

Figure 1: Document by Year

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Subject Area

Table 5 shows the top 20 of subject areas in bankruptcy prediction using supervised machine learning. Computer science has the highest number of publications with 239 publications (31%) since machine learning is a branch of computer science. Business, Management and Accounting area contributed 12.97% of the total publications followed by Engineering with 12.06%, Mathematics with 11.93% and Economics, Econometrics and Finance with 11.93%.

Table 5: Subject Area

Subject Area	Total Publications (TP)	Percentage (%)
Computer Science	239	31.00
Business, Management and Accounting	100	12.97
Engineering	93	12.06
Mathematics	92	11.93
Economics, Econometrics and Finance	87	11.28
Decision Sciences	80	10.38
Social Sciences	22	2.85
Arts and Humanities	10	1.30
Energy	10	1.30
Psychology	9	1.17
Environmental Science	8	1.04
Physics and Astronomy	6	0.78
Materials Science	4	0.52
Neuroscience	3	0.39
Agricultural and Biological Sciences	2	0.26
Chemistry	2	0.26
Multidisciplinary	2	0.26
Biochemistry, Genetics and Molecular Biology	1	0.13
Earth and Planetary Sciences	1	0.13

Most Active Source Titles

According to Table 6, which presents the most active source title, we found that Expert Systems with Applications was the most active source title followed by Lecture Notes in Computer Sciences Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics, Computational Economics, Knowledge Based Systems and Decision Support Systems.

Table 6: Most Active Source Title

Source Title	TP	Publisher	Cite Score	SJR 2021	SNIP 2021
Expert Systems With Applications	41	Elsevier	12.2	2.07	2.985
Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics	14	Springer Nature	2.1	0.407	0.534

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Computational Economics	10	Springer Nature	3.3	0.454	1.015
Knowledge Based Systems	9	Elsevier	12	2.192	2.611
Decision Support Systems	8	Elsevier	11.3	1.973	2.661
European Journal Of Operational Research	8	Elsevier	10.5	2.354	2.815
Journal Of Forecasting	7	Wiley-Blackwell	3.7	0.594	0.948
Applied Soft Computing Journal	6	Elsevier	12.4	1.959	2.396
Information Sciences	6	Elsevier	12.1	2.29	2.404
Sustainability Switzerland	6	Multidisciplinary Digital Publishing Institute (MDPI)	5	0.664	1.31
ACM International Conference Proceeding Series	5	ACM	1	0.232	0.31
Annals Of Operations Research	5	Springer Nature	6.1	1.165	1.732
Quantitative Finance	5	Taylor & Francis	3.4	0.865	1.528
IEEE Access	4	IEEE	6.7	0.927	1.326
Studies In Computational Intelligence	4	Springer Nature	1.8	0.237	0.397
Applied Intelligence	3	Springer Nature	7.8	1.211	1.729
Expert Systems	3	Wiley-Blackwell	4.7	0.599	0.949
International Journal Of Finance And Economics	3	Wiley-Blackwell	2.1	0.424	0.976
Journal Of Theoretical And Applied Information Technology	3	Little Lion Scientific	1.3	0.195	0.394
Lecture Notes In Networks And Systems	3	Springer Nature	0.7	0.151	0.249

Keywords Analysis

The author keywords were charted using VOSviewer, a software instrument designed to construct and visualise bibliometric networks. As seen in Figure 2, colour, square size, font size, and the width of the connecting lines were used to indicate the extent of the correlations between the author keywords and the pre-determined keywords. For instance, similarly coloured keywords are often grouped together. As bankruptcy prediction, support vector machine, bagging, credit scoring, decision trees, random forest, kernel extreme learning machines, and boosting are similarly coloured red in this present study, these keywords are related and commonly appear together.

Table 7 shows top keywords for this study. Among the most frequently encountered author keywords were bankruptcy prediction, forecasting, bankruptcy, neural networks, and machine learning.

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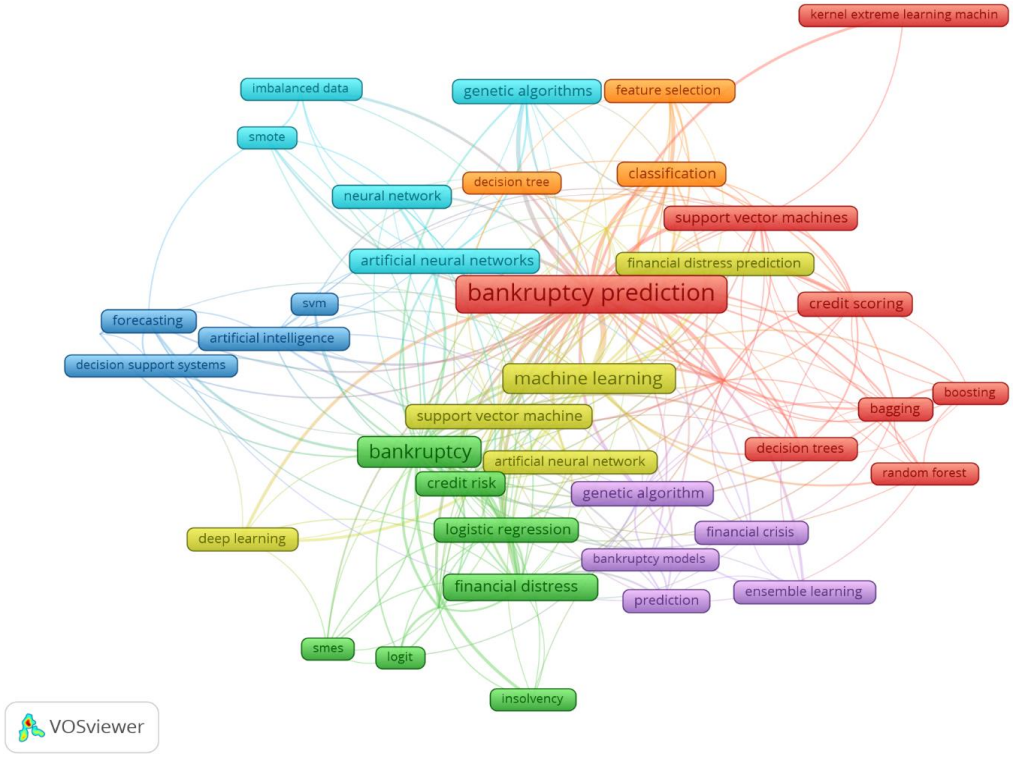

Figure 2: Network Visualization Map Of The Author Keywords

Table 7: Top Keywords

Author Keywords	Total Publications (TP)	Percentage (%)
Bankruptcy Prediction	177	9.13
Forecasting	133	6.86
Bankruptcy	81	4.18
Neural Networks	71	3.66
Machine Learning	56	2.89
Finance	54	2.79
Decision Trees	50	2.58
Support Vector Machines	47	2.43
Learning Systems	37	1.91
Artificial Intelligence	36	1.86
Financial Distress	36	1.86
Genetic Algorithms	35	1.81
Classification (of Information)	33	1.70
Data Mining	32	1.65
Financial Ratios	29	1.50
Logistic Regression	25	1.29
Risk Assessment	24	1.24
Decision Making	23	1.19
Classification	22	1.14
Discriminant Analysis	22	1.14

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Geographical Distribution of Publications

Table 8 reports the top 5 countries with the highest amount of published studies in the bankruptcy literature. The United States is the top, achieving 41 counts (8.99%), followed by China 39 (8.55%), India and Taiwan 34 (7.46%) and South Korea 31 (6.80%). Malaysia is among the lowest with 1.54% that published regarding the issue stated.

Table 8: Top 20 Countries contributed to the publications

Country	Total Publications (TP)	Percentage (%)
United States	41	8.99
China	39	8.55
India	34	7.46
Taiwan	34	7.46
South Korea	31	6.80
Spain	26	5.70
France	16	3.51
United Kingdom	15	3.29
Czech Republic	12	2.63
Italy	12	2.63
Australia	11	2.41
Portugal	11	2.41
Russian Federation	10	2.19
Poland	8	1.75
Slovakia	8	1.75
Belgium	7	1.54
Greece	7	1.54
Iran	7	1.54
Japan	7	1.54
Malaysia	7	1.54

Authorship and Co-Authorship Analysis

Table 9 shows the number of authors per document. A total of 46 (12.74%) documents were single-authored publications while the highest percentage 29.92% are the two-authors publication. The productive authors based on publications number are shown in Table 10. Ravi,V. had the most publications with 15 papers followed by Tsai, C.F. with 11 publications. The third most productive author with 7 publications was Ribeiro, B., followed by Hu, Y.C. total publication is 6. The rest of the authors mostly had 5 publications and below.

Table 9: Number of Author(s) per Document

Author Count	Total Publications (TP)	Percentage (%)
1	46	12.74
2	108	29.92
3	94	26.04
4	71	19.67
5	22	6.09
6	10	2.77
7	8	2.22

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8	2	0.55
Total	**361**	**100.00**

Table 10: Most Productive Authors

Author's Name	Total Publications (TC)	Percentage (%)
Ravi, V.	15	4.11
Tsai, C.F.	11	3.01
Ribeiro, B.	7	1.92
Hu, Y.C.	6	1.64
Chen, M.Y.	5	1.37
Kim, M.J.	5	1.37
Vieira, A.	5	1.37
du Jardin, P.	5	1.37
Baik, S.W.	4	1.10
Jones, S.	4	1.10
Kang, D.K.	4	1.10
Karas, M.	4	1.10
Kou, G.	4	1.10
Le, T.	4	1.10
Chen, H.	3	0.82
Chen, H.L.	3	0.82
Chen, N.	3	0.82
Danenas, P.	3	0.82
De Andrés, J.	3	0.82
Fedorova, E.	3	0.82

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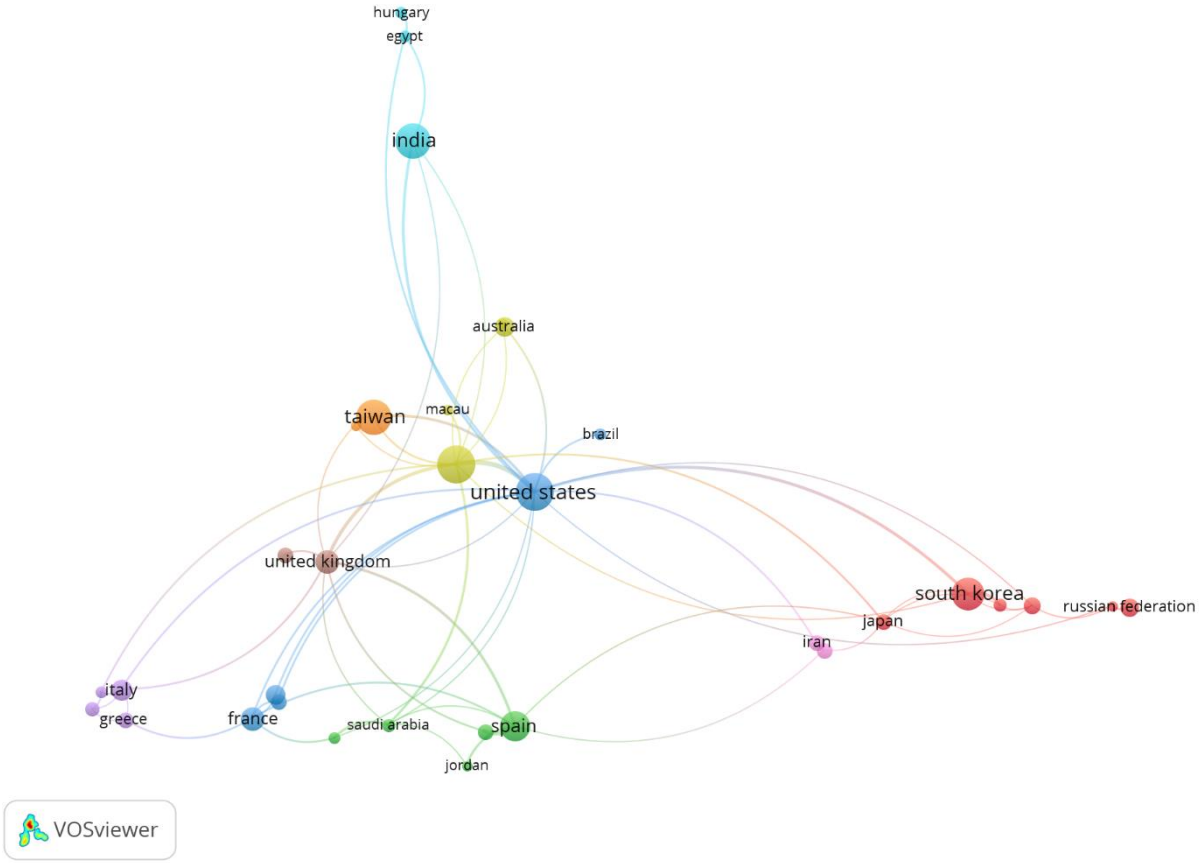

Figure 3: Network Visualization Map Of The Co-Authorship Based On Countries That Have A Minimum Of Five Number Of Citations And Three Number Of Documents (Fractional Counting)

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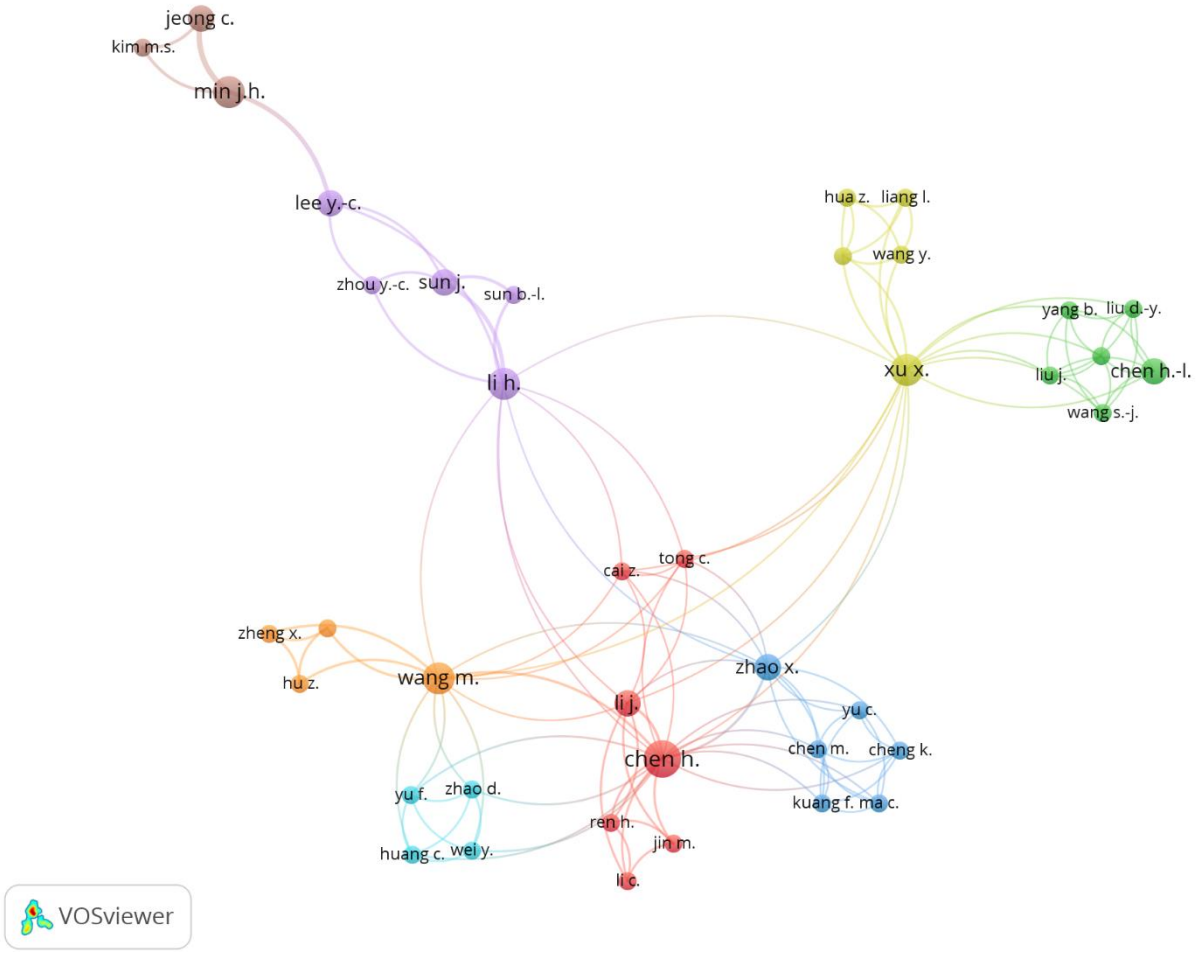

Figure 4: Network Visualization Map Of The Co-Authorship Based On Authors That Have A Minimum Of Five Number Of Citations And One Document (Fractional Counting)

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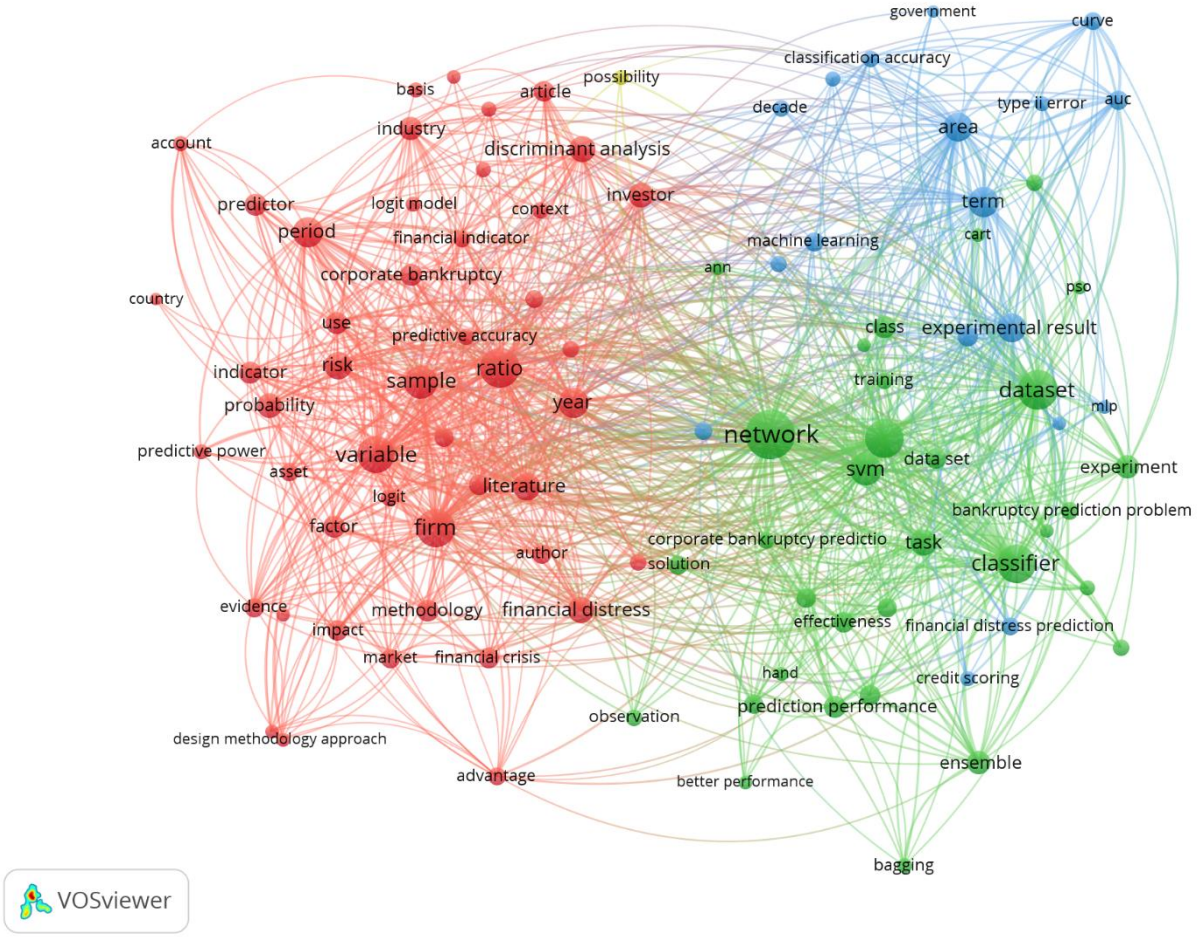

Figure 5: VOSviewer Visualization Of A Term Co-Occurrence Network Based On Title And Abstract Fields (Binary Counting)

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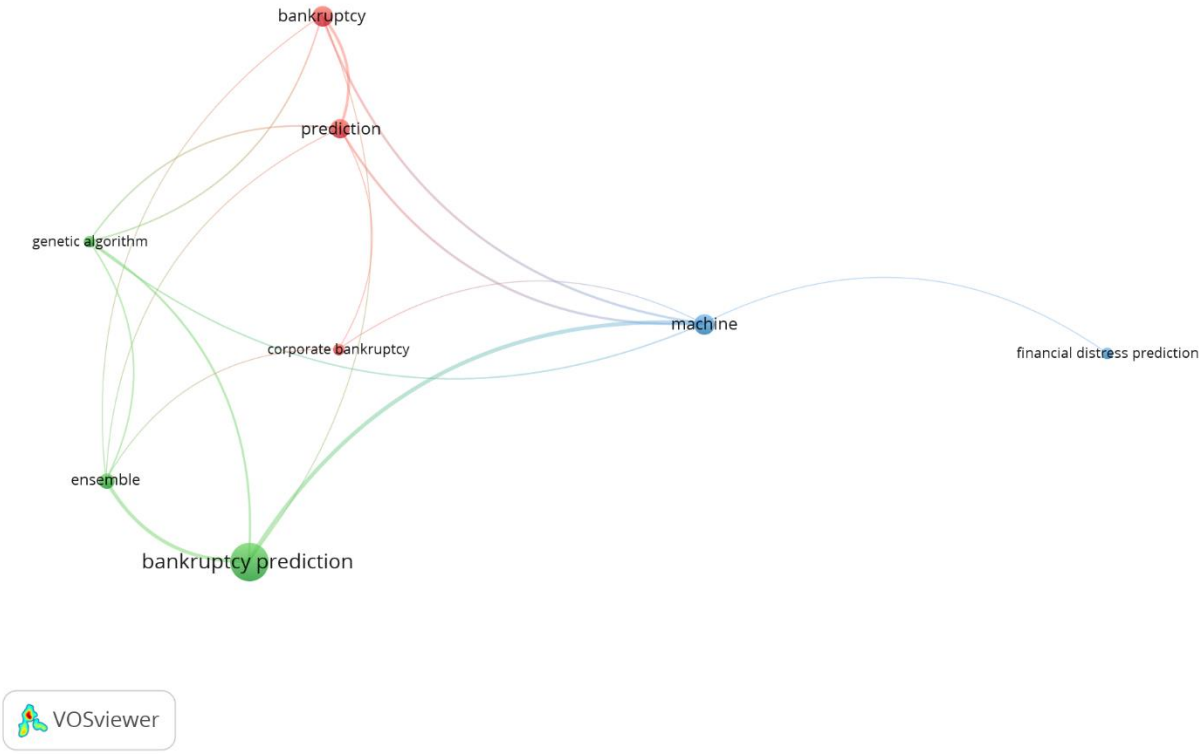

Figure 6: Vosviewer Visualization Of A Term Co-Occurrence Network Based On Title Fields (Binary Counting)

Most Influential Institutions

Table 11 presents information on the institutions that have been sorted based on the total publications. The table shows the highest publications is 14 (3.54%) of Institute for Development and Research in Banking Technology India, followed by National Central University with 9 (2.28%) publications. The other organisations established in different countries contributed a total of 7 (1.77%) publications which are Universidade de Coimbra, Chung Yuan Christian University and University of Coimbra, Centre for Informatics and System.

Table 11: Most Influential Institutions With Minimum Of Five Publications

Institution	Total Publications (TC)	Percentage (%)
Institute for Development and Research in Banking Technology India	14	3.54
National Central University	9	2.28
Universidade de Coimbra	7	1.77
Chung Yuan Christian University	7	1.77
University of Coimbra, Centre for Informatics and System	7	1.77
EDHEC Business School	7	1.77
University of Hyderabad	6	1.52
Pondicherry University	5	1.27
Wenzhou University	5	1.27
HSE University	5	1.27

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The University of Sydney	5	1.27
Universidad de Granada	5	1.27
Sejong University	5	1.27
Korea Advanced Institute of Science and Technology	5	1.27
National Taichung University of Science and Technology	5	1.27

Citation Analysis

The citations metrics were summarised in Table 12 as the documents were retrieved on 9 December 2022 Harzing's Publish and Perish software were used to produce the result by importing RIS formatted files from Scopus database. As a result, the number of publications predicting bankruptcy using machine learning reported from 2002 – 2022 were 361 papers with 12092 citations and the average of 604.6 citations per year. Besides that, there are 33.5 number of citations per paper and the total of h-index and g-index were 60 and 102 respectively.

Table 13 revealed the leading most cited publications with their total citations. The article entitled "Bankruptcy prediction using support vector machine with optimal choice of kernel function parameters" by Min & Lee (2005) has received the highest number of citations (601 citations with an average of 35.35 citations per year) followed by Shin et al. (2005) with 539 citations and 31.71 citations per year.

Table 12: Citations Metrics

Metrics	Data
Publication years	2002-2022
Citation years	20 (2002-2022)
Papers	361
Citations	12092
Citations/year	604.6
Citations/paper	33.5
Citations/author	5003.01
Papers/author	156.54
h-index	60
g-index	102

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Table 13: Top Ten Most Cited Publications

No	Authors	Title (Source)	Year	Citations	Citations per Year
1	Min, J.H., Lee, Y.-C.	Bankruptcy prediction using support vector machine with optimal choice of kernel function parameters	2005	601	35.35
2	K.-S. Shin, T.S. Lee, H.-J. Kim	An application of support vector machines in bankruptcy prediction model	2005	539	31.71
3	C.-F. Tsai, J.-W. Wu	Using neural network ensembles for bankruptcy prediction and credit scoring	2008	342	24.43
4	S.-H. Min, J. Lee, I. Han	Hybrid genetic algorithms and support vector machines for bankruptcy prediction	2006	287	17.94
5	F. Barboza, H. Kimura, E. Altman	Machine learning models and bankruptcy prediction	2017	286	57.2
6	C.-H. Wu, G.-H. Tzeng, Y.-J. Goo, W.-C. Fang	A real-valued genetic algorithm to optimize the parameters of support vector machine for predicting bankruptcy	2007	279	18.6
7	K.-S. Shin, Y.-J. Lee	A genetic algorithm application in bankruptcy prediction modeling	2002	256	12.8
8	D. West, S. Dellana, J. Qian	Neural network ensemble strategies for financial decision applications	2005	253	14.88
9	C.-S. Park, I. Han	A case-based reasoning with the feature weights derived by analytic hierarchy process for bankruptcy prediction	2002	237	11.85
10	E. Alfaro, N. GarcÃa, M. GÃ¡mez, D. Elizondo	Bankruptcy forecasting: An empirical comparison of AdaBoost and neural networks	2008	196	14

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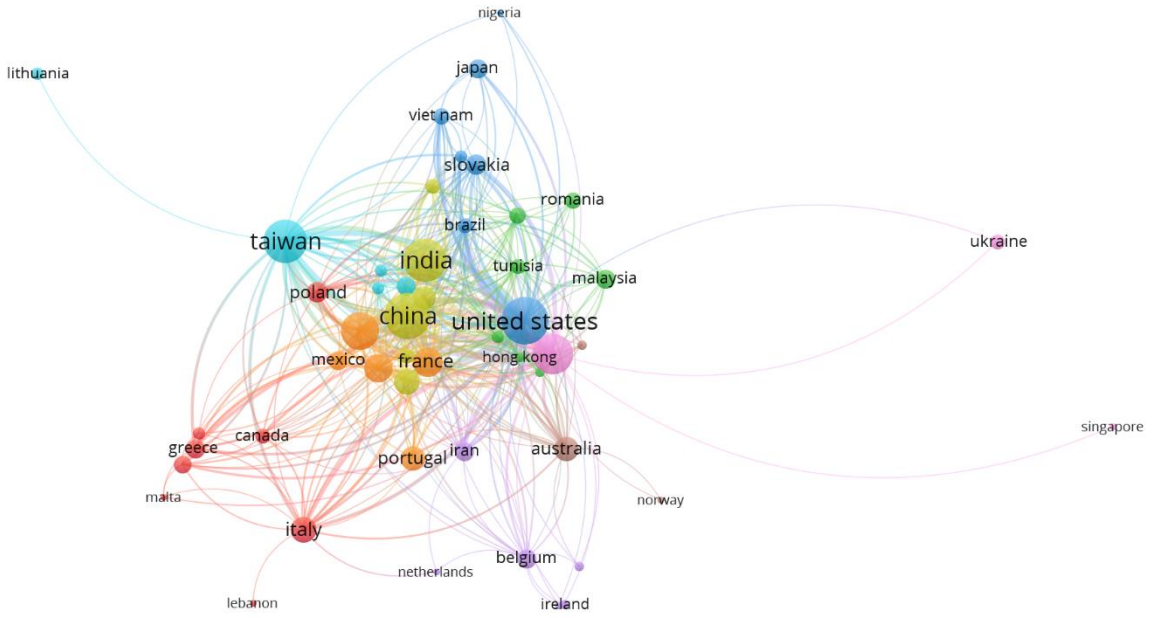

Figure 7: Network Visualization Map Of The Citation By Countries

Minimum number of documents of an author = 1
Minimum number of citations of an author = 5

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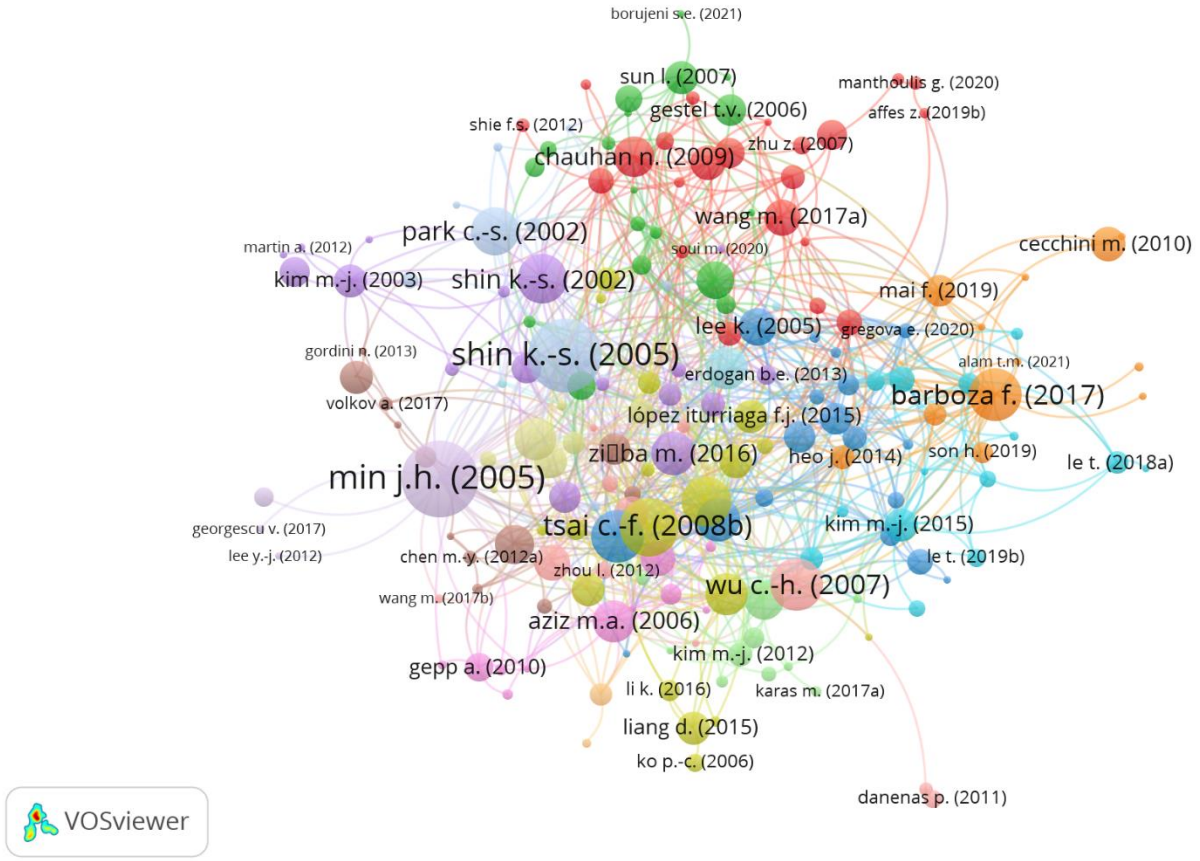

Figure 8: Network visualization map of the citation by documents

Minimum number of citations of a document = 5

Conclusion

In this bibliometric study, we examined the research landscape surrounding supervised machine learning techniques for bankruptcy prediction. By systematically analyzing a variety of academic articles, we have discovered several key trends and findings that shed light on the current state and future direction of this field.

Our analysis revealed a growing interest in using supervised machine learning algorithms for bankruptcy prediction tasks. Searching for the keywords bankruptcy and machine learning in the Scopus database for publications published between 2002 and 2022 revealed that the number of publications on this topic has increased annually over the last decade, reflecting the importance of this research area and the increasing Recognizing the potential of machine learning underlines in tackling complex financial challenges. A total of 46 publications were published in 2022 and a total of 34 cited publications were published in 2021, which is the highest value in the period examined.

Furthermore, our analysis highlighted the interdisciplinary nature of this field, with contributions coming from diverse fields including finance, economics and computer science, with computer science being the most commonly covered area (31%). This interdisciplinary collaboration has enriched the research landscape, promoting innovation and the development of novel methods tailored to the unique challenges of insolvency prediction.

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However, despite the significant advances in this field, several challenges and opportunities for future research remain. Addressing issues related to data quality, model interpretability, and generalization across different economic contexts is paramount to advancing the practical applicability of machine learning-based bankruptcy prediction models. In addition, exploring new methods such as deep learning and reinforcement learning in the context of bankruptcy prediction requires further research to gain new insights and achieve better prediction performance.

In summary, this bibliometric study provides a comprehensive overview of the evolving landscape of supervised machine learning for bankruptcy prediction. By synthesizing existing knowledge and identifying research gaps, our findings contribute to the ongoing discourse on financial risk management and pave the way for future advances in this critical area. Therefore, future studies should also conduct bankruptcy-related studies in other developing countries on other topics worth exploring, such as using AI to predict bankruptcy.

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