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Review

Bibliometric Method for Manufacturing Servitization: A Review and Future Research Directions

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Abstract: To gain sustainable development, it is a trend that manufacturing companies are change the value chain from manufacturing-centric to service-centric. Therefore, the capability of the manufacturing service is as significant as the production ability of enterprises, which reflects the supply chain management (SCM), flexible production, production efficiency, and other indicators of the enterprises. It is the first paper to discuss the sustainability of service-oriented manufacturing using bibliometric analysis. It derives a detailed review and future outlook on the development of manufacturing servitization, indicating the research directions for future development, and provides a valuable reference for researchers in related directions. The bibliometric analysis discusses countries or regions, research areas, authors, keywords, institutions, and journals based on the literature data from the Web of Science (WoS). The results show that research on manufacturing services has gradually received attention since its inception and has become popular since 2008. The papers published from 2008 to 2021 account for 77.62%. The USA is the most studied country on this topic, followed by China and the UK. The *International Journal of Production Research* regarding the most quantity of articles, and Beihang University is the most influential institution in this field. The largest amount of articles published in the area of "business and economics", amounting to 1565 articles. In recent years, the main research areas included "Industry 4.0", "cloud manufacturing (CMfg)", "Internet of Things (IoT)", "big data" and "services innovation". Finally, "digital and intelligent manufacturing" and "product-service systems" are potential research directions for the future.

Keywords: manufacturing servitization; bibliometric; Web of Science; hot topics; development trend

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1. Introduction

According to a literature survey, academic research on the servitization of manufacturing began in the 1980s. At that time, Vandermerwe and Rada [1] introduced "manufacturing servitization". They defined it as increasing the value of core products, and business managers must add a more complete "product-service bundle" by considering customer needs as a whole. Manufacturers must focus on customer-centric services, support, self-service, and knowledge. This view resonated with practitioners, prompting product-oriented companies to develop service growth strategies. In 2009, Baines et al. [2] described the servitization of manufacturing as "service-oriented innovation in organizational capabilities and processes". They believed that product service systems (PSS) can bring more value to customers. Therefore, product-service innovation and PSS have also become a research area of manufacturing servitization.

Manufacturing servitization has been studied in various aspects. Opresnik and Taisch [3] proposed to combine big data and servitization to create a new basis for decision-making in enterprises. This approach can reduce costs, improve efficiency, increase business opportunities, and increase revenues. It becomes a unique and sustainable model for enterprises. Kohtamäki et al. [4] analyzed the correlation between digitalization and

enterprise efficiency. They suggested that manufacturing companies should actively digitize to serve production and customer needs better. From a value chain perspective, Rymaszewska et al. [5] indicated adding the IoT to the manufacturing production processes by acquiring data and using it for the serviceability and profitability of the enterprise. Coreynen et al. [6] investigated how digital methods can extend the servitization function of manufacturing through four cases. Liu [7] et al. developed an optimization model of task scheduling to achieve load balancing of distributed resources and efficient utilization of manufacturing resources in a cloud manufacturing model. Kohtamäki et al. [8] analyzed the cases of four companies to illustrate the difference between a product and a service solution as a product, which helps to explain the development model of the servitization process in manufacturing.

The COVID-19 pandemic has profoundly affected and changed the global and regional economic activity, and manufacturing [9,10], which has accelerated the transformation of manufacturing. With the development of "Industry 4.0", the service level has become the standard for measuring the manufacturing capability of a country, and various production support modes have derived from it. Therefore, the study of the servitization of manufacturing is necessary. Currently, there are many studies related to the servitization of manufacturing, but all of them are in different directions. For the sustainability of servitization of manufacturing, it is necessary to analyze the literature over these 30 years to review the development and make recommendations for the future.

In contrast to the above literature, a bibliometric perspective is applied to this paper. Rousseau [11] mentioned that Otlet first introduced bibliometry in 1934 in Traité de Documentation. It was defined as measuring indicators of various aspects of a publication. In 1969, Pritchard [12] defined bibliometric as "the application on books and other spread media of mathematic and statistic methods". With the development of statistics and information science, bibliometric techniques have evolved into a sophisticated method for analyzing data trends. Due to the remarkable intuitiveness and objectivity of bibliometric, it has been used extensively in various disciplinary directions, such as tourism management [13], manufacturing [7], smart cities [14], medicine [15], social psychology [16], ecological sustainability [17], economics [18], neuroscience [19], environmental pollution [20] and chemosphere [21]. It is the first paper to discuss the sustainability of service-oriented manufacturing using bibliometric analysis. It provides a detailed review and outlook on the development of servitization of manufacturing, indicates the research directions for future development, and provides a useful reference for researchers in related directions.

Manufacturing servitization has become a hot topic in various areas, such as science, sociology, economics, and management. The field of manufacturing servitization is still in its infancy. The purpose of this paper is to review the development of manufacturing servitization and to find a potential direction. This paper used a bibliometric method to quantitatively and qualitatively analyze the research areas, journals, countries, keywords, institutions, authors, trends, and citations of manufacturing servitization. Then, the research directions for the future development of manufacturing servitization are analyzed. Finally, it provided valuable suggestions for researchers in manufacturing servitization-related from three aspects: research direction, cooperation, and application development direction. It will benefit industry and academia for further research on manufacturing servitization.

The rest of this paper is organized as follows. Section 2 describes the data source, search strategy, and analysis methods. Section 3 presents the analysis results and discusses these results in detail. Implications for future research are given in Section 4. The conclusions are presented in Section 5.

2. Material and Methodology

Figure 1 shows the flow chart of this paper's bibliometric analysis method. The process of bibliometric analysis can be summarized as four steps: the search query, data screening, data analysis, and data visualization.

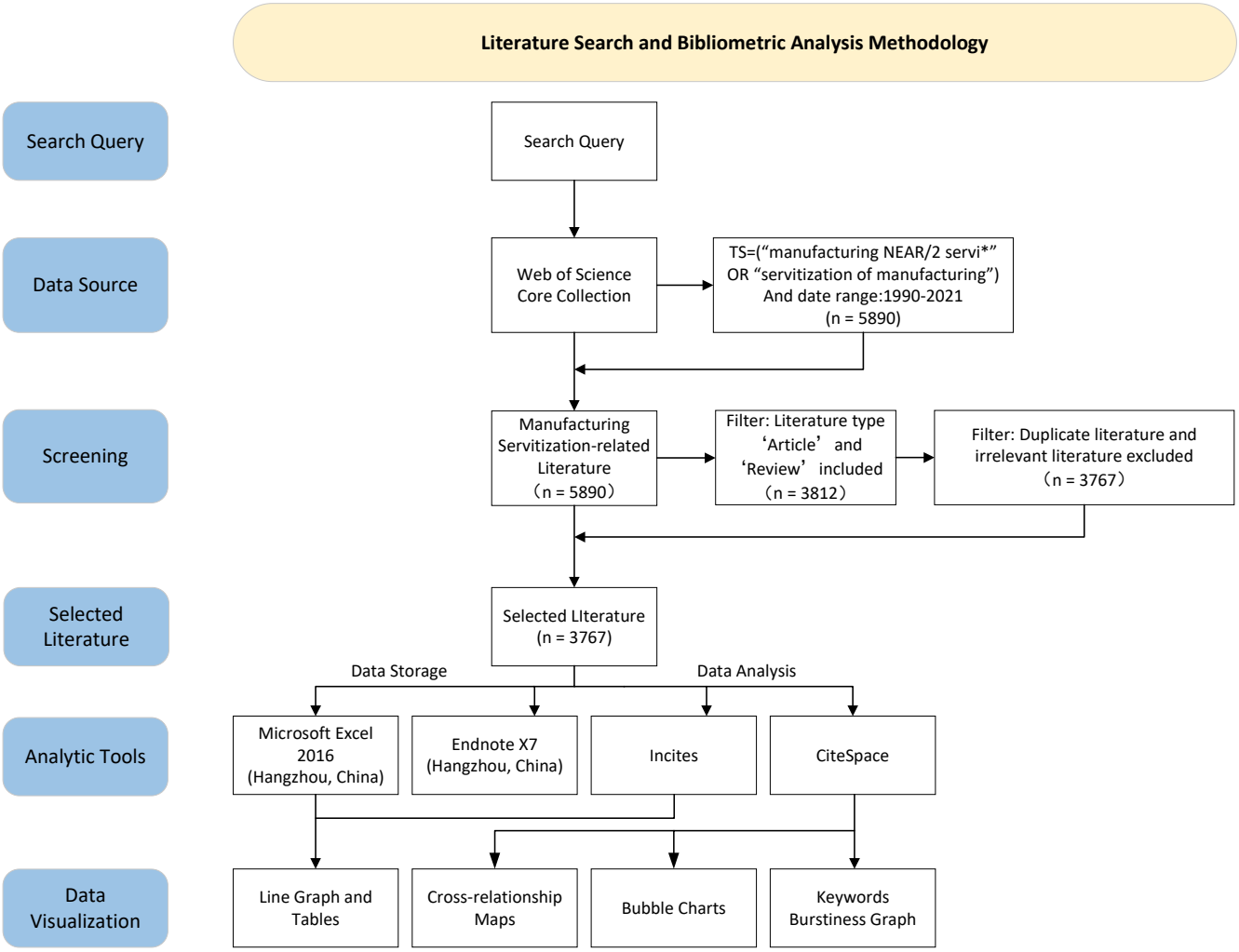

Figure 1. The flow chart of literature search and bibliometric analysis methodology.

2.1. Literature Source

In this work, bibliometric analyses were implemented based on the WoS database, which enabled the retrieval of literature on the servitization of manufacturing. A multidisciplinary document database is established by the WoS, which covers more than 12,000 authoritative and high-impact academic journals [22,23], including those on natural science, social sciences, arts and humanities [24–26] etc., and is widely regarded as an essential tool for accessing global academic information [27].

The literature retrieval time was May 2022. Since the academic research on manufacturing servitization began in the late 1980s, the publication years for the search ranged from 1990 to 2021.

2.2. Search Strategy

The documents were retrieved through the advanced search of the WoS core collection database with the following search terms: manufacturing servitization, manufacturing service, servitization of manufacturing, and service of manufacturing. According to the WoS search formula setting method, the search formula was: TS = ("manufacturing NEAR/2 servi*" OR "servitization of manufacturing"), and the publication date were from 1990 to 2021. As the Figure 1 shows, the original data retrieved were filtered, and only articles and review articles types were retained, such as book reviews, letters, news items, editorial materials, etc., were excluded. Then duplicate documents were removed. Literature whose

content was entirely irrelevant to the topic of manufacturing servitization was also removed manually. Finally, a total of 3767 papers were collected.

2.3. Analysis Methods

Some bibliometric indicators were analyzed to evaluate the research trends and milestones of manufacturing servitization. The total records and citations of all documents retrieved are downloaded from WoS and input to Endnote and CiteSpace. Endnote is an internationally renowned software tool for managing and citing references.

The CiteSpace is a data mining and visualization platform that provides burst detection to detect changes in hot research trends across generations and help analyze the rise or decline of a topic or keyword.

Besides, some other metrics, including impact factor (IF), h-index, were analyzed using InCites, a WoS-based tool that allows for data analysis and normalized processing of organization names.

In this paper, the bibliometric techniques were used to analyze the research subject through quantitative and qualitative analysis of data [24,28,29]. The document data searched from the WoS are sent to InCites for data analysis and storage. The indicators, including the number of articles published, citation frequency, h-index, and IF, were demonstrated in table form to illustrate the features of servitization in manufacturing from various perspectives. Python is used to process the Microsoft Excel data. Line charts can intuitively display the trend of global contribution [30,31]. The analysis of the bubble chart was used to reveal the development trends of manufacturing servitization research fields, journals, keywords, and authors, and the cross-relationship chart visually showed the cooperation between countries or regions, research fields, authors, and institutions, etc. The hot topic analysis of CiteSpace provided the latest information on research interests and perspectives.

3. Results and Discussions

3.1. The Global Research Status

The literature data includes 3767 documents, with 3614 articles and 153 reviews, covering research on the servitization of manufacturing in 107 countries or regions. An average of 118 papers are published each year. According to Figure 2, the amount of publications on the topic of servitization of manufacturing shows a slow and steady growth trend from 1990 to 2021. The earliest article on the servitization of manufacturing was published in 1990, with Goldhar [32] as the first author, from the Illinois Institute of Technology in the USA, who studied the opportunities and challenges of "the automation of custom manufacturing" in future through the development of computer-integrated manufacture (CIM) technology.

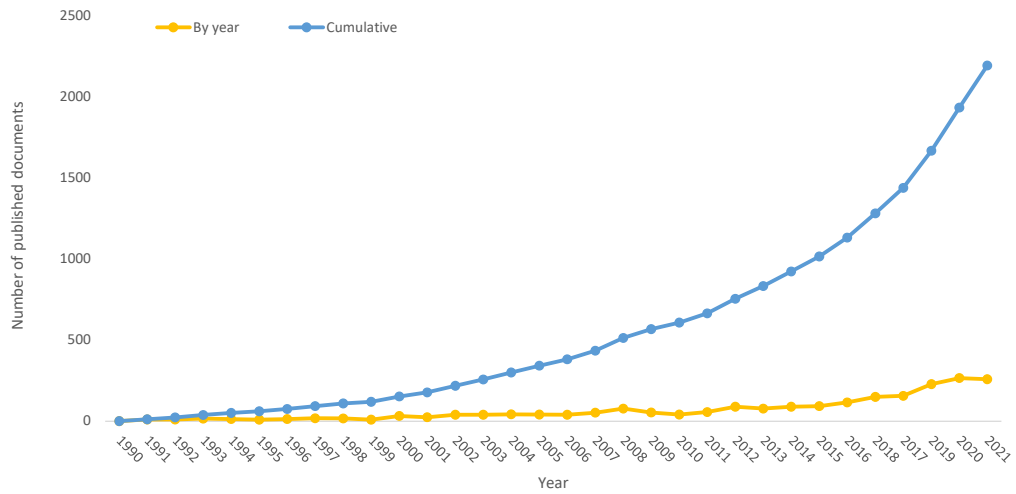

Figure 2. The quantity of annual literature in manufacturing servitization research.

Table 1 illustrates the 20 countries with an enormous quantity of publications on manufacturing servitization. The USA ranks first with 930 publications, followed by China with 760 and the UK with 501. It is noticeable that although the amount of publications in the Netherlands, Finland, and Switzerland is relatively small, the average impact factor per publication of the articles published in these three countries is high, with the Netherlands at 6.61 and its average citations per publication at 46.08. It indicates that the level of European countries in this research area of manufacturing servitization is high. The number of publications in Northern Europe is small, but those papers have a strong influence.

Table 1. The top 20 places with the most publications in manufacturing servitization research.

Rank	Country/Region	TP [1]	TC [2]	ACPP [3]	IF [4]
1	USA	930	34,142	36.71	4.88
2	China Mainland	760	16,071	21.15	4.62
3	UK	501	20,349	40.62	5.13
4	Italy	198	5319	26.86	4.48
5	Spain	196	4362	22.72	4.45
6	Germany	184	5906	32.10	4.73
7	Sweden	148	6470	43.72	5.68
8	Canada	136	3716	27.32	4.65
9	Taiwan	134	2447	18.26	4.07
10	Australia	122	3158	25.89	4.56
11	South Korea	116	1108	9.55	3.91
12	France	112	5378	48.02	5.08
13	Netherlands	111	5115	46.08	6.61
14	Finland	110	4319	39.26	6.21
15	India	92	2673	29.05	4.35
16	Switzerland	73	4082	55.92	5.08
17	Japan	64	939	14.67	3.88
18	Turkey	62	768	12.39	3.82
19	Singapore	60	1794	29.90	4.88
20	Iran	59	964	16.34	4.03

TP [1]: total publications; TC [2]: total citations; ACPP [3]: average citations per publication; IF [4]: average impact factor per publication.

As Figure 3 shows, the USA, Germany, and Canada are the research countries that published the most documents on manufacturing servitization. From 1990 to 1999, a few papers were published by a small number of countries each year. It can be inferred that manufacturing servitization was still an unpopular research direction at that time or that the research results were insignificant. After 2000, the number of papers in this direction ushered in explosive growth. Although China, Italy, Sweden, France, and Finland started quite late on the servitization of manufacturing, their steady increase in the number of their published documents since 2000 has contributed significantly to this field of research.

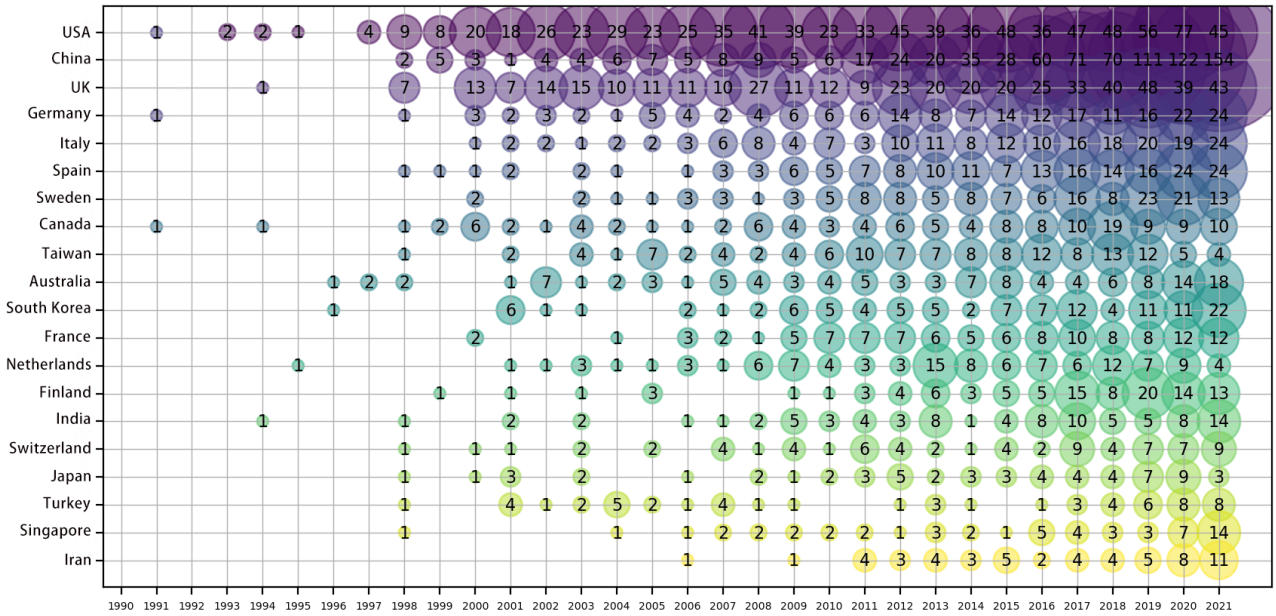

Figure 3. The bubble chart of the top 20 productive countries/regions by year.

As shown in the Figure 4, this cross-correlation chart illustrates the collaboration across the 20 countries. The connecting lines represent their correlation, with thicker lines indicating a greater correlation between them. The size of the yellow circles is positively correlated with the number of papers published in that country. The USA has the highest number of published papers and is the dominant country of cooperation among 107 countries or regions. In addition, countries such as Finland, Sweden, and Switzerland have close collaboration with each other, indicating that the Nordic region also pays more attention to the servitization of manufacturing. Recently, Chinese researchers have closely cooperated with Taiwan, Japan, Canada, Australia, and other countries or regions, demonstrating a successful development.

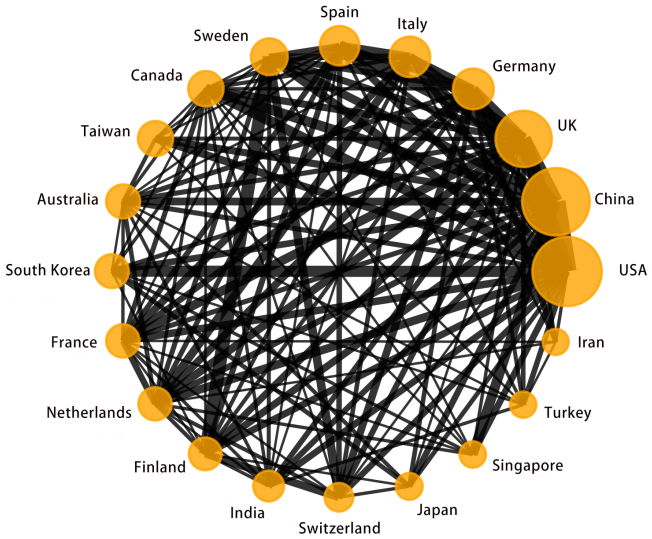

Figure 4. The cross-relationship chart of the top 20 countries/regions.

3.2. The Main Research Fileds

The applicability of "manufacturing servitization" can be reflected in the relevant field. The 3767 papers retrieved from WoS cover 183 research areas, indicating that the area of manufacturing servitization has been widely studied. Table 2 lists the top 20 research areas with the most publications in manufacturing servitization, where "business and economics" ranks the list with 1565 papers, accounting for 41.54%, and its average citations per publication (ACPP) is 36.63. It is followed by "engineering", with a total of 1262 related studies, accounting for 33.50%, then "operations research & management science" (564, 14.97%), "computer science" (550, 14.60%), "environmental science and ecology" (366, 9.72%). Although the published articles "Robotics" and "automation & control systems" are only 48 and 135, respectively, their ACPP is 40.15 and 41.31.

Table 2. The 20 research fields with the most publications during 1990–2021.

Rank	WoS Research Area	TP	TPR (%) [1]	TC	ACPP
1	Business & Economics	1565	41.54	57,329	36.63
2	Engineering	1262	33.50	39,433	31.25
3	Operations Research & Management Science	564	14.97	22,453	39.81
4	Computer Science	550	14.60	16,181	29.42
5	Environmental Sciences & Ecology	366	9.72	10,196	27.86
6	Science & Technology	212	5.63	4905	23.14
7	Materials Science	167	4.43	5359	32.09
8	Automation & Control Systems	135	3.58	5577	41.31
9	Public Administration	118	3.13	3228	27.36
10	Geography	103	2.73	3101	30.11
11	Mathematics	89	2.36	1592	17.89
12	Telecommunications	77	2.04	1638	21.27
13	Public, Environmental & Occupational Health	70	1.86	1723	24.61
14	Development Studies	65	1.73	1135	17.46
15	International Relations	65	1.73	899	13.83
16	Urban Studies	60	1.59	1840	30.67
17	Social Sciences	55	1.46	1366	24.84
18	Physics	53	1.41	771	14.55
19	Information Science & Library Science	50	1.33	1671	33.42
20	Robotics	48	1.27	1927	40.15

TPR (%) [1]: the percentage of articles of areas in total articles.

Figure 5 shows the development trend of manufacturing servitization. The earliest paper on the servitization of manufacturing was published in "computer science", "business and economics", "engineering", "operations research and management science", and "computer science" were the study areas for fewer than 15 papers per year before 2000. From 2001 to 2010, the number rose and began to surge in 2010. In 2020, the number of publications of "business and economics" boosted to 134. The "environmental sciences and ecology", "science and technology", and "material science" were the research areas for fewer papers before 2000, but after 2000, they began to increase at a stable speed. In the past five years, the main research direction of manufacturing servitization has been "business and economics" and "engineering", which are the top two areas with the most publications. "computer science" and "environmental sciences and ecology" ranked fourth and fifth, respectively, and have also emerged as significant research areas for the servitization of manufacturing.

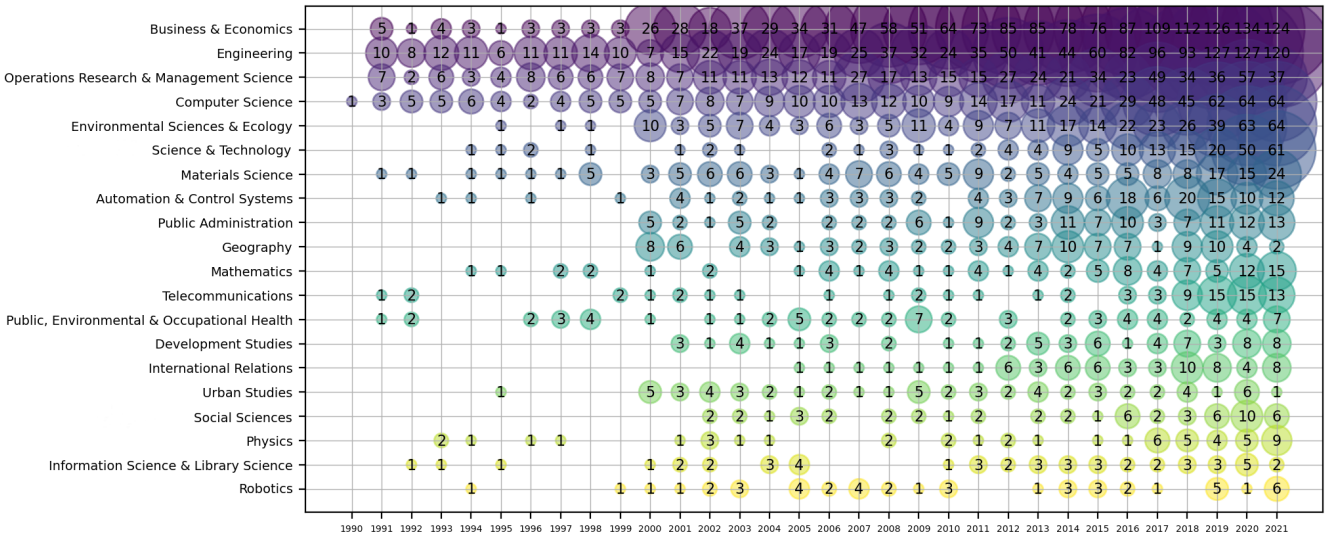

Figure 5. The bubble chart of the top 20 research fileds by year.

Figure 6 indicates that the documents belonging to "engineering" have close links to other research areas in the top 20, except "public administration", "public, environmental & occupational health", "mathematics", and "urban studies", and "social sciences". It was followed by "business and economics", which extensively links with 15 other research fields. The strong cross-correlation among the five top areas "business and economics", "engineering", "operations research and management science", "computer science", and "environmental sciences & ecology" indicates that they appear together with high frequency. Besides the strong cross-correlations of the above study areas, the weak crossover of "automation & control systems", "social science", "geography", and "international relations" also needs to be considered, representing the potential research relevance among these research fields.

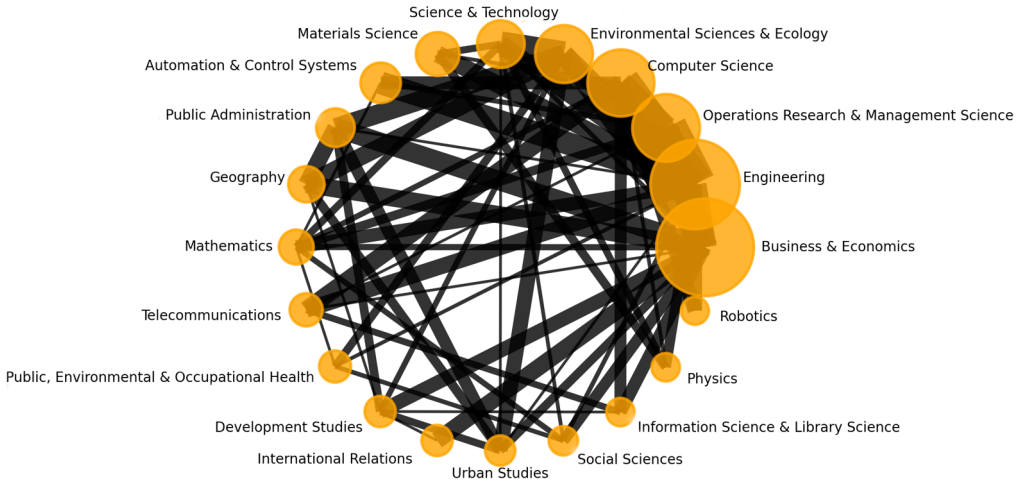

Figure 6. The cross-relationship chart of the top 20 research areas.

3.3. The Leading Journals

It is significant for researchers who study manufacturing servitization to know which journals relate to it. From 1990 to 2021, 3767 articles were published in 2536 journals on the servitization of manufacturing. As Table 3 shows, the *International Journal of Production Research* has the most comprehensive documents of manufacturing service information (80, 2.12%), and its ACPP is 29.33. This is succeeded by the *International Journal of Production Economics* (78, 2.07), *Sustainability* (77, 2.04), the *International Journal of Advanced Manufacturing Technology* (77, 2.04), etc. The top 10 journals collectively published 16.46% of the total literature, while the rest of each journal was less than 1%. The *International Journal of Operations & Production Management* has the largest ACPP with 62.98, followed by the *International Journal of Production Economics* (62.09), *Industrial Marketing Management* (55.82) and *Small Business Economics* (44.45), and the average citations of publications are over 44. In terms of the IF of journals, the *International Journal of Cleaner Production* ranks first with 7.597, and it is followed by *Computers in Industry* (7.247), and *International Journal of Production Economics* (7.079) and *Small Business Economics* (7.005).

Table 3. The 20 journals with most publications in manufacturing servitization.

Rank	Journal	TP	TPR (%)	TC	ACPP	IF
1	International Journal of Production Research	80	2.12	2346	29.33	6.091
2	International Journal of Production Economics	78	2.07	4843	62.09	7.079
3	Sustainability	77	2.04	645	8.38	2.355
4	International Journal of Advanced Manufacturing Technology	77	2.04	2761	35.86	2.406
5	International Journal of Computer Integrated Manufacturing	62	1.65	1201	19.37	2.795
6	Journal of Business Research	54	1.43	2235	41.40	6.74
7	Journal of Cleaner Production	54	1.43	2250	41.67	7.597
8	International Journal of Operations & Production Management	49	1.30	3086	62.98	5.937
9	Industrial Marketing Management	45	1.19	2512	55.82	4.95
10	Computers & Industrial Engineering	44	1.17	1018	23.14	4.728
11	Robotics and Computer-integrated Manufacturing	36	0.96	1557	43.25	4.753
12	IEEE Access	34	0.90	388	11.41	2.454
13	Journal of Intelligent Manufacturing	31	0.82	732	23.61	5.107
14	Regional Studies	31	0.82	785	25.31	4.033
15	Total Quality Management & Business Excellence	30	0.80	626	20.85	3.223
16	Computers in Industry	30	0.80	1222	40.73	7.247
17	Service Industries Journal	27	0.72	536	19.85	5.275
18	M&SOM-Manufacturing & Service Operations Management	26	0.69	472	18.14	6.32
19	Research Policy	26	0.69	399	15.33	4.725
20	Small Business Economics	26	0.69	1156	44.45	7.005

As Figure 7 shows, the most published journal is the *International Journal of Production Economics*, which focuses on SCM, sustainability, the IoT, etc. Sustainable supply management: An empirical study, published by Ageron et al. [33] in 2012, has been cited 314 times in terms of supply chain management. In an article published in 2011, Blome et al. [34] proposed the frameworks and methods to help companies deal with supply chain risks in the production crisis. Saccani et al. [35] explored the options for after-sales and supply chain configurations by studying seven manufacturing companies. In this area of service operation management, Gunasekaran et al. [36] published an article in 2012 that was cited 110 times; it studied the development of operation management and developed a framework for a new operations management strategy to improve the internal competitiveness of enterprises.

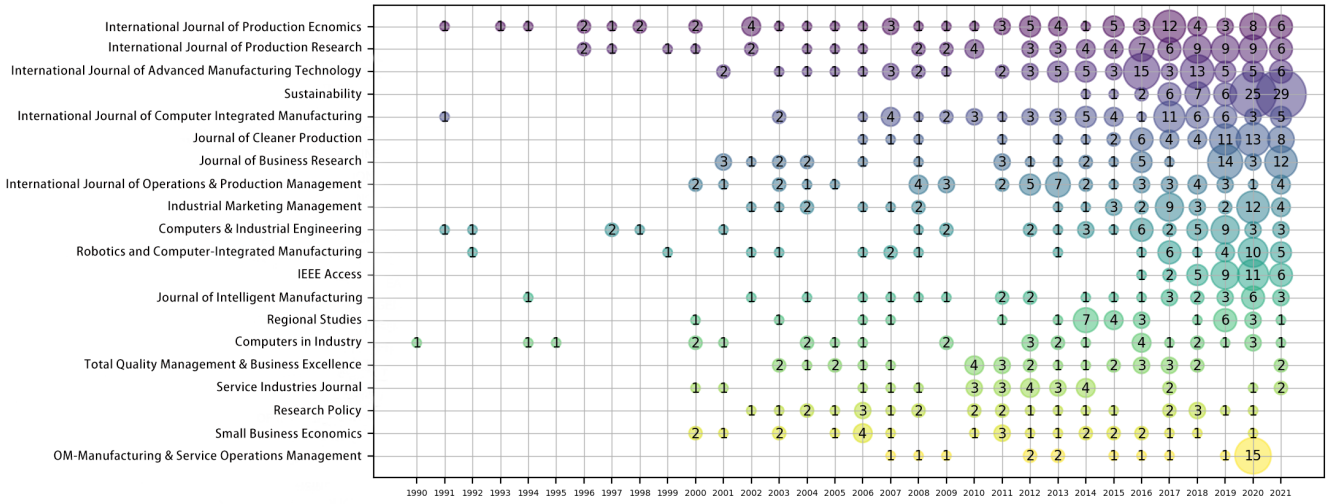

Figure 7. The bubble chart of the top 20 journals by year.

They were followed by the *International Journal of Production Research*. The second most cited literature was published in 2018 by Moeuf et al. [37] with 328 citations which concluded that small and medium-scale corporations do not have enough resources to implement Industry 4.0 but only on cloud computing (CC) and the IoT. Second, Ardolino et al. [38] examined how the IoT, CC, and predictive analytics (PA) can facilitate the servitization of manufacturing through developing digital technologies in a business case. Gunasekaran and Yusuf [39] presented agile manufacturing and pointed out that the feature of the servitization process based on agile manufacturing is an integration of product design, production, marketing, and support services between the whole customer and supplier. Theorin et al. [40] proposed using a line information system architecture model that can help enterprises build the Industrial Internet of Things to make decisions based on factory data.

Figure 8 shows the top 20 most productive publishers. Elsevier is the publisher of the most articles, with 985 documents (26.15%), followed by Taylor and Francis with 510 papers (11.54%) and Springer with 388 documents (10.30%). Emerald Group Publishing ranks fourth with 289 publications (7.67%), followed by Wiley (269, 7.14%) and MDPI (135, 3.58%).

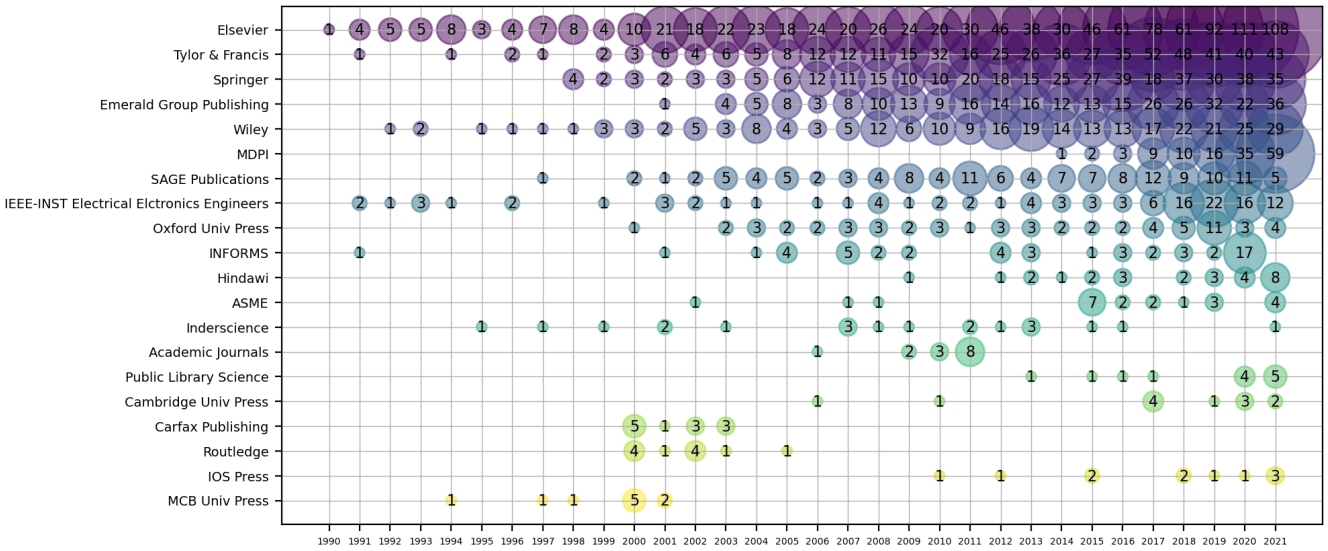

Figure 8. The bubble chart of the top 20 productive publishers by year.

3.4. Analysis of Keywords

The 6112 keywords were analyzed to reveal the research hotspots and trends in manufacturing servitization. The results demonstrated extensive research interest related to manufacturing services, and the most used 20 keywords are shown in Figure 9. In this paper, "services" is the most frequently used keyword, mainly service marketing, service resource combination strategies, and product-service systems. Since 1999, it has continuously increased for over 20 years and has been used 262 times. Among them, 63 articles with more than one hundred citations each. In 1999, Meyer [41] presented introduced the concept of product services and elaborated on these ideas through a comprehensive analysis of different industry cases. In 2008, Tao et al. [42] proposed that in distributed manufacturing systems, especially in manufacturing grid systems, tasks that require multiple service resources to be invoked in a specific order can be accomplished by gathering only one service resource. For product service systems (PSS), a paper by Tukker [43] reviewed the major literature about PSS, delving into the framework for building PSS and the key factors and types of businesses for which they are implemented. In 2011, Gao et al. [44] proposed that service and physical products be integrated into the PSS to provide customers with comprehensive solutions, and the characteristics and evolution of various product-service systems are discussed. The theories about the organizational complexity–innovation relationship were explained in greater detail in a paper published by Damanpour [45].

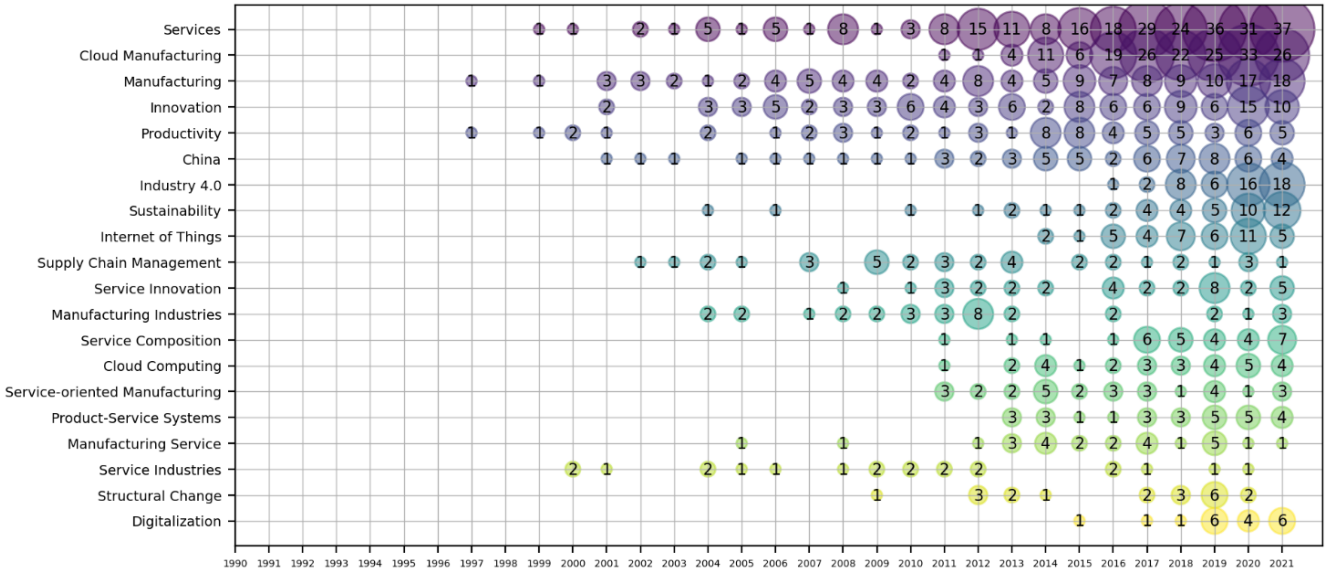

Figure 9. The bubble chart of the top 20 keywords.

Another top keyword, "cloud manufacturing", first appeared in 2011 and has been used 174 times over the past ten years. As of 2021, 6 articles with "cloud manufacturing" as the keyword have been cited more than 100 times. The paper published by Tao et al. [46] describes the architecture and key technologies through several classical service models based on cloud manufacturing and analyzes its advantages and potential challenges. An article published by Wu et al. [47] in 2013 has 372 citations with an ACPP of 41.33. In the same year, the literature was published by Wang et al. [48] in 2013, which was cited 214 times, with an ACPP of 23.78.

"Manufacturing" (131 times), as the earliest keyword, was also the focus of research, especially in the last nine years (from 2012 to 2021), and the citations of 8 documents have exceeded 100 times. Tao et al. [49] proposed a big data-driven service model for manufacturing and illustrated the application architecture and methods of the digital twin (DT), which enables the management of the entire product lifecycle. It has 759 citations, with an ACPP of 253. In 2017, Rymaszewska et al. [5] presented to add the IoT to the

organization of a company's production process and to expand its service chain through big data to obtain better benefits which was cited 180 times with an ACPP of 45.

The keyword "innovation" first appeared in 2001, and the number of papers increased steadily after 2005. The research content included service innovation, product innovation, enterprise internal organizational structure innovation, and 25 articles with no less than 100 citations. In a paper published by Low et al. [50] in 2001, a solution was introduced to generate an innovative service environment through the Teoriya Resheniya Izobreatatelskikh Zadatch (TRIZ) model and provided a solution centered on service ecology. In 2009, Van et al. [51] proposed that the most critical challenge of open innovation is related to enterprises' internal organization and corporate culture, which was 1026 citations, with an ACPP of 78.92.

"Productivity" (ranked fifth, 65 times) was also among the earliest keywords used. Arnold et al. [52] investigated the relationship between service intensity inputs and manufacturing productivity and showed a positive correlation, which provides a theoretical basis for continuing to accelerate the servitization of manufacturing. As a mainstay and primary market of the manufacturing industry, "China" (ranked sixth, 60 times) has been widely studied, and Wang [53] explored the potential mechanism between Western relationship marketing and Chinese relationship. "Industry 4.0" (ranked seventh, 51 times) is one of the significant study hotspots in recent years.

The articles with "supply chain management" (ranked tenth, 36 times) as the keyword received the highest number of citations at 323. Frohlich and Westbrook [54] studied the relationship between supply chain integration strategies supporting the internet and manufacturing and service performance. Olhager [55] proposed a supply chain model about the order penetration point, and the factors considered by manufacturing enterprises, such as customer service, manufacturing efficiency, and inventory cost, were taken as factors affecting the model. Pettit [56] proposed a novel supply chain assessment tool that has been validated on several manufacturing industries' supply chain management capabilities worldwide, which is used to evaluate the degree of supply chain stability.

It is worth mentioning that the two keywords "Industry 4.0" (ranked seventh, 51 times) and "Internet of Things" (ranked ninth, 41 times) first appeared in this paper published by Yue et al. [57] in 2015. They proposed a new model of industrial network-based information systems. It analyzed the development trend of information and communication technology and explored how to effectively improved service capability under its application. In 2014, Tao et al. [58] established a production model architecture that integrates cloud computing, IoT, and cloud manufacturing analyzes its application methods, and concludes that it has the advantage of optimizing resource allocation. It has received an enormous amount of citations with 459. Followed by Tao et al. [59], studied the correlation between cloud manufacturing and IoT and proposed an architectural model based on IoT fused cloud manufacturing, which was cited 422 times.

As Figure 10 shows, "services" are associated with almost all other keywords, especially "product-service systems (PSS)" and "service innovation". "Cloud manufacturing" was linked to most other keywords, except "structural change" and "supply chain management". "Service composition" had a strong relationship with "cloud manufacturing". Huang et al. [60] proposed a new approach for solving combinatorial optimization problems in CC services and demonstrated its superiority through simulation and comparison with other classical algorithms. "Manufacturing industries" and "service industries" also are highly relevant. Schmenner [61] reviewed the development of servitization and analyzed the relationship between manufacturing and service industries in different stages of history and the reasons for their formation. Not only "cloud manufacturing", "CC" and "IoT" and smart manufacturing also have a strong correlation. Tao and Qi [62] proposed using information technology to assist the manufacturing, accelerating the development of manufacturing services under smart manufacturing.

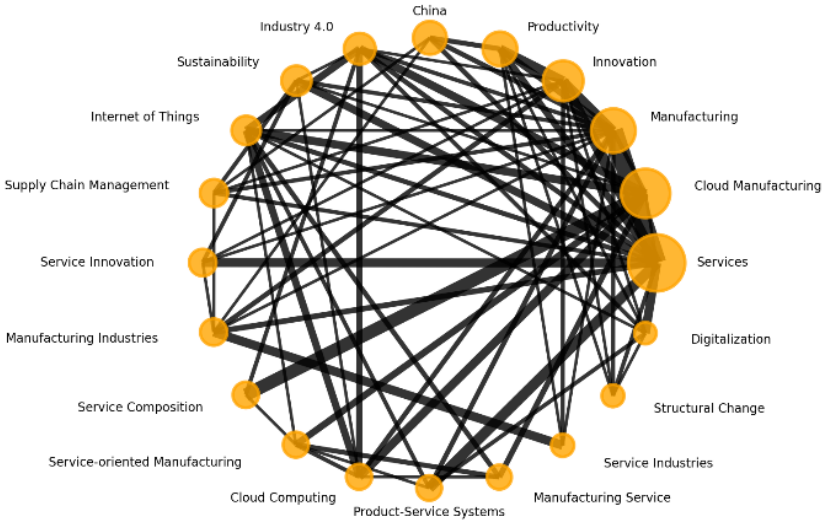

Figure 10. The cross-relationship chart of the top 20 keywords.

3.5. The Leading Institutions

Table 4 shows the 20 institutions with the most publications in manufacturing servitization from 1990 to 2021. The most productive institution was Beihang University, China, with 71 published papers accounting for 1.88% of the total publications; the University of Vaasa, Finland, and the University of California System, the USA, tied for second place with 47 articles, 1.25%; and the University of London and the University of Cambridge, two UK institutions, tied for third place with 44 articles, 1.17%. Concerning ACPP, the State University System of Florida, the USA, ranked highest at 68.19, followed by Beihang University, China (66.93), Linkoping University, Sweden (65.58), and the University of Cambridge, the UK (62.98); except for these four institutions, all other ACPP were below 60.

Table 4. The 20 institutions with most publications in manufacturing servitization.

Rank	Institutions	TP	TPR (%)	TC	ACPP	H-Index	Country/Region
1	Beihang University	71	1.88	4752	66.93	29	China Mainland
2	University of Vaasa	47	1.25	1970	41.91	26	Finland
3	University of California System	47	1.25	1616	34.38	18	USA
4	University of London	44	1.17	1665	37.84	19	UK
5	University of Cambridge	44	1.17	2771	62.98	24	UK
6	Lulea University of Technology	43	1.14	1585	36.86	23	Sweden
7	University of Birmingham	42	1.11	1295	30.83	19	UK
8	Xi'an Jiaotong University	41	1.09	875	21.34	16	China Mainland
9	Zhejiang University	40	1.06	663	16.58	14	China Mainland
10	Shanghai Jiao Tong University	39	1.04	1389	35.62	14	China Mainland
11	Linkoping University	38	1.01	2492	65.58	25	Sweden
12	State University System of Florida	37	0.98	2523	68.19	16	USA
13	Hong Kong Polytechnic University	35	0.93	1229	35.11	16	Hong Kong
14	Tsinghua University	34	0.90	789	23.21	13	China Mainland
15	Chinese Academy of Sciences	33	0.88	1457	44.15	16	China Mainland
16	University of Manchester	32	0.85	1827	57.09	20	UK
17	University System of Georgia	31	0.82	1722	55.55	15	USA
18	University of Michigan System	30	0.80	1412	47.07	19	USA
19	Aston University	29	0.77	1573	54.24	19	UK
20	University of Michigan	28	0.74	1288	46.00	18	USA

The top 20 institutions are from 5 countries, of which seven belong to China, accounting for 35%, indicating that China has gradually become a dominant country related to the research of manufacturing services. The USA and the UK also have obvious advantages, with five institutions each (25%), significantly contributing to the servitization of manufacturing literature.

3.6. The Leading Authors

Table 5 shows the 20 authors with the most publications in manufacturing servitization. Tao, Fei, from Beihang University, China, was the most productive author with 37 articles (0.98%), followed by Zhang, Lin, Beihang University, China (32, 0.85%) and Parida, Vinit, Lulea University of Technology, Sweden (24, 0.64%). Regarding the ACPP, Tao, Fei also has the highest ACPP with 106.19. He was then followed by Baines, Tim, Aston University, UK (100.09) and Gebauer, Heiko, Swiss Federal Institute of Aquatic Science & Technology (EAWAG), Swizerland (91.20).

Table 5. The 20 authors with the most publications in manufacturing servitization.

Rank	Author	TP	TPR (%)	TC	ACPP	H-index	Institution, Country/Region
1	Tao, Fei	37	0.98	3929	106.19	22	Beihang University, China Mainland
2	Zhang, Lin	32	0.85	2673	83.53	21	Beihang University, China Mainland
3	Parida, Vinit	24	0.64	885	36.86	16	Lulea University of Technology, Sweden
4	Gebauer, Heiko	21	0.56	1915	91.20	10	Swiss Federal Institute of Aquatic Science & Technology (EAWAG), Swizerland
5	Kohtamaki, Marko	20	0.53	836	41.81	14	University of Vaasa, Finland
6	Cheng, Ying	15	0.40	1160	77.33	13	Beihang University, China Mainland
7	Zhang, Wenyu	15	0.40	168	11.20	8	Zhejiang University of Finance & Economics, China Mainland
8	Zhang, Shuai	15	0.40	168	11.20	8	Zhejiang University of Finance & Economics, China Mainland
9	Vendrell-Herrero,Ferran	14	0.37	557	39.80	10	University of Birmingham, UK
10	Baines, Tim	13	0.35	1301	100.09	11	Aston University, UK
11	Zhang, Yingfeng	13	0.35	452	34.79	9	Northwestern Polytechnical University, China Mainland
12	Bustinza, Oscar F.	13	0.35	776	59.73	12	University of Granada, Spain
13	Yao, Xifan	12	0.32	475	39.58	8	South China University of Technology, China Mainland
14	Wang, Lihui	12	0.32	1060	88.36	9	Royal Institute of Technology, Sweden
15	Huang, George Q.	11	0.29	544	49.42	9	University of Hong Kong, Hong Kong
16	Zhou, Zude	11	0.29	268	24.40	7	Wuhan University of Technology, China Mainland
17	Jiang, Pingyu	11	0.29	221	20.09	7	Xi'an Jiaotong University, China Mainland
18	Kowalkowski, Christian	10	0.27	903	90.30	9	Linkoping University, Sweden
19	Xu, Xun	10	0.27	775	77.50	10	University of Auckland, New Zealand
20	Jiang, Zhibin	10	0.27	107	10.73	6	Shanghai Jiao Tong University, China Mainland

It is worth noting that the first two authors and the sixth author have close collaboration relationships because they published 12 articles [58,63–73] together, and all three come from Beihang University, China. Zhang, Wenyu and Zhang, Shuai, both from Zhejiang University of Finance and Economics in China, are coauthors of 15 articles [74–88] on the servitization of manufacturing. Notably, Parida, Vinit not only holds a position at the Lulea University of Technology, Sweden, but he has also worked as a visiting professor at the University of Vaasa, Finland. Therefore, he cooperated deeply with Kohtamaki, Marko, a professor at the University of Vaasa, Finland; they jointly published ten articles [4,89–97] on the servitization of manufacturing. In addition, Kohtamaki, Marko, University of Vaasa, Finland, Parida, Vinit, Lulea University of Technology, Sweden, and Gebauer, Heiko, Swiss Federal Institute of Aquatic Science & Technology, Switzerland, have a close cooperative relationship with each other.

As Figure 11 shows, Gebauer Heiko published four articles [98–101] in 2007, which provided relevant insights on marketing strategies and service improvements to help manufacturing companies shift to servitization.

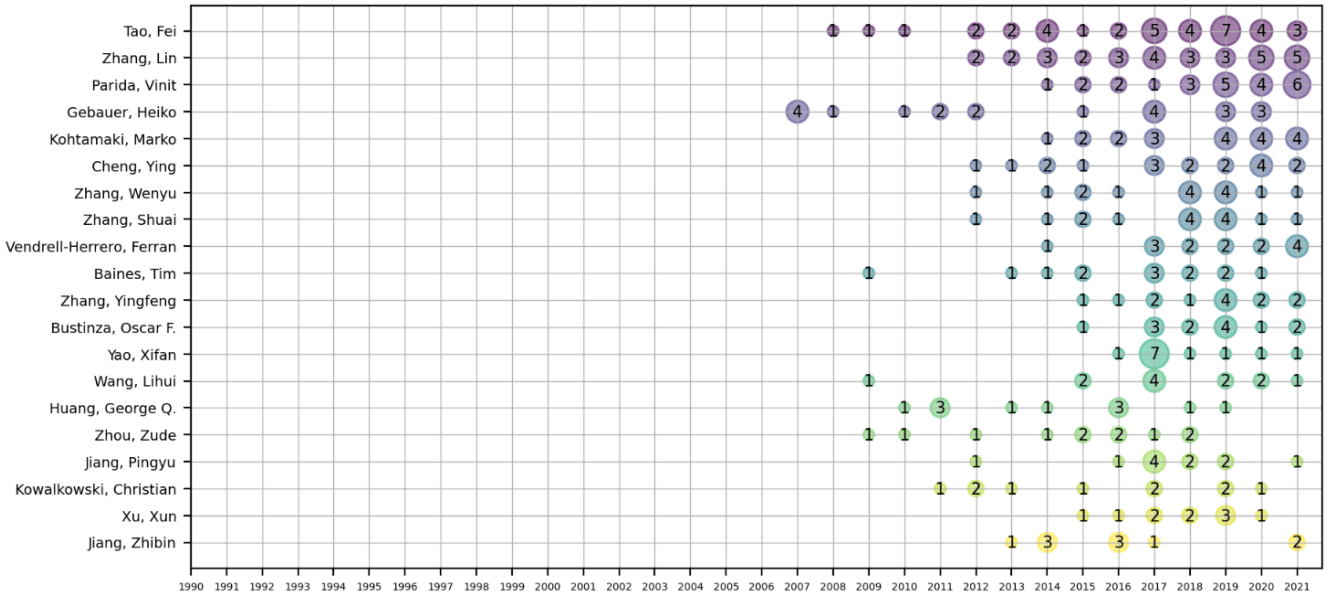

Figure 11. The bubble chart of the top 20 productive authors by year.

In 2008, Tao published his first paper on manufacturing servitization. Since 2012, Tao began cooperating with Zhang and continuously output beneficial views for manufacturing servitization. Three authors, Cheng, Zhang, and Zhang, published a steady number of articles per year and were the most important contributors to the servitization of manufacturing from 2012 to 2021. In addition, the annual publications of other authors have been relatively stable since 2014.

3.7. The Most Cited Publications

The indicator of the quantity of cited is used to measure the value of this work. From 1990 to 2021, the citations of 247 documents exceeded 100 times (6.56%), the citations of 294 articles were 50–99 (7.80%), and the citations of 561 papers were 25–49 (14.89%). Table 6 shows the 20 literature with the most citations in manufacturing services from 1990 to 2021. The first literature appeared in 2000, and the latest one in 2018. Three of them were published by the same author, Fei Tao, and two of them were published in the *IEEE Transactions on Industrial Informatics*. The most cited article was published by Combs et al. [102] in 2006. The literature presents a meta-analysis methodology to systematically assess the impact of superior workability on manufacturing and service organizations.

The second most cited paper was published by Van de Vrande et al. [51] in 2009, with 1024 citations. In this work, the management challenges faced by small and medium scale corporations in the process of open innovation are discussed

Additionally, in 2009, the article published by Hertwich and Peters was cited 967 times and ranked third. The study quantified greenhouse gas (GHG) in 73 countries and 14 regions from the perspective of carbon emissions, analyzed the effects of eight categories, including manufactured products, services, and trade, and provided some compiled statistics and insights into the global carbon cycle that will help in future green manufacturing research.

Table 6. The top 20 most cited publications related to manufacturing service research.

Rank	Author	Journal	TC	TCY [1]	Year
1	Combs et al. [102]	Pers. Psychol.	1118	74.53	2006
2	Van de Vrande et al. [51]	Technovation	1024	68.27	2009
3	Hertwich and Peters [103]	Environ. Sci. Technol.	967	64.47	2009
4	Desimone [104]	Science	829	55.27	2002
5	Tukker [43]	J. Clean. Prod.	768	51.20	2015
6	Tao et al. [49]	J. Adv. Manuf. Technol.	756	50.40	2018
7	Wang et al. [105]	Int. J. Distrib. Sens. Netw.	734	48.93	2016
8	Grant and Parker [106]	Acad. Manag. Ann.	612	40.80	2009
9	Holweg [107]	J. Oper. Manag.	587	39.13	2007
10	Westhead et al. [108]	J. Bus. Ventur.	579	38.60	2001
11	Colombo and Grilli [109]	Res. Policy	560	37.33	2005
12	Rose [110]	J. Press. Vess.-T. ASME	533	35.53	2002
13	Frank et al. [111]	Int. J. Prod. Econ.	505	33.67	2019
14	Siddique et al. [112]	Waste Manag	472	31.47	2008
15	Boyer [113]	Econ. Soc.	466	31.07	2000
16	Tao et al. [58]	IEEE Trans. Ind. Inform.	459	30.60	2014
17	Homburg andFurst [114]	J. Mark.	448	29.87	2005
18	Oliveira et al. [115]	Inf. Manage.	435	29.00	2014
19	Ageron et al. [33]	Int. J. Prod. Econ.	429	28.60	2012
20	Tao et al. [59]	IEEE Trans. Ind. Inform.	421	28.07	2014

[1] TCY: total citations per year.

4. Implication for Future Research

As shown in Figure 12, the concept of the servitization of manufacturing was proposed and put into practice 30 years ago, and the number of publications from 2000 to 2010 steadily increased. Since 2010, an increasing quantity of scholars have been attracted to studying this field, and the research results of manufacturing servitization have been continuously enriched. In the era of Industry 4.0, servitization-based manufacturing has become interdisciplinary with the potential for development in multiple directions. This work is considered the first article to discuss the sustainability of manufacturing around servitization using bibliometric analysis. It also makes the following suggestions for the future development of servitization in manufacturing regarding research areas, collaboration, and future application trends.

Figure 12. The quantity of publications in manufacturing servitization by year.

First, future directions for the exploration of manufacturing servitization are suggested based on the bibliometric analysis.

Secondly, specific suggestions for cooperative development among different disciplines are proposed based on its current status as an interdisciplinary discipline.

Finally, the research directions for future applications of manufacturing servitization are analyzed.

4.1. A Research Areas Perspective

As shown in Table 2, business and economics are the main research fields of manufacturing servitization. Business and economics are constantly seeking to maximize profits. The manufacturing servitization is a good method to integrate service as the last component of goods into the whole life cycle of products to improve enterprise benefits. Therefore, manufacturing servitization can be explored more widely and deeply from different perspectives, such as , complaint management [114], cloud computing [115], lean production [116], value streams [117], service business models [118], balanced growth models [119], and operations management (OM) [120].

The intersections between different fields bring many research opportunities for the development of manufacturing services; in addition to business and economics, engineering, operations research and management science, computer science and environmental sciences, and ecology, which also have strong cross-relationships. There are also essential references between disciplines with weak cross-relationships, such as robotics, physics, information science and library science, social sciences, urban studies, and other research fields. As the Figure 5 shown, the strong intersecting relationships represent hot research areas, while weak intersecting areas represent potential study fields.

4.2. A Cooperative Perspective

Currently, the field of manufacturing servitization is flourishing, and many disciplines are excelling in manufacturing service, such as the combination of Automation control systems and lean production, which has produced the smart factory, and the IoT combined with simulation technology, which has produced the digital twin. In the era of Industry 4.0, there are many other examples where the combination of different disciplines has been well developed. Based on the previous analysis, researchers in the field of the IoT and big data can collaborate and continue exploring this direction's potential. Researchers in other related directions, such as CMfg, CC, and DT, can collaborate to facilitate the development of these directions. Researchers in different countries or regions and different directions can also actively collaborate to advance the areas of manufacturing servitization.

The analysis results show that the USA, China, the UK, Germany, and Italy are the countries that contribute the most to the literature on manufacturing servitization. They have the highest number of publications and cooperate closely with each other and with other countries. Iran, Singapore, Turkey, and Japan are the countries that have published a few papers and have relatively weak cooperative relationships with other countries. The three Nordic countries, Sweden, the Netherlands, and Finland have a very close cooperative relationship. Beihang University has the most publications and established a close cooperative network, which continues to produce high-quality papers every year. Tables 4 and 5 and Figure 11 point out the institutions and authors with the highest number of publications in the direction of manufacturing servitization. It provides suggestions for researchers from different institutions and research directions to collaborate to achieve better development in manufacturing servitization.

4.3. The Future Application Trends Perspective

The research hotspots in manufacturing servitization have changed over time. The results in Sections 3.4 and 3.7 show that manufacturing and productivity are enduring research directions, while Industry 4.0 and sustainability are emerging hotspots that have attracted increasing attention from scholars. Services, cloud manufacturing, and innovation, including servitization, digital, and business models, are the prevalent topics and have attracted scholarly interest in the past few years.

Figure 13 shows the top 20 topics with the most vigorous citation bursts, which are used to visually show the drop or rise of detected citation topics or keywords over time.The cyan line represents the period from 1990 to 2021. The red line represents the period when the keyword was used most frequently. The length of the red line represents how long the keyword has been popular. The keyword corresponding to the red line on the far right is the most studied now. Similar to the results given in Section 3.4, value cocreation, business model, and production service system are high-frequency phrases in the last three years that play a key role in manufacturing services. On the other hand, the internet, big data, and cyber-physical systems are constantly being proposed and discussed, including digital twins (Tao et al. [49], 2018), smart factories (Wang et al. [105], 2016) and Industry 4.0 (Frank et al. [111], 2019). Recently, with the Internet of Things, cloud services, big data analytics, and other topics becoming hotspots, the future development trend of manufacturing servitization will prosper in applications of digitization and informatization.

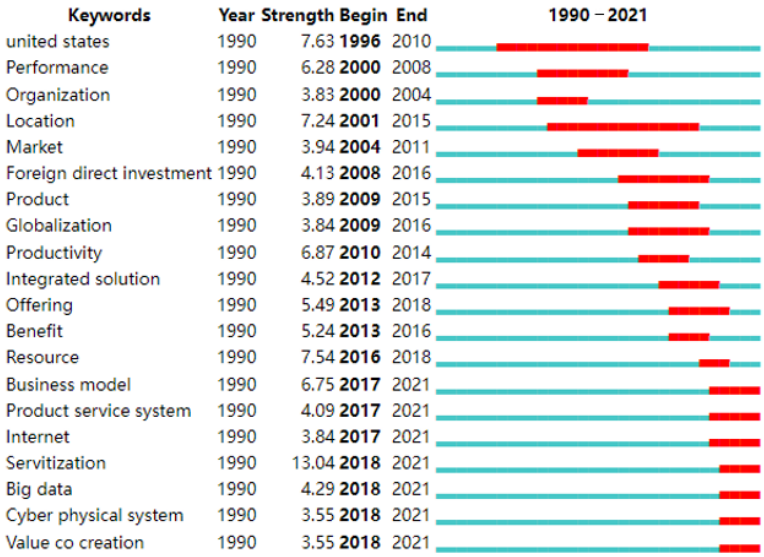

Figure 13. The top 20 keywords with the strongest citation bursts.

Germany's "Industry 4.0", the United States' "Industrial Internet", and "Made in China 2035" all take manufacturing servitization as the strategic core and strive to improve the value chain of enterprises through manufacturing servitization. With the development of artificial intelligence, cloud manufacturing, big data, IoT, and intelligent manufacturing will be popular research directions for manufacturing services in the coming period. An increasing number of enterprises are considering combining emerging advanced manufacturing technologies (such as CC, IoT, virtualization, and advanced computer technology) with current "informatization technology" manufacturing modes to provide better customer service. In addition, service, service marketing, service resource portfolio strategy, and product-service system innovation will always be essential directions of manufacturing service research. Through the limited resources of service to maximize the provision of the best service to customers, the use of effective service operates to obtain adequate customer information for enterprises. Enterprises are also concerned about supply chain management and total quality management. In the process of manufacturing servitization, outstanding product quality is used to gain the trust of customers. The SCM is used to evaluate the flexibility of a enterprise's supply approach in the face of complex customer needs and reduce supply chain risks. The multi-objective mixed-integer linear programming models and meta-heuristic algorithms have also shown promising results in solving the SCM problem [121,122], which also reflects the current status of multidisciplinary integration of manufacturing servitization.

To show the development of manufacturing servitization research hotspots over time, some important information is organized in Figure 14. In 2002, Cano et al. [123]

researched the relationship between market positioning and firm performance in a global context through a meta-analysis and analyzed some reasons for the continuous shift from manufacturing to service.

Figure 14. The articles about the field of manufacturing servitization [2,3,47,123–138] .

In 2004, Lan [124] proposed a networked manufacturing service system structure to develop a Web-based information service system that can help manufacturing create a collaborative production environment to solve production scheduling planning problems.

In 2005, Gebauer et al. [125] proposed that the main reason for servitization was to achieve better financial performance and that the complete servitization management of manufacturing enterprises required an interdisciplinary theory combining service management with a behavioral approach.

In 2008, Neely and Andy [126] believed that manufacturing servitization was creating service value through the innovation in a firm's product life cycle, from selling products to providing PSS or a more complete market package.

In 2009, Baines et al. [2] introduced lean thinking into PSS operation management under the new information technology environment, aiming to reduce waste and waiting and improve reliability and service level.

Wu et al. [47]introduced cloud manufacturing and its closely related fields and proposed that the service function of cloud manufacturing for the industry drives the innovation of manufacturing production models. In 2015, Opresnik and Taisch [3] put forward a two-stage model of "data generation-data application" to analyze the process of manufacturing services and value creation under big data application: by collecting and analyzing customers' data, they can perceive changes in customers' behaviors, and then provide customers with new services and create new revenue streams.

In 2016, Huxtable and Schaefer [127] proposed that with the support of big data technology, enterprises can design novel service modes, including condition monitoring, preventive diagnosis, data sales, advanced pricing model, big data consulting, big data outsourcing and so on to expand the product-service system. In 2017, Lu et al. [128] presented a sustainable scheduling problem for welding shops from balancing economic and environmental development. It solved it using a novel multi-objective algorithm with an energy-saving strategy, providing a new approach to green manufacturing. In 2018, Lim et al. [129] have shown that by collecting customer behavior data (such as operation records) and product status data (such as operation parameters), enterprises can obtain helpful information (such as product operating status) by processing these data, thus realizing fault warnings and ensuring the smooth operation of products.

In 2019, Tao et al. [130] believed that the main technical issue in achieving smart manufacturing is how to share data efficiently in real-time. He reviewed the development of the digital twin and CPS in several aspects and pointed out their role in transforming the way manufacturing is produced. In 2020, Sholihah et al. [131] proposed a methodology to help manufacturing enterprises analyze their development status and select the appropriate competencies to develop service-oriented strategies, and validate the applicability of the methods through practical applications in enterprises. In 2021, Yu et al. [132] analyzed a sample of dozens of countries and manufacturing companies worldwide and concluded that servitization could increase its advantages and take over critical competitive capabilities internationally. In the same year, Liang et al. [133] introduced a novel deep reinforcement learning approach to solve some combinatorial optimization problems of services in cloud manufacturing and demonstrated through comparative experiments that the method has a good performance both in terms of effectiveness and generalization capability. In 2022, Zhang [134] analyzed the impact of manufacturing services on industrial productivity worldwide, concluded that manufacturing services are significantly and positively correlated with production capacity, and pointed out that the rearrangement of industry chains such as advanced information technology and business services is an important direction to accelerate the future manufacturing services. Caiado et al. [135] introduced a framework in terms of SCM to establish a new paradigm for the sustainable growth of manufacturing servitization. Other contributors [136–138] in the field of manufacturing servitization are shown in Figure 14.

The above analysis indicated that the servitization of manufacturing is a process of continuous integration with other disciplines. Therefore, this article also encourages the

collaboration of researchers from different directions to promote the progress of manufacturing servitization. According to the analysis, the paper can draw the following conclusions on the future development application of manufacturing servitization.

Firstly, manufacturing servitization is receiving more and more attention and has become one of the most researched fields. The development of SCM, PSS, and DT will revolutionize the manufacturing industry's industrial model and management system. They have great growth potential, and it is worthwhile for researchers to continue to explore this field. Second, the future development of the DT cannot be separated from the support of technologies such as the CC, CMfg, and CPS, so these directions also have an essential impact on the development of manufacturing servitization. On the other hand, digital twin, cloud manufacturing, CPS, and IoT require the analysis of the collected raw data, which involves the support of big data science such as data mining and data analysis. Finally, the maximum utilization of resources will generate production scheduling problems, and meta-heuristics and deep reinforcement learning approaches have reasonable solutions for this type of NP-hard problem.

5. Conclusions and Limitations

Based on the WoS database, 3767 relevant articles and reviews published from 1990–2021 were retrieved and obtained. Bibliometric methods were used to qualitatively and quantitatively study the development characteristics and trends of manufacturing servitization, analyze the development background of manufacturing servitization in terms of global contributions, countries or regions, leading journals, authors, keywords, and research fields, and look forward to potential future research directions. It is a high reference value for researchers in the servitization of manufacturing and other related directions. And it can help them to choose their future research directions and collaborating institutions or personnel.

The results show that the research on manufacturing servitization started in 1991, and the number of documents increased steadily from 1990 to 2011, rapidly increased after 2011, and peaked in 2020. Bibliometric analysis showed that more than 77.62% of the papers were published between 2008 and 2021. The USA has the largest number of documents on manufacturing servitization, with 930 articles published, followed by China (760) and the UK (501), and they have contributed significantly to the research on manufacturing servitization. Regarding the amount of collaboration, the USA and China are the most proactive in cooperation with other countries or regions, particularly with the UK, Germany, Italy, South Korea, and Canada. Beihang University is the most published institution globally, contributing 71 articles.

Regarding the journals, the *International Journal of Production Research* and *International Journal of Production Economics* are the two journals with the most literature, publishing 80 and 78 papers in the servitization of manufacturing, respectively. The impact factors of both journals are above 6, which is significant to the literature references and publications.

Concerning research areas, business and economics are the most extensive study directions, publishing 1565 articles in this field. Engineering (1262) ranked second, followed by operations research and management science (564). According to keyword analysis, "service" is the most used keyword since it was first proposed in 1999, 262 times. It is followed by "cloud manufacturing" and "manufacturing". The keywords such as "service innovation", "IoT", "big data", and "Industry 4.0" suggest that manufacturing servitization is widely studied in different aspects. "Digital and intelligent manufacturing", "cyber-physical system", and "product-service system" are still hot research directions at present and in the foreseeable future. Finally, suggestions are given from three aspects: research area, partnership, and future application development. It is also concluded that collaborative research on big data, CC, CMfg, SCM, IoT, PSS, DT, and other disciplines will effectively promote the development of manufacturing servitization in the future.

However, it is essential to point out that this paper still has limitations. First, data indicators such as h-index, IF, etc., must be updated over time. Secondly, this analysis method

can only conclude and make suggestions for future directions but cannot explain the underlying reasons behind the phenomena. In addition, besides the WoS, other databases such as the Scopus may also contain publications with the theme of servitization of manufacturing. The literature may be missed because the data sources are not comprehensive enough.

Future work should add different databases to expand the data sources and be more timely and in-depth in analyzing the underlying reasons.

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