A Bibliometric Analysis of Lean Manufacturing

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Abstract:

The manufacturing philosophy known as "Lean Manufacturing" is now widely discussed and used in a range of industries around the world. Lean manufacturing is a production method aimed primarily at reducing timelines within the production system as well as using optimum resources by elimination of wastes. The purpose of the study is to examine lean manufacturing from a bibliometric angle. Scopus - The largest database of peer-reviewed literature, including scientific journals, books, and conference proceedings, is used to extract documents for bibliographic analysis. Two software tools used for conducting analysis are Biblioshiny and VOS viewer. Performance analysis and Science mapping are done to identify evolution of research on "Lean Manufacturing" across the world. Evolution of keyword, thematic map and trend analysis done to identify future trend in the field. Studies have already matured, but the subject is indeed robust enough to offer fresh opportunities for collaboration with other management systems. This study tries to comprehend "Lean Manufacturing" and its patterns in order to guide future research.

Keywords: Lean Manufacturing, Bibliometric Analysis, Scopus, VOS viewer

1. Introduction:

During the second industrial revolution, A new concept of mass production based on job division, production lines, interchangeable parts and economy of scale by building enormous factories to minimize costs was developed in Henry Ford's automotive plants. Japanese manufacturers at the time were experiencing a resource shortage which prompted Toyota to produce it with the minimum possible resources and minimum possible time. In its initial auto factory, Toyota was only partially able to adapt the Ford production system. Only the paint, assembly, and foundry shops were able to profit from conveyor systems for production due to financial limitations. For the other production facilities, Toyota emphasized streamlining the manufacturing process and picking up new, adaptable machinery to be adjusted to any car model. Toyota's production system was formed by Taiichi Ohno using the just-in-time and autonomation principles. As a result, the TPS (Toyota Production System) model of production was developed. The TPS, later named lean manufacturing started to take over the industrial world. After James Womack and Daniel Jones' book "The Machine That Changed the World" was published in 1991, western industry started to converge towards the adoption of lean manufacturing. This has prompted the production of a variety of research publications addressing lean manufacturing and its relationship to the organization's performances.

Previous research articles have acknowledged the capability of lean manufacturing in reducing inventories, enhancing quality, satisfying customer demands on time, and eliminating wastages throughout the entire production process. Over the years, Lean Manufacturing has undergone numerous changes that have been discussed in great

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detail in numerous research papers and articles. Recent research on Lean Manufacturing has centered on organizational productivity, which aims to assign workers to thinker roles while minimizing human effort and encouraging continuous improvement. One of the most popular statistical methods for examining published materials that have become more significant with the development of technology through computers and the internet is bibliometric analysis. It allows us to explore the complexities of a particular field's evolutionary history while highlighting its emerging trends. This study is conducted to examine lean manufacturing through bibliometric perspective. Variety of choices are available for choosing software packages for bibliometric analysis, Biblioshiny tool is used for main techniques of bibliometric analysis and VOS viewer tool is used for bibliographic coupling analysis. Previous studies on bibliometric analysis for lean manufacturing were focused on identifying evolution of concept through authors, journals, countries, various industries. This paper focuses on previous trends, currents and future trends in the topic. This paper is organized in the way, first introduction of lean manufacturing and bibliometric analysis, methodology for bibliometric analysis, Performance Analysis, Science mapping. Finally, conclusion and scope for future research is discussed.

2. Methodology
2.1 Research Criteria

The research was initially developed in the Google Scholar and Scopus databases. Both databases contain a variety of high impact publications and research items. The Google Scholar database is dropped because to its limitations, which include the inability to focus frequent author name searches and the abundance of non-peer-reviewed sources. It also contains noise that is unconnected to scientific study. The Scopus database was chosen for this study because it contains the most abstracts and citations of reports, peer-reviewed books, and journals. It also offers sophisticated tools for tracking, analyzing, and comparing researches. Keyword used for initial search in Scopus database is "Lean", which showed results of 114942 documents. Since it was too difficult to manage this volume of information modified search done with criteria for "engineering" domain and keyword "Lean Manufacturing" which resulted into 2035 documents. Below mentioned Table 1 Shows data summary and its further screening of documents. Total 1936 documents are downloaded in .csv format to perform further analysis. This file was imported to the open source "Biblioshiny" with bibliometric package in "R Studio" software and additionally VOS viewer software is used to perform bibliographic coupling.

Document Types	Document Count	Criteria for Analysis
Article	1354	Included
Conference Paper	457	Included
Review Article	125	Included
Book Chapter	32	Excluded
Book	21	Excluded
Short Survey	15	Excluded
Note	13	Excluded
Editorial	3	Excluded

Table 1: Data Summary

Main information about data extracted from .csv file is uploaded in Biblioshiny software as a bibliographic information and the results obtained as Table 2. Results obtained covers timespan from year 1991 to year 2023. Total 1936 documents obtained with average citation per document is 39.37

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and 76232 references used, total number of keywords plus generated by algorithm are 6032, author keywords are 3586. Total 4266 authors of which single author document author are 199 and multi author document authors are 1735 with co-author per document is 3.01 and international co-authorship is 17.95%.

Description	Results
Timespan	1991:2023
Sources (Journals, Books, etc)	687
Documents	1936
Average Citations per document	39.37
References	76232
Keywords Plus (ID)	6032
Author's Keywords (DE)	3586
Authors	4266
Authors of single-authored docs	199
Single-authored docs	223
Co-Authors per Doc	3.01
International co-authorships %	17.95

Table 2: Main Information about Data Collected

2.2 Publication Growth Pattern

It started since the phrase "Lean Manufacturing" was first used in 1991 by researchers from the Massachusetts Institute of Technology, James P. Womack, Daniel T. Jones, and Daniel Roos in their book The Machine That Changed the World, in which they compared Japanese and American manufacturing businesses. Publication growth pattern can be divided into 4 phases. First is precursor phase where research in the field is just initiated by Womack and other scientists begin to focus on new field and published articles. Second phase is growth phase starting from year 2004 from the publication of research of Jefferey Liker in this book- 'The Toyota Way', which states 14 management principles from Toyota motor company. It became popular worldwide in this phase. The global economic crisis increased in 2008, and many businesses from all walks of life started looking for ways to improve their economic situation. Third phase started from the advancement of lean into fields other than manufacturing such as service industries like healthcare banking etc. This is exponential growth phase of lean where various scientific researches were done through lean method and terms like Lean management evolved. Later, during the consolidation period, when the studies conducted become iterative or stagnant, slowly less research is done in that area. Declining trend observed post year 2018 where studies showed maturity. This has provided opportunity to researchers to collaborate lean manufacturing with other topics like digitalization, industry 4.0. Internet of things and lean methodology can interact and have the potential to advancement in lean to the next level.
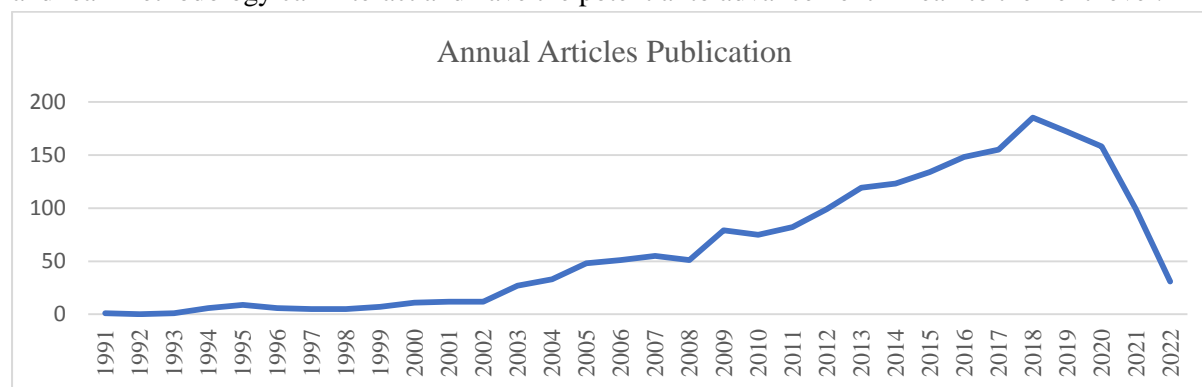

Figure 1: Annual Articles Publication

3. Performance Analysis

The contributions of study participants are taken into consideration in bibliometric studies through performance analysis. It helps in identifying the most influential and productive topics (based on the volume of papers produced). Software tool is chosen for Performance analysis if Biblioshiny R since it has better user interface and visualization options available to study publication and citation related metrics.

3.1 Top 10 Contributing Journals

Table 3 displays the top journals that the researcher most regularly refers. *The International Journal of Production Research* and *Journal of Manufacturing Technology and Management* are two significant publications in this area, with 88 and 70 documents and 2713 and 1518 citations, respectively. The impact factor can be helpful to evaluate a journal's relative 'importance', especially when compared to others in the same field. All top 10 journals have impact factor more than 10 is measure of its significance.

Ranking	Journal Name	No. of Documents	No. of Citation	h_index
1	INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	88	2713	47
2	JOURNAL OF MANUFACTURING TECHNOLOGY MANAGEMENT	70	1518	36
3	INTERNATIONAL JOURNAL OF LEAN SIX SIGMA	63	905	24
4	PRODUCTION PLANNING & CONTROL	54	741	28
5	PROCEDIA CIRP	37	541	19
6	JOURNAL OF CLEANER PRODUCTION	35	1466	27
7	INTERNATIONAL JOURNAL OF PRODUCTION ECONOMICS	29	1863	21
8	INTERNATIONAL JOURNAL OF PRODUCTIVITY AND PERFORMANCE MANAGEMENT	23	484	16
9	INTERNATIONAL JOURNAL OF OPERATIONS & PRODUCTION MANAGEMENT	17	2399	15
10	JOURNAL OF OPERATIONS MANAGEMENT	11	2232	10

Table 3: Most Contributing Journals

3.2 Top 10 Contributing Authors

Table 4 refers topmost contributing authors in this research field. Vinod S. is the most productive author with 40 articles published in this field and 213 number of citations with impact factor 26. Further detailed abstract was checked for author Vinodh S. for understanding their contribution. Major papers were published in 'International Journal of Lean Six Sigma' and 'International Journal of Production Research'. Papers are based on building conceptual framework of lean manufacturing along with six sigma, environment sustainability, environmental focus are covered. Structural equation modelling, axiomatic modelling, analytical network process, interpretative structural modelling, fuzzy TOPSIS, fuzzy logic test are majorly used as methodological approach for writing these papers.

Ranking	Authors Name	No. of Articles	No. of Citation	h_index
1	VINODH S	40	213	26
2	KODALI R	23	156	18
3	KUMAR V	20	156	12
4	GARZA-REYES JA	18	165	14
5	TORTORELLA GL	15	64	12

6	GODINHO FILHO M	14	99	13
7	NALLUSAMY S	14	72	11
8	AHUJA IS	13	9	8
9	JAIN R	13	44	10
10	KUMAR R	13	46	8

Table 4: Most Productive Authors
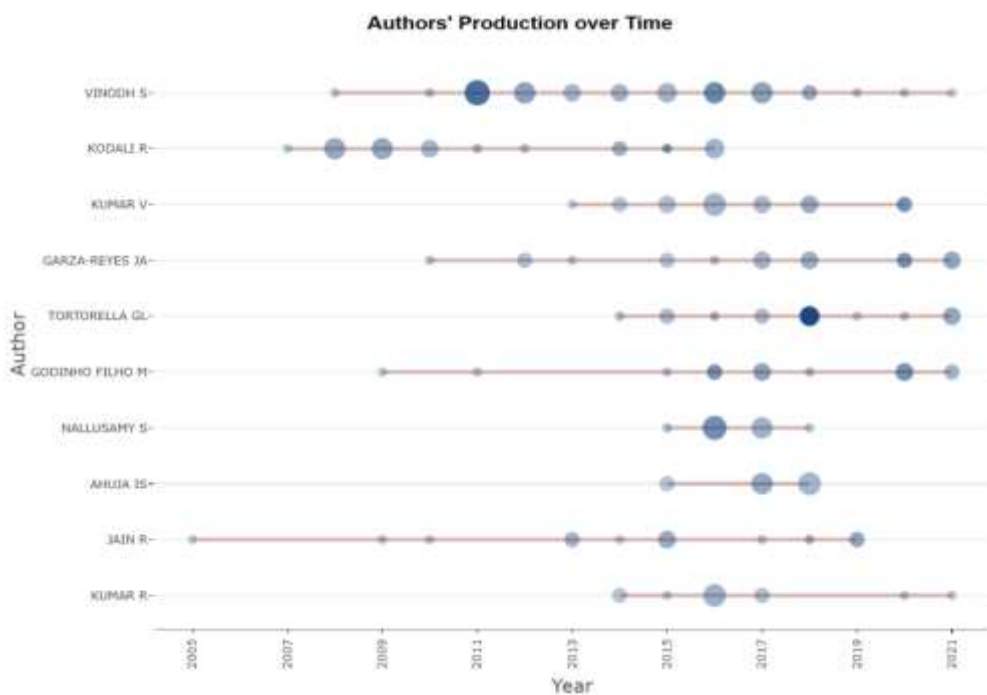
3.3 Authors Production Over Time

Figure 2: Authors Production Over Time

Top authors contributing to the field of lean manufacturing are consistent to produce research articles for a span more than 10 years consecutively. Figure 2 also describes that year 2008 to 2018 is the period for exponential growth in the field of research.

3.4 Country wise Contribution to Research

Top 20 countries providing maximum research on lean manufacturing are India, USA and United Kingdom followed by Brazil, Malaysia and Italy. Figure 3 also provides intra country collaboration and inter country collaboration during selected period of time.
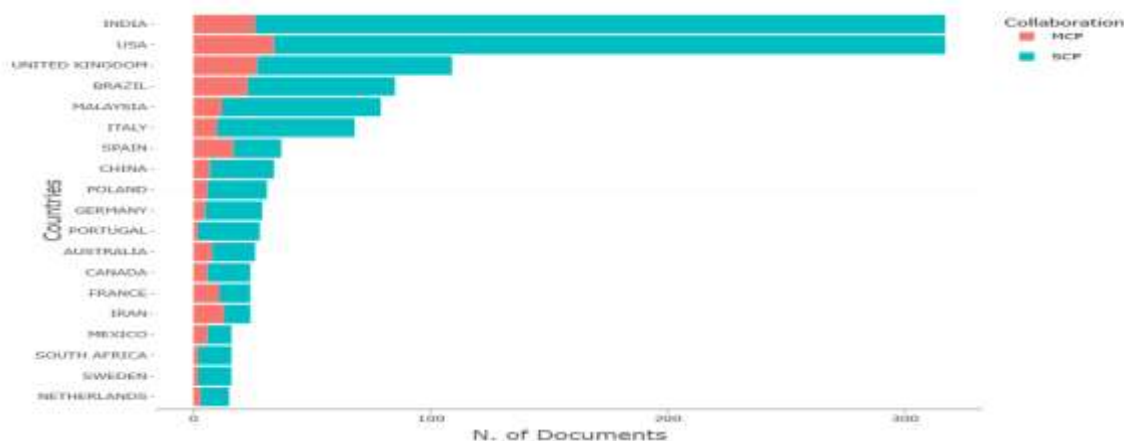

Figure 3: Country-wise Contribution to Lean Manufacturing

3.5 Country wise Evolution of Lean Manufacturing

Research shows that Lean manufacturing evolved in Japan and term was coined in USA and later it spread to the world as the most efficient way to make car production. Figure 4 represents country-wise evolution of lean manufacturing for top 5 countries. USA has initiated scientific research on lean manufacturing from year 1991 and dominated in the research world till year 2018. In India the research was popularized after year 2007 and exponential growth in research publication is seen. United Kingdom has initiated research publication at same time as that of India and USA and received more research putout than Malaysia and Brazil.
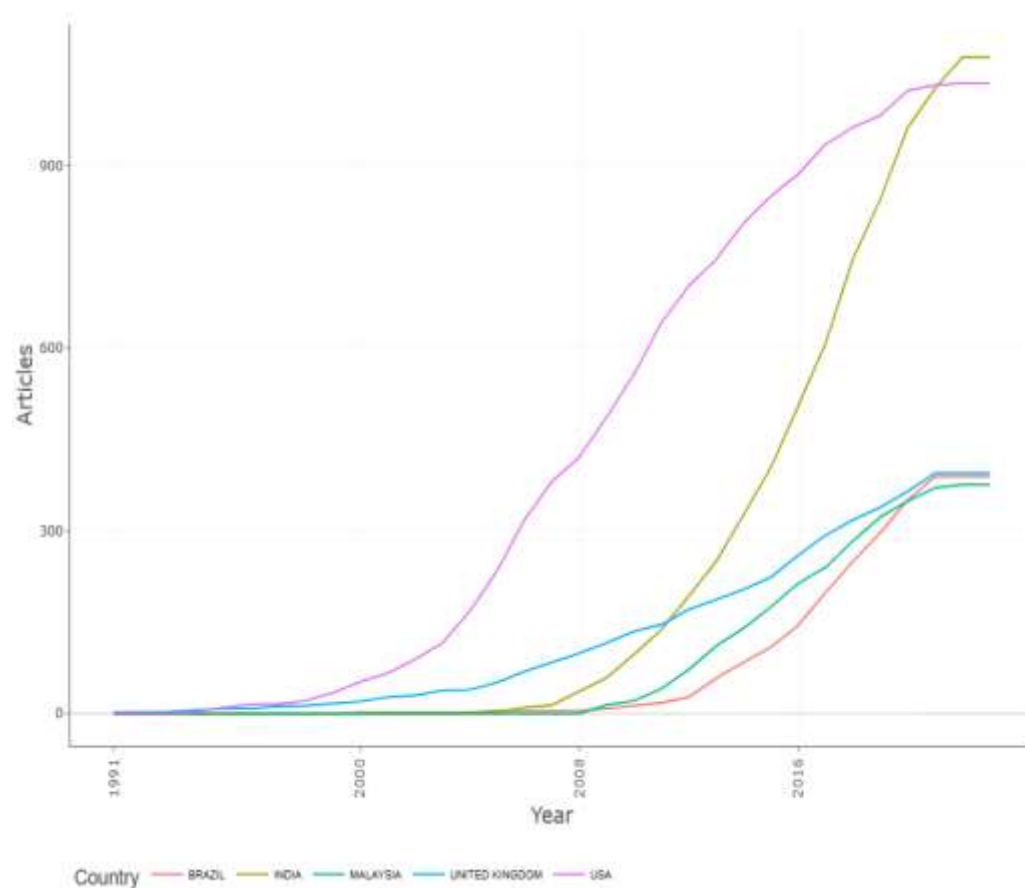

Figure 4: Country-wise evolution of Lean Manufacturing

3.6 Keyword Analysis

Most frequent keywords used in the research are identified with keyword analysis. It is observed that lean manufacturing is the most frequent keyword being used. In the third phase of evolution of lean manufacturing from year 2008 to year 2018 highest growth in research observed with average 10 years for impactful research. Trending topic are identified as mentioned in figure 5 are lean automation, industry 4.0, smart manufacturing and internet of things. These topics are gaining advancements from year 2018.
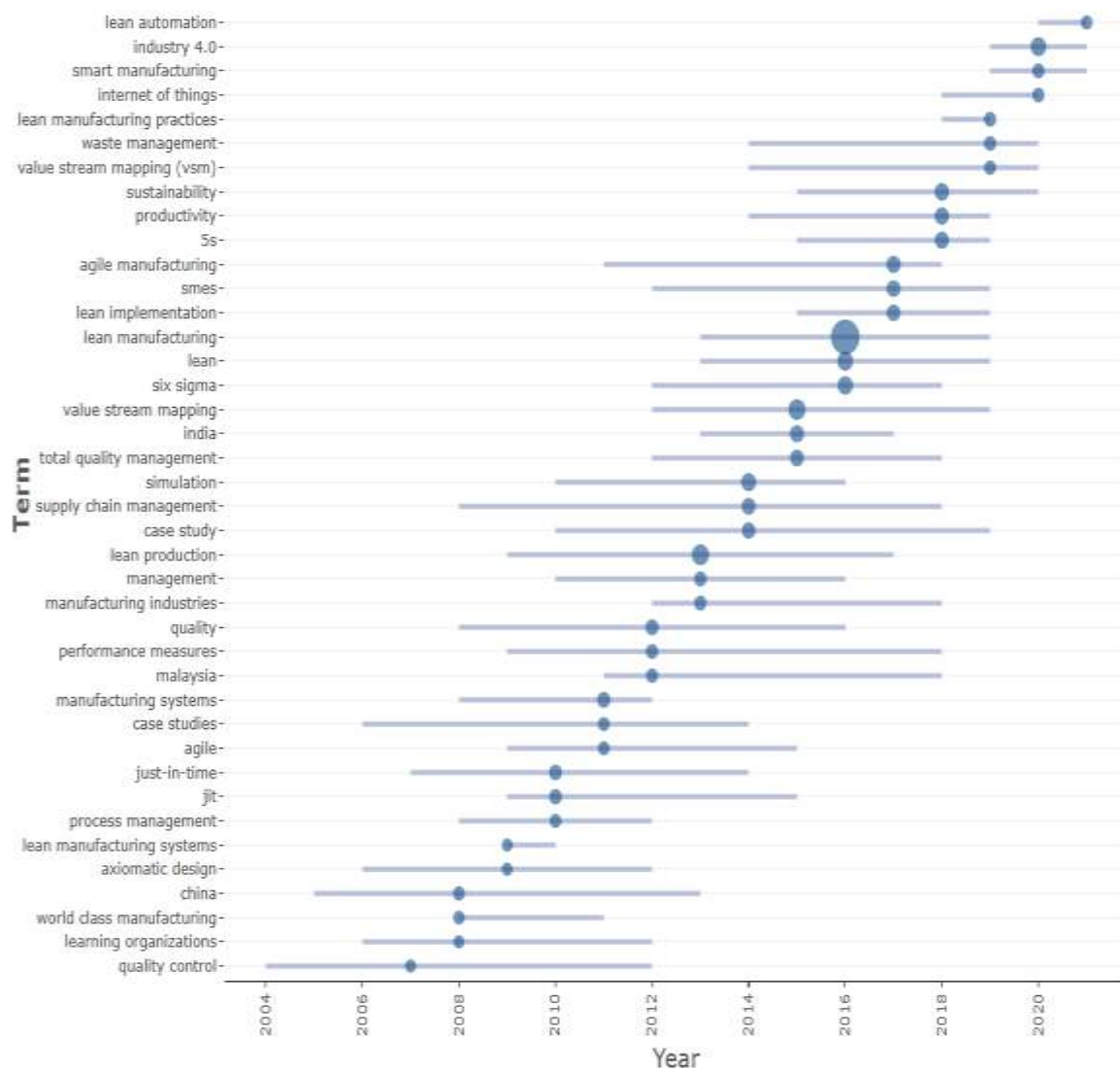
Figure 5: Keywords Trending in Lean Manufacturing

4.   Scientific Mapping

Science mapping summarizes the bibliometric structure and the intellectual structure. Science mapping focuses on the relationships between research constituents and allows for an evaluation of author and institutional or country wise productivity. It is the body of methods and techniques that have been developed to generate science maps. Software tool used for science mapping is VOS Viewer since it provides better visualization for thematic map as compared t Biblioshiny Tool.

4.1 Co-occurrence Analysis

Keyword co-occurrence is done to uncover relationship among the author listed where keyword converging into common cluster represents a common theme. Out of total 6032 keywords, minimum number of occurrences 30 is selected which is showing 99 results. Thematic map development was done using Co-occurrence Keyword wise for identifying themes. Major Themes used are lean manufacturing, agile Manufacturing, Lean Production, Value stream Mapping.
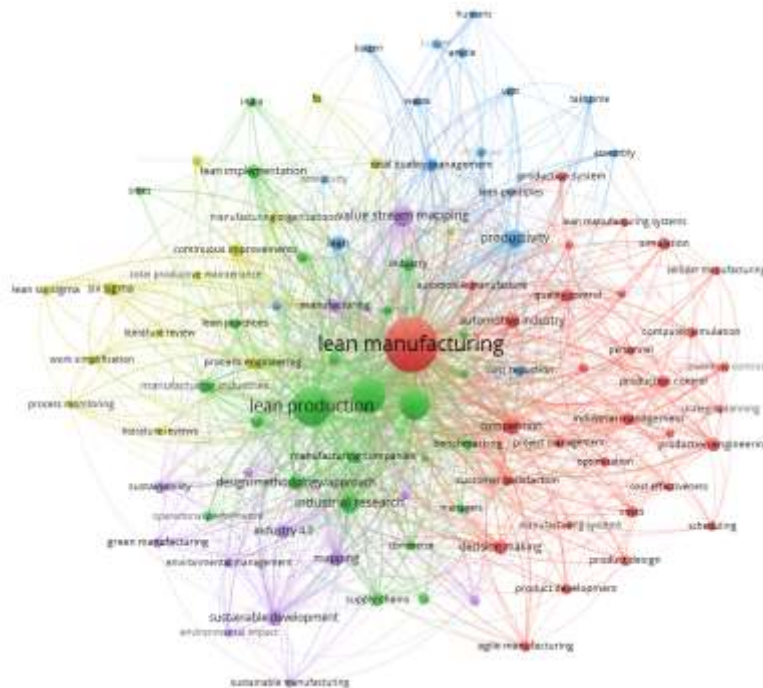
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Figure 6: Keyword co-occurrence Analysis

4.2 Bibliographic coupling

Bibliographic coupling usually done to uncover relationships among citing publications, wherein citing publications converging into cluster represents a common theme. Bibliographic coupling done with respect to unit of analysis taken as countries for full counting method, maximum number of countries per document are 25, minimum number of documents per country is taken as 5 and minimum 5 citation are taken for analysis which meets criteria for 55 countries as threshold. Thematic map developed as Figure 7 shows Unites States as strongest cluster with 465 documents, India as second cluster with 403 documents followed by United Kingdom with 185 documents, Brazil with 134 documents and Malaysia with 123 Documents.
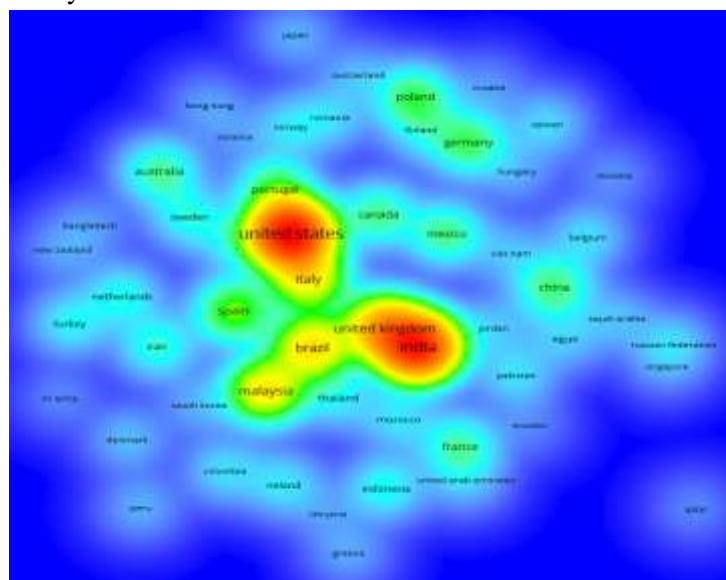
5. Conclusion

This paper describes Bibliometric analysis of the term "Lean Manufacturing", Analysis run through Performance analysis and Science mapping to obtain below conclusions.

1. Annual publication trend divides it into four phases as:
   - 1991-2004 Precursor Phase
   - 2004-2008 Growth Phase
   - 2009-2018 Exponential Growth Phase. (Maturity at FY 2018)
   - 2019-2023 Consolidation Phase.
2. Topic publishing can be improved by incorporating advanced digitalization and lean manufacturing with other management methods.
3. The *International Journal of Production Research* has evolved as most significant source chosen by authors to publish their work. Their recent trend in last 3 years is based on 'Agile Manufacturing Systems' and 'Industry 4.0'
4. Vinod S. have actively contributed in the field through single and multi-author publication.
5. When country-wise research production studied and pareto principle applied to this data, only 16 countries out of total 82 countries are contributing to 80% of the research publication which concludes lean is not popular among rest 80% countries. United States ranks at top position with respect to total number of publication and it is then followed by India and United Kingdom.
6. Output of co-occurrence shows that lean manufacturing, agile manufacturing and value stream mapping are the major themes in this field.

6. Limitations

The study has limited to its search to only articles published at Scopus database. Not all academic journals are indexed in Scopus. Many other databases like Web of Science, Google scholar, Microsoft academia are not considered. During search criteria in Scopus database only engineering domain article published are considered omitting other science, finance journals.

7. Scope for Further Research

Based on findings of Bibliometric analysis, we can recommend several topics for further research as:

1. Build a framework for incorporation of lean with digitalization and information revolution through emerging techniques as Internet of things, Industry 5.0
2. Industry specific Bibliometric Analysis required to identify specific industry trend in current position and to draw future trend.
3. There are many lean tools not evident from the network map studied in this research.
4. Country specific research to be studied with international author collaboration to help them benefited from this concept.

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