RESEARCH LANDSCAPE OF MANUFACTURING INTELLIGENCE AND BUSINESS PERFORMANCE: A REVIEW

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Abstract: To match the standards of Industrial Revolution 4.0, implementation of manufacturing intelligence is essential for excelling the business performance. In today's paradigm of modern industrialization smart manufacturing with intelligent data driven systems have become an integral part of automation. Business performance measurement plays important role in the success of unit specially when there is cut throat competition. Bibliometric method is used for the analysis of journal articles from 1998 to 2018. Analysis for Time trend, high frequency keywords and theme analysis is done for the review of research done on manufacturing intelligence and business performance. With reference to the conclusions Manufacturing Intelligence and Business Performance found highest presence in Business, Experimental and Engineering Subject area. Majority of articles on Manufacturing Intelligence, Business Performance are written by Chien, Whiting and Bornagiu.

Index Terms: **Bibliometrics, Business Performance (BP), Manufacturing Intelligence (MI), Business Intelligence (BI)**

I. INTRODUCTION

Manufacturing Intelligence and its effect on business performance have opened doors for new researcher to explore it on new horizons as MI has become essential part of automation. The data associated with various activities, machines and processes of the shop floor is critical for analysis in order to support the decision making process. Majority of machine tools from manufacturing units have ready interface for the data acquisition system. Still deployment of MI is not affordable for SME sector but found its presence in many big organizations. Ample academic research is found on business performance but MI yet to set its roadmap. The number of research papers with considerable emphasis on MI is still scarce; however overview of the published research will definitely help the research scholars to explore it on new horizons.

Bibliometric study is done to find out the academic research output on "Manufacturing Intelligence" and "Business Performance". Publication data retrieved from University of Eastern Finland with period from 1998 to 2018. The publication data analyzed and presented in this paper for giving roadmap for the future researchers. The remainder of this paper is arranged as follows. Section **2** covers literature review on the content related to MI, BP and both. The research methodology adopted is discussed in Section **3**. Time trend analysis is covered in section **4**. Section **5** provides brainstorming review of journal articles on MI, BP and both. Section **6** provides map of co-authors network and high frequency keywords. Details of Source and subject are provided in section **7**. Section **8** throws light on future scope. Section **9** covers conclusions.

II. LITERATURE REVIEW

Literature relevant to "Manufacturing Intelligence" started appearing in journal article from around 2010 whereas "Business Performance" since 1993. According to Davis, et al (2012) sensor based data acquisition devices are used for data collection forming database to support the decision making process. MI has become integrated part of automation in many of the manufacturing units. Chien et al have written maximum number of research articles covering semiconductor industry with due importance to manufacturing intelligence. Within the span of 10 years he have written more than 20 articles. Hsu et al (2012) emphasized on yield enhancement by real time decisions as a part of intelligent manufacturing in semiconductor industry. Gen (2014) explored production scheduling with design of multi-objective evolutionary algorithms (MOEA).

Wilcox (2003) elaborates role of performance prediction with careful study on performance measurement. He correlated employee performance with the main objective of business performance. Mcdam (2014) done case studies for developing performance measurement models. He explained the relevance of performance measurement models on business strategy and culture, operational routine and functional strategy. Chung (2014) analyzed data collected from survey for 450 chinese firms in order find effect of guanxi managerial ties on business performance.

III. RESEARCH METHODOLOGY

We have collected data from Eastern University of Finland website (Open access only) for various analyses. Bibliometrics methodology applied to show connectivity of downloaded articles and expedition for analyzing themes. Qiqqa and Vosviewer tools are used for this purpose.

Bibliometrics is a research methodology extensively applied for analysis of publications such as journal articles, books etc. Statistical and analytical analysis of bibliographic data is possible with this method. Wide range of statistics covering different analysis can be carried out

We get the answer of following questions by bibliometric analysis:

- Growth of literature in terms of academic output over a selected period of range
- Leading authors
- Leading disciplines
- Influential papers
- Most cited papers

We searched for "Manufacturing Intelligence" and "Business Performance" for time period 1998 to 2018 resulting into 133020 articles for MI and 1889583 articles for BP. Search for collective "MI + BP" result into 44040 articles.

IV. TIME TREND ANALYSIS

Figure 4.1 shows the time trend of literature on MI over period of 1998 to 2018. From the year 1998 to 2000 the number of articles is varying linearly. Number of articles is found in range of 5000 to 7000 since 2000. It clearly indicates that considerable attention is required by the researcher to explore this area of research. Ref. [41]

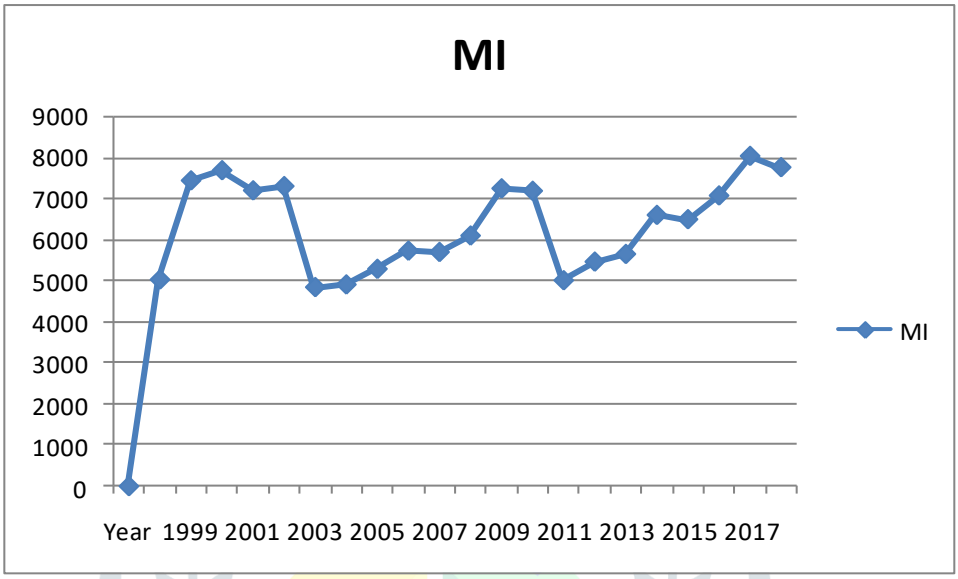

Figure 4.1 – Manufacturing Intelligence

Figure 4.2 shows the time trend of Business Performance from 1998 to 2018. There is gradual increase in the number of articles since 1998. The research work is continuously growing in terms of number of research articles. Ref. [41]

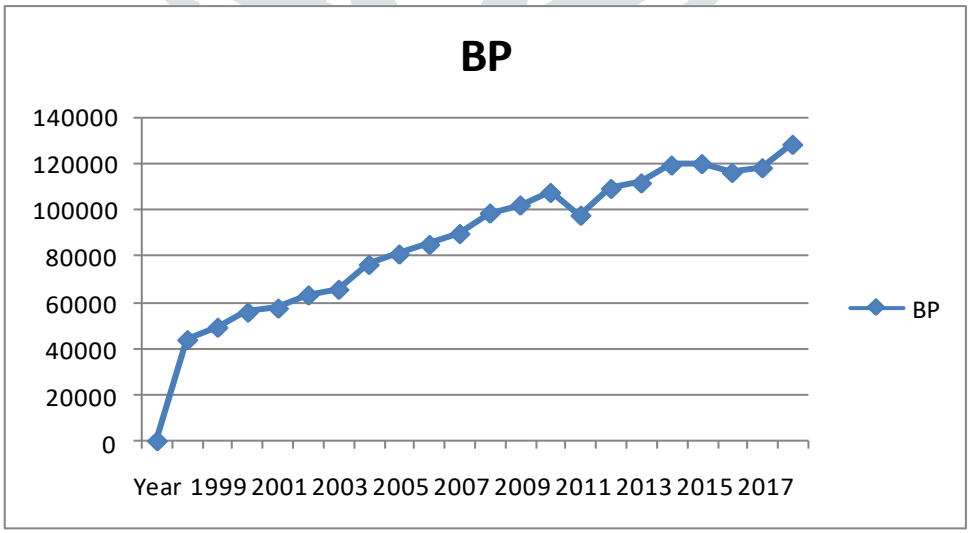

Figure 4.2 – Business Performance

Figure 4.3 shows the time trend of both MI and BP collective search. The graph shows gradual increase since 1998. Even though the research work is growing gradually but the number of articles are very less and there is huge scope to explore this area of research. Ref. [41]

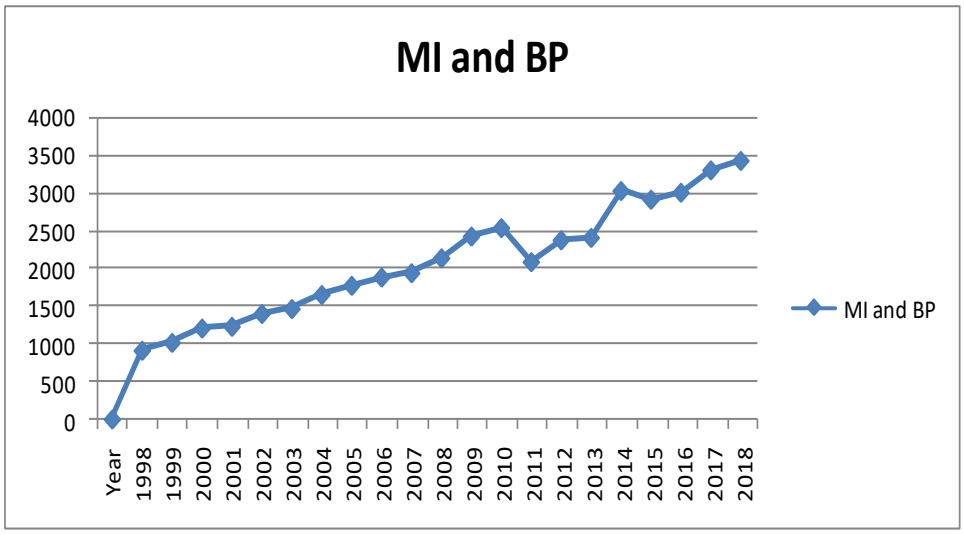

Figure 4.3 – Manufacturing Intelligence and Business Performance

Table 4.1 Ref. [41] shows the statistical analysis on content type. Out of the total articles on MI 76.78% are E-Articles.

Table 4.1 - Content Type

1998-2018						
	Manufacturing Intelligence		**Business Performance**		**Manufacturing Intelligence and Business Performance**	
Content Type	**No. of Articles**	**%**	**No. of Articles**	**%**	**No. of Articles**	**%**
E-Article	101510	76.78%	1466157	78.15%	32620	74.74%
Conference Proceeding	13482	10.20%	89233	4.76%	3180	7.29%
Text Resource	6961	5.27%	42945	2.29%	4978	11.41%
Newspaper Article	6199	4.69%	236964	12.63%	1079	2.47%
Review	1974	1.49%	29510	1.57%	935	2.14%
Book	1365	1.03%	6686	0.36%	770	1.76%
Technical Report	403	0.30%	68	0.00%	4	0.01%
Book Chapters	128	0.10%	1685	0.09%	3	0.01%
Reference Entry	93	0.07%	470	0.03%	38	0.09%
Others	57	0.04%	1454	0.08%	23	0.05%
Stastical Data Sets	22	0.02%	401	0.02%	10	0.02%
Dissertations	10	0.01%	310	0.02%	2	0.00%
Website	6	0.00%	81	0.00%	2	0.00%

V. BRAINSTORMING REVIEW

Brainstorming analysis carried out on two articles by leading authors on BP and MI. The analysis for journal article by Mcdam on quality measurement frameworks in public sector and another by Chien on MI for determining machine subgroups to enhance yield in semiconductor manufacturing is provided below. The visualized analysis is shown in figure 5.0 Ref. [42]. The analysis shows the inter connectivity of author articles with reference to the overlapping keywords. The keywords with author connectivity found are manufacturing firm, firm performance, total quality management, smart production, semiconductor manufacturing etc. The same analysis repeated for combination of various articles from total 160 downloaded articles.

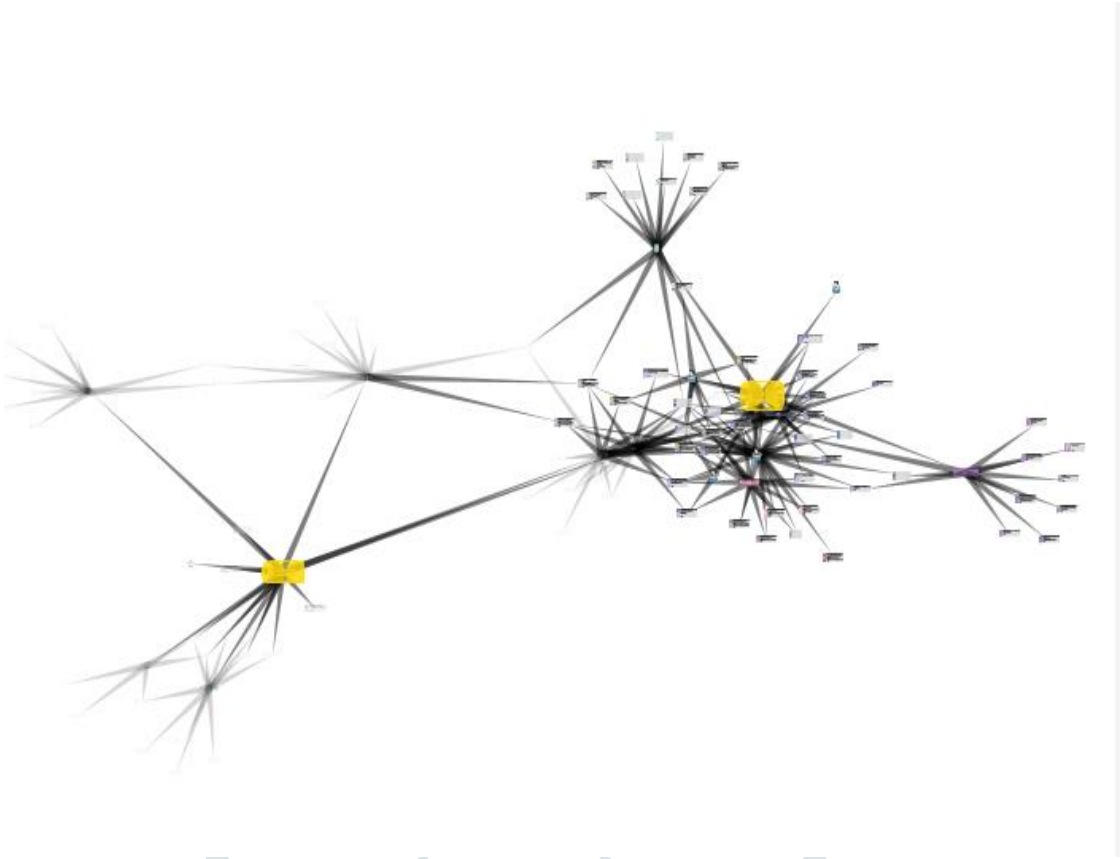

Figure 5.0 - Brainstorming

Expedition review shows the dominance of themes in article by Mcdam on quality measurement frameworks in public sector. Figure 5.1 shows the expedition for the selected article Ref. [42]. Total 13 themes are part of this article with theme number 8-performance measurement contribute around 62%, theme number 6-firm performance around 13%. This procedure is repeated for many downloaded articles.

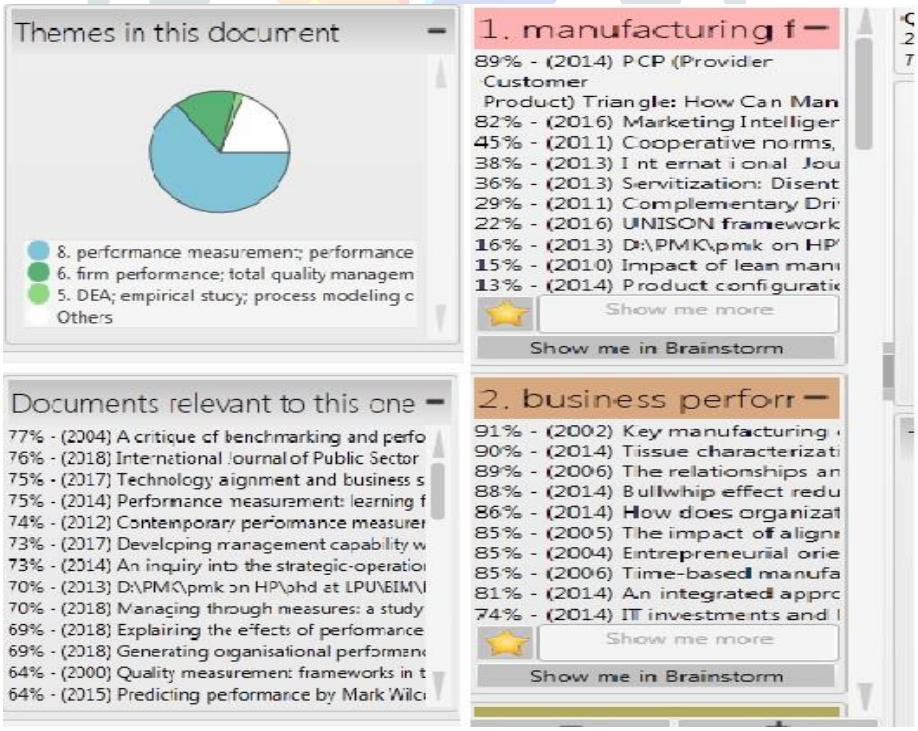

Figure 5.1 - Themes in selected article

VI. CO-AUTHORS AND KWYWORD MAP

Figure 6.1 shows co-authorship map Ref [43]. The analysis answers the following question

i. Most Influential Author
ii. Author with highest link strength

Analysis was carried out on 60 articles on BP. Figure 6.2 Shows author, number of documents and link strength for the above analysis. Mcdam tops the list with 16 documents with total link strength of 24. He is the most influential author for literature on content related to BP.

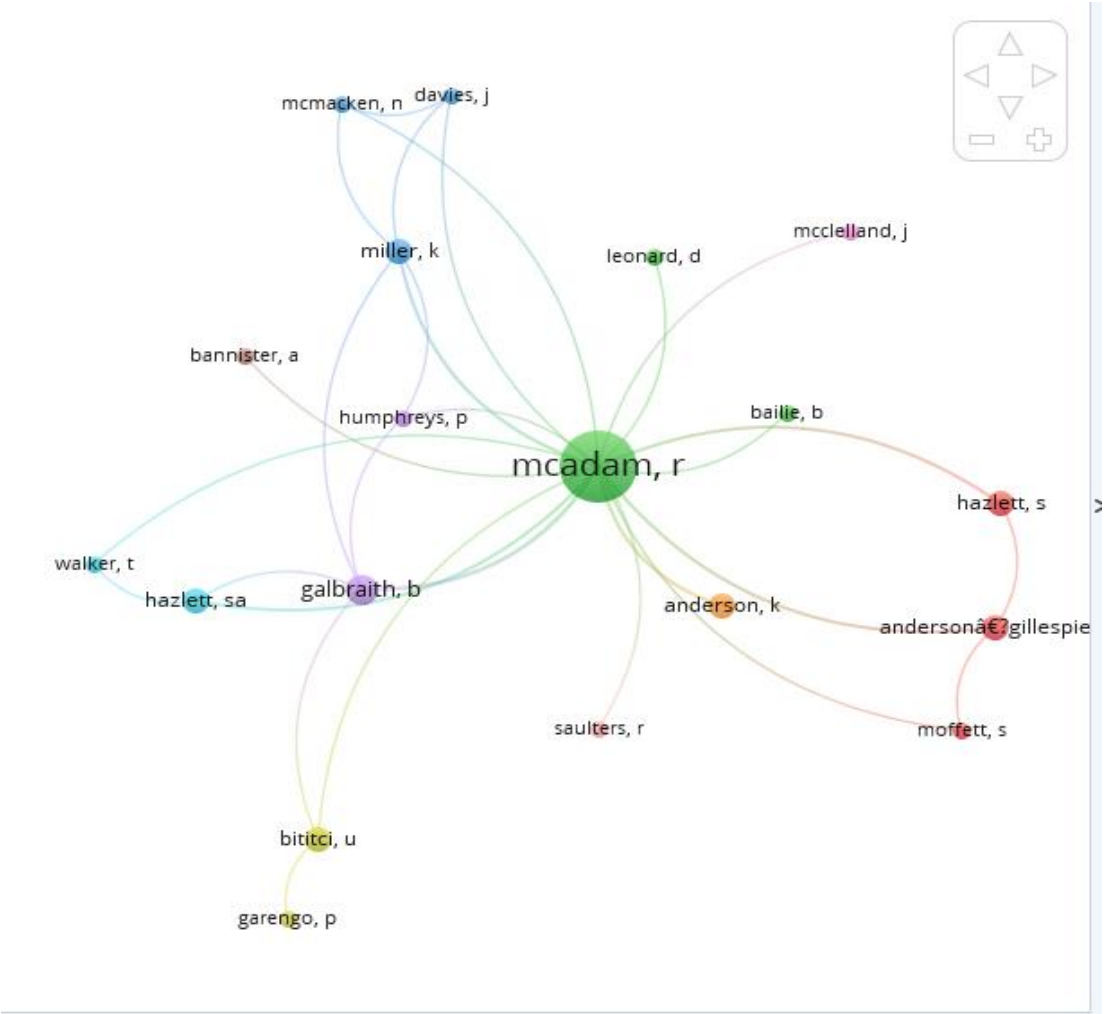

Figure 6.1 - Co-authorship Analysis

Selected	Author	Documents	Citations	Total link strength
☑	mcadam, r	16	0	24
☑	yang, z	9	0	17
☑	bourne, m	8	0	12
☑	cai, s	4	0	8
☑	galbraith, b	3	0	7
☑	cao, q	4	0	6
☑	franco-santos, m	2	0	6
☑	lucianetti, l	2	0	6
☑	miller, k	2	0	6
☑	chung, h	2	0	5
☑	pavlov, a	2	0	5
☑	wiklund, j	3	0	5
☑	andersonâ€?gillespie, k	2	0	4
☑	hazlett, sa	2	0	4
☑	mura, m	1	0	4
☑	bititci, u	2	0	3
☑	davies, j	1	0	3

Figure 6.2 - Total link strength for authors

Figure 6.3 shows network visualization key text extracted from the title and abstract of 60 articles downloaded on BP. Ref. [43]

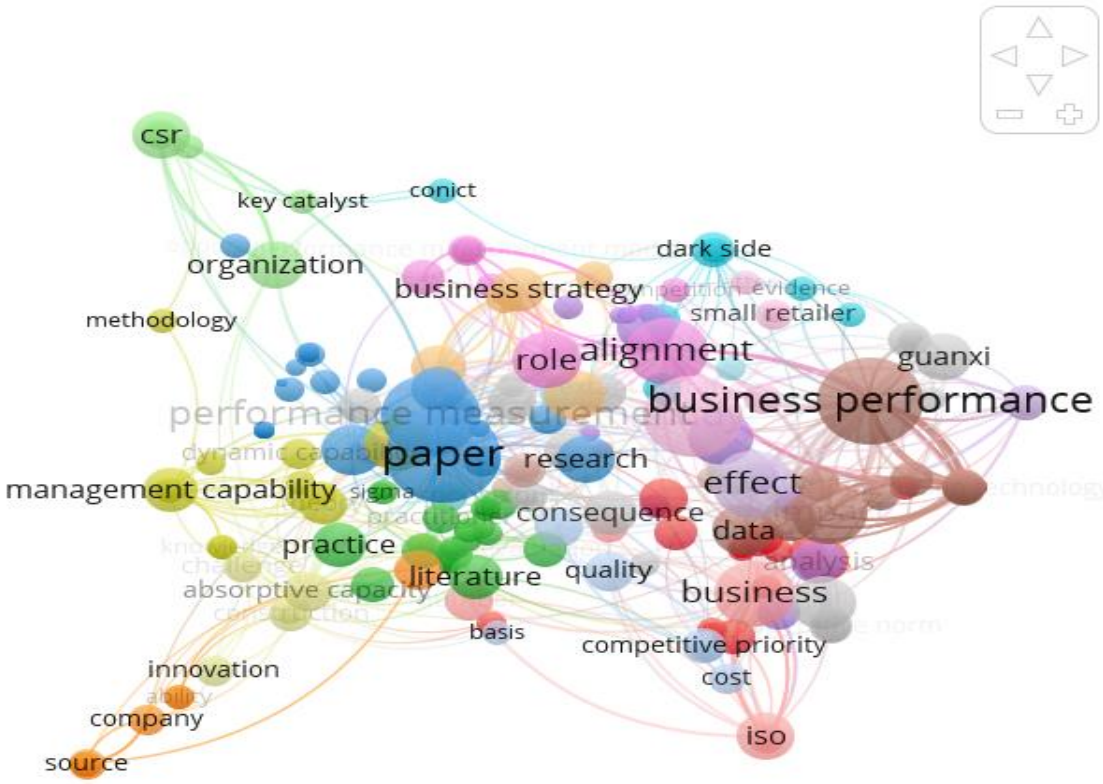

Figure 6.3 Key Text Analysis

VII. DATA ANALYSIS FOR SOURCE AND SUBJECT

Table 7.1 Ref. [41] provides information on the count of publication sourced from University of Eastern Finland online database. Onefile (GALE) is on tops search on MI and BP individually whereas ABI/INFORM complete tops for combined search.

Table 7.1 – Data on Source of Publication

	MI	BP	MI and BP
Source	**Pub. Count**		
Onefile (GALE)	67207	859991	14804
ABI/INFORM Complete	48177	718563	24744
ABI/INFORM GLOBAL	38301	613063	19011
ABI/INFORM Trade and Industry	21905	-	-
ProQuest Pharma Collection	17053	479899	9812
ScienceDriect Journals (Elsevier)	13327	172774	4957
Taylor and Francis Online – Journals	15532	159174	5788
Elsevier (CrossRef)	12007	156728	4314
IEEE Conference Publications	11551	-	2483
SpringerLink	7188	284172	3363
Springer (CrossRef)	6623	261074	3350
MEDLINE/PubMed (NLM)	4743	172240	-
ProQuest Biological Science Collection	4660	175505	1075
JSTOR Archival Journals	3910	79545	2483
Health Reference Center Academic (Gale)	3031	-	740
ACM Digital Library	2414	-	-
IEEE Journal and Magazines	1595	-	-

IEEE (CrossRef)	1578	-	-
Wiley Online Library	1175	37746	573
Wiley (CrossRef)	1141	35864	569
Informa Taylor and Francis (Crossref)	-	140073	-
Emerald Insight	-	80998	5168
Accounting and Tax	-	78807	677
Sage Journal (Sage Publications)	-	41679	-
Directory of Open Access Journal DOAJ	-	38729	-
Sage Publications (Crossref)	-	35003	-
ABI/INFORM Trade and Industry	-	-	7222
JSTOR Current Journals	-	-	2127
INFORMS Journals	-	-	358

Table 7.2 Ref. [41] provides data on disciplinary distribution for search on MI. Engineering field tops the content written on manufacturing intelligence

Table 7.2 – Disciplinary Distribution on MI

Subject	**Pub. Count**
Engineering	14442
Computer Science	7776
Artificial Intelligence	6734
Computing and Processing	6601
Algorithms	5756
Mathematical Models	5322
Software and Systems	3188
Optimization	2945
Manufacturing	2857
An	2675
Neural Networks	2240
Robots	1989
Intelligence	1899
Robotics	1476
Artificial Neural Networks	1454
Expert Systems	1236
Machine Learning	1022
Artificial Intelligence (General) Ci	946

Table 7.3 Ref. [41] provides data on disciplinary distribution for search on BP. Maximum articles are found on business subject with minimum articles on market orientation.

Table 7.3 – Disciplinary Distribution on BP

Subject	**Pub. Count**
Business	187830
Engineering	182035
Economics	165841
Experimental/Theoretical	148797
Experiment/Theoretical Treatment	101538
Management	47517
Marketing	47338

Financial Performance	39328
Organizational Behavior	35541
Performance Evaluation	29584
Performance	20528
Innovation	16841
Small Business	16654
strategic Management	13257
Entrepreneurship	12795
Business Performance Management	2745
Market Orientation	1684

Table 7.4 Ref. [41] provides information on disciplinary distribution for collective search on MI and BP. Business area finds maximum number of articles whereas minimum number of articles on neural network.

Table 7.4 – Disciplinary Distribution on MI and BP

Subject	**Pub. Count**
Business	9596
Experimental/Theoretical	6964
Engineering	6054
Economics	5225
Experiment/Theoretical Treatment	3683
Computer Science	3057
Marketing	2775
Information Technology	1759
Us	1684
Software and Systems	1546
Manufacturing	1471
Algorithms	1285
Software	897
Artificial Intelligence	792
Intelligence	598
Software Industry	558
Neural Networks	538

VIII. FUTURE SCOPE

The analysis provide in the previous sections provide roadmap for further research on MI and BP. There is huge potential for research work on MI and BP individually for various sectors like automobile, chemical, healthcare etc. Collaborative work by industry, university and individual researcher find ample scope for research in the area of MI and its impact on the business performance. Different models can be developed showing impact of various parameters of MI and BP on each other. Few of the parameters for MI are listed below.

A. Related to Business Data
   1. Customers
   2. Partners
   3. Plans
   4. Costs
   5. Materials
   6. Compliance

B. Related to Manufacturing
   1. Schedules
   2. Materials
   3. Yield
   4. Efficiency
   5. Assets

C. Related to Distribution and Logistics
   1. Schedules
   2. Inventory
   3. Facilities

Following parameters are listed for BP
   1. Product Quality
   2. Operating Efficiency
   3. After-sales Service
   4. Product Development
   5. Service
   6. Time of Delivery
   7. Product range
   8. Price
   9. Information

IX. CONCUDING REMARKS

Bibliometric analysis of published journal articles on "Manufacturing Intelligence" and "Business Performance" is provided in this review article. Qiqqa and Vosviewer tools are extensively used for interpreting different types of analysis. The data is retrieved from UEF website for a period from 1998 to 2018. Total 160 downloaded articles from various journals (60 on MI, 50 on BP and 50 on both collective searches) considered. Brainstorming analysis performed on article by key author Mcdam and Chien. Similarly expedition analysis is carried on article by Mcdam who is on the top in literature on BP. Also co-authorship network analysis and key text analysis is done with Vosviewer.

We found huge number of research articles on BP spread across various fields, but on MI limited research literature is found and only small percentage of it is completely relevant to the core manufacturing. The word MI found its presence considerably but the content relevance is not up to the mark. It is found that there is gradual growth in literature BP and collectively with MI. But after initial gradual growth in MI, it is progressing in certain range steadily from 5000 to 8000 articles per year which is very small as compared to BP. Value added research is required from forthcoming researchers on MI.

The key text terms business performance, alignment, and management capability shows considerable presence with maximum link strength.

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