

Artificial Intelligence as a Vehicle for Innovation: Literature Review and Bibliometric Study

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ABSTRACT

Artificial Intelligence has been a conceptual area for several decades. It has been studied extensively through experiments by the Information Systems community. When Information Systems supported with Information Technology became all pervasive in business and other allied areas, gradually the advancements in Artificial Intelligence also emerged as innovations across domains. Artificial Intelligence by definition is expected to substitute Human Intelligence, thereby making a huge space for innovation. In fact, all processes effected by human intelligence are liable to be replaced by AI which in itself is a massive innovation space. This paper will study the publication's repository (Scopus and Google Scholar from 1983 till 2021) in the area of Artificial Intelligence and innovation, then analyze the trend to gain insight into the evolution of AI as a vehicle for innovation.

Keywords: Artificial Intelligence, Innovation, Evolution, New Business Models, Applications, Design

I . Introduction

Artificial Intelligence is a buzzing concept in contemporary times. The rapidly growing applications of AI have penetrated business and academics in practically all spheres. Organizations have also used AI for curating new products, services and realigning strategies to continuously reach out to customers (Campbell et al., 2020). Artificial Intelligence(AI) is a technique being deployed in many fields for quick data collection, analysis and decision making. AI car-

ries an enormous potential for service and product innovation (Prem, 2019). There are evidences in literature showing that different fields are evolving in a unique manner using AI, these range from health-care, infrastructure, governance, finance to name a few. There have been references where AI systems have actually performed better than human doctors (Bohr and Memarzadeh, 2020). AI concepts and technologies can influence and improve the manner in which the cities serve their citizens and provide everyone with the responsible urban design (Yigitcanlar

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et al., 2020). Governance has been another area where AI can play a transformative role, governance has a wide implication which encompasses corporate, business and political governance; Artificial Governance is an innovation which has been discussed in detail by Hilb (2020). The accessibility of enormous, diverse and at the same time nimble information resources, also known as Big Data, warrants undisturbed consideration to AI applications with considerable developments in study and design of methodologies based on intelligent algorithms, impacting business and societies (Duan et al., 2019; (Dwivedi et al., 2019). Analytics has logically given way to AI in organizational development irrespective of domain, AI was being adopted at the rate of 20-47% in 2017-19 and machine learning was a larger part of the same (Wladawsky-Berger, 2019). Artificial Intelligence encompasses both analytical and non-analytical tools like machine learning, deep learning, natural language processing, robotics process automation and rule based systems thus paving a way for innovation, which clearly is becoming the life line of businesses. Artificial Intelligence can be used to innovate most important processes of an organization for long term survival and competitive advantage. As firms embrace AI centric operating models they are increasingly digitizing businesses there by changing the context of human involvement and processes, thereby leading to innovation (Verganti et al., 2020).

Innovation is acknowledged as one of the core capabilities companies require to sustain in the fast-changing and highly competitive environment (Danneels, 2002). Additionally, innovation is a field which is of interest not only to the practitioners, in fact it is attracting increasing interest of the researchers as well. It has been observed that earlier IT was a tool for innovation, however as IT evolved

and AI has moved center stage, increasingly AI techniques are facilitating innovation. (Zhang et al., 2016). Artificial Intelligence is an umbrella technology which entails Machine Learning, Robotics, Natural Language Processing, usage of vision sensors all of these tend towards collation of data for decision making which proves to be the basis of simulated intelligence a.k.a Artificial Intelligence. This decision making is increasingly being denoted as pre cursor to innovation (Prem, 2019)

Author has undertaken the study to establish the relationship between AI and Innovation. It is evident from the highly cited and iconic publications (Allam, 2016; Haefner et al., 2021; Mühlroth and Grottko, 2020; Paschen, 2020; Verganti, 2020) that AI is being used for product and process innovations. This study establishes the trend across the years, also identifies the prominent journals and articles in the domain, the leading countries and institutions in the domain, existing research themes and future research opportunities. The same are documented as the research questions below (Donthu et al., 2021):

- RQ1: What is the annual growth trend of literature in the field of AI and Innovation?
- RQ2: Which are the prominent publications (articles and outlets) of AI and Innovation?
- RQ3: Which are the leading countries, institutions and authors of AI and Innovation?
- RQ4: What are the existing research themes in AI and Innovation field?
- RQ5: What can be the future research opportunities to enrich understanding of AI and Innovation?

To address the above said research questions authors have implemented a bibliometric study using 5,267 articles which were identified in the first search.

The articles were subsequently trimmed using various filters. The text below is organized into following sections: section two presents a literature review of the publications connecting Artificial Intelligence to Innovation, section three discusses the methodology used to implement the bibliometric study, section four presents an analysis of results generated by implementing the methodology discussed. It also relates the results to the research questions raised above. Section five further reflects on the research questions and the outcome of the bibliometric study. Section six explores further research directions and puts forth concrete ideas for the same. Section seven concludes the discussion and reiterates the contributions made by the research

II. Literature Review

Artificial Intelligence is defined as “the science of making machines do things that would require intelligence if done by men” (Minsky, 1968) . AI is also defined as a study of computations which make it possible to perceive, reason and act, however there are perspectives of intelligence being a function of not necessarily of humans, implying that non humans can also be intelligent. These non-humans may be other living species of machines (Kak, 1996).

Innovation is the practice of adapting the process, structure and technique of doing a set of tasks differently with a view to further the organizational goals (Birkinshaw, 2008). In the digital era innovation is increasingly becoming a function of information technology. AI being a contemporary paradigm is emerging as a key to innovation in business practices, it is a concept that has evolved over the years, following study is considering the development in the field of AI and Innovation in the period beginning 1983

till 2021. In late 1990s AI was studied mostly as an academic subject and the practitioners were not considering it for any application purpose, it remained a research agenda. Ever since the scholarly interest in AI as an agent of change in the way humans approach workplace and personal lives has been on the rise (Brynjolfsson and McAfee, 2017). The basic premise remains that AI can deliver more effectively and efficiently than humans (Agrawal et al., 2018). Artificial Intelligence is a technique due to replace human intelligence, this can be attributed to the fact that technology has devised ways to replace the five senses of humans and to take complex decisions as well using Machine Learning (Verganti et al., 2020). AI is actually making machines emulate the human intelligence thus AI is increasingly becoming an enabler for Innovation.

Because of increasing alignment to technology organizations tend to collate large amount of data for the purpose of analyzing the past, current and future trends using AI and ML. These trends help organizations to innovate further, thus AI has emerged as a vehicle for innovation in business and other domains. Yablonsky published in 2019 that “The field has existed since the 1950s and is only now emerging as viable for commercial markets. Many enterprises are placing bets on AI that will determine their future. Today AI innovation becomes useful when it enriches decision-making that is enhanced by applying Big Data (BD) and Advanced Analytics (AA), with some element of human interaction using digital platforms.” (Yablonsky, 2019).

Artificial Intelligence and Innovation have a unique ability to be hand in glove and to create modern systems which might be more efficient than humans. AI may potentially be used for innovation because of its unique capabilities to make decisions based on huge amount of data (Lu, 2019). Lee et

al. (year) have published that AI is a catalyst for business model innovation, they further point out that “companies that successfully capitalize on AI can create disruptive innovation through their new business models and processes, enabling them to

potentially transform the global competitive landscape” (Lee et al., 2019).

We can clearly identify the relationship of Artificial Intelligence to Innovation in different domains. It is evident that researchers have established that

<Table 1> The Literature Review Table

Sno	Paper Details	Journal & Year	Method Adopted	Highlights of the Study	Total Citations
1	Innovation analytics: Leveraging artificial intelligence in the innovation process.	Business Horizons, 2020	Case study analysis	AI has an important role in the innovation process, from the exploration of problems to the selection of solutions. AI can substantially drive innovation analytics (Kakatkar, C et al., 2020)	58
2	AI-enabled business-model innovation and transformation in industrial ecosystems: A framework, model and outline for further research.	Journal of Business Research, 2021	Interview based	The core contribution of this paper has been to establish the need for AI business model innovation to be aligned with ecosystem innovation	59
3	How AI capabilities enable business model innovation: Scaling AI through co-evolutionary processes and feedback loops., 134, 574-587.	Journal of Business Research, 2021	Interview based	The development of AI capabilities in manufacturing forms and digital servitization	44
4	Algorithmic bias in data-driven innovation in the age of AI.	International Journal of Information Management, 2021	Review	To create algorithms for data driven innovation.	50
5	Tackling COVID-19 Through Responsible AI Innovation: Five Steps in the Right Direction	Social Science Research Network, Rochester, NY, 2020	Theoretical research	Modern techniques(including AI) for societal upliftment	59
6	Implementation of artificial intelligence (AI): a roadmap for business model innovation	AI,2020	Theoretical research	Connecting AI to Business Model Innovation	44
7	Innovation and design in the age of artificial intelligence.	Journal of Product Innovation Management, 2020	Theoretical research	AI for business, innovation and design	136
8	People and machines: Partners in innovation.	MIT Sloan Management Review, 2019	Article	AI for innovation in different domains	82
9	The Impact of Artificial Intelligence on Innovation-An Exploratory Analysis	International Journal of Creative Research Thoughts, 2016	Article	AI, ML , Robotics for Innovation in business	77
10	Artificial intelligence for innovation in Austria.	Technology Innovation Management Review, 2019	Interview based	AI and Innovation	22

Artificial Intelligence is proving to be a tool for innovation in business. The same is further studied and presented in the <Table 1> below.

Authors were able to research articles which have been published in the domain of Artificial Intelligence and Innovation applied to certain specific areas. Also Scopus and Google Scholar reported many articles in the domain under study which were essentially review papers or quantitative research papers. However, there was no footprint of bibliometric study particularly in the domain of AI and Innovation. Thus the literature review clearly showed a space for the bibliometric research on AI and Innovation which further establishes the evolution of connect between the two areas and establishes that AI leads to innovation in business (Yams et al., 2020).

III. Methodology

3.1. Bibliometric Search

The authors adopted the search strategy proposed by Feng et al. (2017) which included defining a search approach and identifying a database for the same, filtering initial test results, improving the search results, analyzing the search results to extract descriptive statistics finally performing the Science Mapping for co-citation analysis. The search for articles was guided by a search strategy that consists of four stages: database search, scholarly filtration, language filtration, and subject filtration (see <Figure 1>).

Step 1: Defining a search approach and selecting a database

Authors chose Scopus because it is a credible database for academic documents with wider coverage

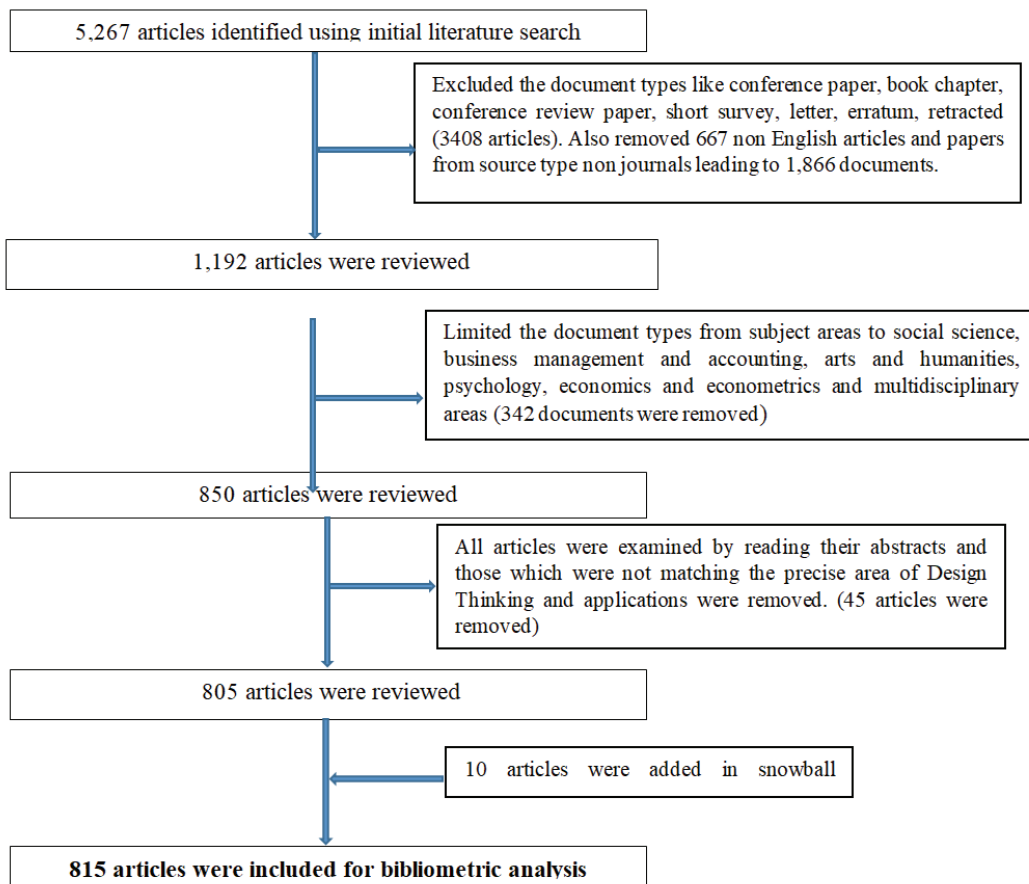
of publications meeting the stringent indexing requirements. This database is frequently recommended for bibliometric reviews (Donthu et al., 2021) as it provides comprehensive and high quality data for review (Bass et al., 2020). It has several operational tools that enable bibliometric analysis and has been used by many bibliometric scholars (eg. Kumar et al., 2020). (“Artificial Intelligence” AND “Innovation”), was used as a search key-word as it is the central concept of this review and Title, Abstract. Keywords were used as search fields. The search was extended till December 2021 though authors decided to use the data till 2020 for the simple reason to collect full year data and the database search generated 5,267 articles.

Step 2: Filtering the test results

In order to ensure a better focus on the articles being analysed, we chose subject domains which were more akin to innovation by application of Artificial Intelligence thus we withdrew 1192 i.e. 22.6% of the total search outcome.

Step 3: Sharpening the search results

The search was further limited to subject areas namely social science, business management, finance and accounting, decision science, economics and econometrics and multidisciplinary areas. These are broadly the fields broadly considered to be more relevant to “Business & Management” within which this study of AI and Innovation was focused. The subject filtration excluded another 342 articles, thus leading to 850 documents. Authors read the abstracts of all these papers to discern if those were within the scope of our analysis and removed 45 articles which appeared irrelevant, they subsequently read



<Figure 1> Steps for Identification and Collation of Article Corpus for Bibliometric Study

through the references of included articles and to identify more papers, 10 articles were added which were found to be of high impact in the domain. This criterion enabled us to narrow down our analysis to 815 papers, which served as the data for this study.

Step 4: Analysing the search results to extract descriptive statistics

Once the data set was finalized from Scopus, it was downloaded into the .csv and .bib files which then became basis for detailed analysis. The .csv format was downloaded for use in Excel and Science

Mapping software VOS viewer for co-citation analysis. The .bib file was used for extracting descriptive statistics and to study Performance Analysis for journal, author and citation using Bibliometrix package (biblioshiny () app in R)

Step 5: Finally performing the Science Mapping for co-citation analysis.

Co-citation analysis was conducted using VOS viewer 3.0 tool and Bibliometrix() package in R for journals, authors and references (Geng, 2020).

3.2. Bibliometric Analysis

This review conducted a bibliometric analysis of the AI and Innovation literature. Using 815 articles that were taken from the bibliometric search in Scopus, we analysed a series of bibliometric-based dimensions. These were global citation, local citation and social network analyses to describe the publication trends(RQ1), the leading contributors (authors, countries, and institutions) and publications (outlets, articles) of AI and Innovation research (RQ2 and RQ3). We used VOS viewer and Bibliometrix (R package) to enhance our exploration of the leading contributors and publications through co-authorship and PageRank analyses. VOSviewer was also used to map the intellectual structure through keyword co-occurrence analysis(RQ4), which can also help future research to identify avenues for future exploration (RQ5). Gephi was used to visualize the networks in our review

IV. Results and Discussions

The review highlights that the earliest article on AI and Innovation was published in 1983 and this study examined 815 documents from 537 sources over a period of 1983-2021, 798 of these documents were research articles, and 17 were editorials. These were written by 2428 authors, while 187 were written by single authors, the rest 628 documents had more than one author, highlighting that majority of the research on AI and Innovation is the outcome of collaborative work of various authors. <Table 2> indicates that in all there were 2608 author appearances with 2.98 authors per documents and 0.336 documents per author. Average citations per document stood around 8.828 with an average of 1.312 citations per year.

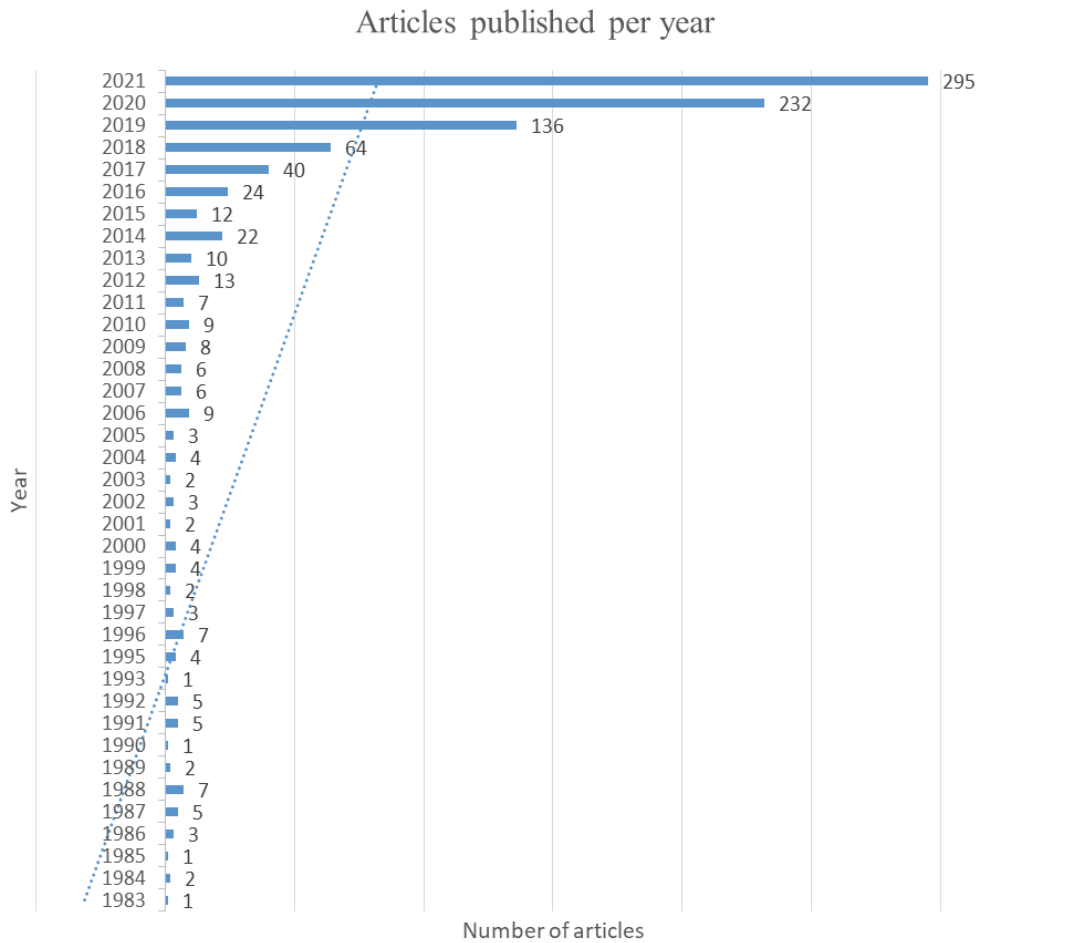
4.1. Summary of Quantitative Results

<Table 2> Summary of Quantitative Results

Description of Data	Results
Timespan	1983:2021
Sources (Journals, Books, etc)	537
Documents	815
Average years from publication	5.73
Average citations per documents	8.828
Average citations per year per doc	1.312
References	35158
DOCUMENT TYPES	
Article	798
Editorial	17
DOCUMENT CONTENTS	
Keywords Plus (ID)	3941
Author's Keywords (DE)	2643
AUTHORS	
Authors	2428
Author Appearances	2608
Authors of single-authored documents	187
Authors of multi-authored documents	2241
AUTHORS COLLABORATION	
Single-authored documents	197
Documents per Author	0.336
Authors per Document	2.98
Co-Authors per Documents	3.2

4.2. Publication Trends (Year-Wise) (RQ1)

<Figure 2> highlights the publication trends of papers on a yearly basis. While the term AI and Innovation came into usage since 1983, the research in this area took time to take off, till 2011 the number of articles published every year was in single digit. The pattern of publications can be shown in three stages - the early stage was



<Figure 2> Publication Trend of AI and Innovation Research (1983-2021)

from 1992 to 2011, when on an average there three or four articles, maximum of nine publications in a year and remained within single digit. The second phase involved from 2012 onward till 2016 when the research output gained momentum and articles picked-up from 13 in 2012 to 24 in 2016. While from 2016 onwards, the research output picked-up momentum with an average more than 40 publications each year from 2016 onwards and crossed 100 publications in 2019 ($n = 136$), 2020 ($n = 232$) and 2021 ($n = 295$), This is clear pointer that research in this field gained momentum, and research community

had started examining this field from 2016 onwards.

4.3. Publication outlet (RQ2)

<Table 3> shows the ranking of the top ten journals on the basis of number of papers published in the field of AI and Innovation along with the total citations received for the papers published in a particular journal along with average citations per document, the impact factor and H-Index of journal. The results indicate that IEEE Access is the most prolific outlet for publishing AI and Innovation papers ($n = 20$)

<Table 3> Most important outlets in AI and Innovation

Rank	Journals	Papers	Citations	Average Citations/Paper	IF	CiteScore	h-Index
1	IEEE Access	20	208	10.4	3.745	4.83	7
2	International Journal of Innovative Technology and Exploring Engineering	11	9	0.81	0.6 (same as Cite Score)	0.6	2
3	NTT Technical Review	11	9	0.81	0.11	0.8	2
4	Technology in Society	11	72	6.54	2.414	4.2	3
5	Technology Innovation Management Review	9	13	1.44	1	0.4	2
6	AI Magazine	8	331	41.3	2.18	5.1	6
7	Futures	8	31	3.8	3.33	5.5	4
8	Journal of Advanced Computational Intelligence and Intelligent Informatics	8	3	0.3	0.51	0.9	1
9	Journal of Advanced Research in Dynamical and Control Systems	8	0	0	0.31	0.4	1

with a total of 208 citations, followed. It is a very interesting observation from the table below that International Journal of Innovative Technology and Exploring Engineering, NTT Technical Review and Technology in Society all have 11 papers but amongst them Technology in society has the highest citation count of 72. AI magazine has only 8 publications but highest citations in the table i.e., 331, this is a strong indicator of relevance of AI research in Innovation.

4.4. Publication Performance (RQ2)

4.4.1. Global Citation

Global citations refer to the number of citations received without applying any filter (e.g., discipline) (Baker et al., 2020). In this review, the article with the highest number of global citations is “Artificial intelligence in service” ($n = 322$ citations), followed by “Design for manufacture and design for ‘X’: concepts, applications, and perspectives” ($n = 304$ cita-

tions) (ref. <Table 4>). The common theme across the most influential articles in <Table 3> clearly emerges as Innovations of Artificial Intelligence in different domains namely service, medicine, manufacturing’ for innovation and development of new technologies.

4.4.2. Local Citation

Local citations refer to citations received from the articles in the review space for the bibliometric study (Baker et al., 2020). This implies, local citations are calculated basis the citations received from 815 articles on “AI and Innovation” which were retrieved from Scopus and retained after applying filters as shown in <Figure 1>. In this review, the article with the highest number of local citations is “Artificial intelligence in service.” ($n = 8$ citations) (see <Table 5>). As shown in <Table 4> this article was also the most globally cited article and the same has received highest number of citations in the identified 815 articles for study. This is followed by “Artificial

<Table 4> Global Citation

Article Title	Author(s)	Year	Total Citations
Artificial intelligence in service	Huang, M. H., and Rust, R. T.	2018	322
Design for manufacture and design for 'X': concepts, applications, and perspectives	Kuo, T. C., Huang, S. H., and Zhang, H. C.	2001	304
Toward interconnected virtual reality: Opportunities, challenges, and enablers	Bastug, E., Bennis, M., Médard, M., and Debbah, M.	2017	207
A dataset and a technique for generalized nuclear segmentation for computational pathology	Kumar, N., Verma, R., Sharma, S., Bhargava, S., Vahadane, A., and Sethi, A.	2017	196
Automated intelligent pilots for combat flight simulation	Jones, R. M., Laird, J. E., Nielsen, P. E., Coulter, K. J., Kenny, P., and Koss, F. V.	1999	193
Intelligent tracking in manufacturing.	Brewer, A., Sloan, N., and Landers, T. L.	1999	148
Artificial intelligence in medicine and cardiac imaging: harnessing big data and advanced computing to provide personalized medical diagnosis and treatment	Dilsizian, S. E., and Siegel, E. L.	2014	143
Why space matters in technological innovation systems – Mapping global knowledge dynamics of membrane bioreactor technology.	Binz, C., Truffer, B., and Coenen, L.	2014	141
The segmentation of the left ventricle of the heart from ultrasound data using deep learning architectures and derivative-based search methods.	Carneiro, G., Nascimento, J. C., and Freitas, A.	2011	127
Leveraging knowledge, learning, and innovation in forming strategic government - university - industry (GUI) R&D partnerships in the US, Germany, and France	Carayannis, E. G., Alexander, J., and Ioannidis, A.	2000	120

<Table 5> Local Citation

Article	Authors	Year	Local Citations	Global Citations
Artificial intelligence in service	Huang, M. H., and Rust, R. T.	2018	8	322
Artificial intelligence: Building blocks and an innovation typology	Paschen, U., Pitt, C., and Kietzmann, J.	2020	3	24
Artificial intelligence as a growth engine for health care startups: Emerging business models.	Garbuio, M., and Lin, N.	2019	3	26
AI governance in the public sector: Three tales from the frontiers of automated decision-making in democratic settings	Kuziemski, M., and Misuraca, G.	2020	2	15
Innovation analytics: Leveraging artificial intelligence in the innovation process	Kakatkar, C., Bilgram, V., and Fuller, J.	2020	2	4
Machine learning for enterprises: Applications, algorithm selection, and challenges	Lee, I., and Shin, Y. J.	2020	2	25

<Table 5> Local Citation (Cont.)

Article	Authors	Year	Local Citations	Global Citations
Transforming business using digital innovations: The application of AI, blockchain, cloud and data analytics	Akter, S., Michael, K., Uddin, M. R., McCarthy, G., and Rahman, M.	2020	2	18
Ten ways artificial intelligence will transform primary care	Lin, S. Y., Mahoney, M. R., and Sinsky, C. A.	2019	2	23
Me or information technology? Adoption of artificial intelligence in the delegation of personal strategic decisions.	Schneider, S., and Leyer, M.	2019	2	12
Design in the Age of Artificial Intelligence	Verganti, R., Vendraminelli, L., and Iansiti, M	2020	1	11

intelligence: Building blocks and an innovation typology” ($n = 3$ local citations). After analysing the articles listed in <Table 3> it becomes evident that Artificial Intelligence which included Machine Learning, Block Chain, Analytics is being used extensively for Innovations in different domains.

4.5. Most Productive Authors (RQ3)

<Table 5> lists the 10 most prolific authors in the domain of AI and Innovation. Since AI as a vehicle for innovation (Verganti et al., 2020) is fast emerging as an important domain, it is very relevant to understand the key researchers and their primary contributions; this will help new researchers to further the research direction. <Table 6> shows that Chen Y along with Lichtenthaler U, Liu C and Wang Y have been the most published authors with 6 publications, however highest citation score is of Parida V though he has 4 publications. Bai X, Zhang X and Zhao X have the next highest publication i.e. 5 articles.

The <Table 5> also reveals that the focal themes for authors have been Artificial Intelligence (AI), Innovation and other technologies related to AI like Machine Learning, Block chain, Integrated Intelligence,

Deep Learning, AI adoption, Smart Systems. Also authors have written about the application of these technologies like Smart Contract, Smart Servitization, Digital Transformation, Water Management and Collaborative Design. <Table 6> also shows that authors are from primarily China and USA.

4.6. Most Productive Regions/Countries (RQ3)

4.6.1. Leading Countries

The distribution of articles by countries indicates that authors from 58 countries (<Figure 3>) have contributed to and published research on AI and Innovation.

4.6.2. Leading Country Collaborations

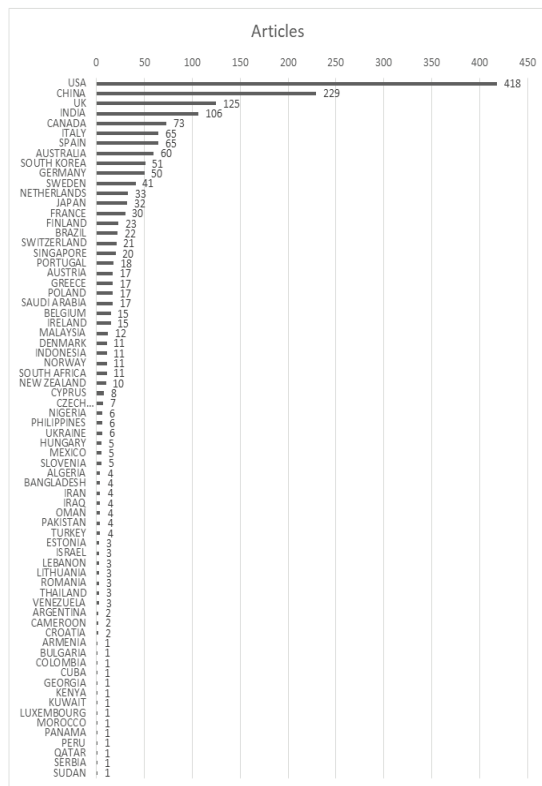
The network analysis reveals four major social networks in AI and Innovation research (<Figure 4>). The first major social network centers around United States, second major social network centers around China, third major social network is around UK .The fourth major social network has India at its center and includes Spain, Malaysia and South

<Table 6> Most productive authors in AI and Innovation

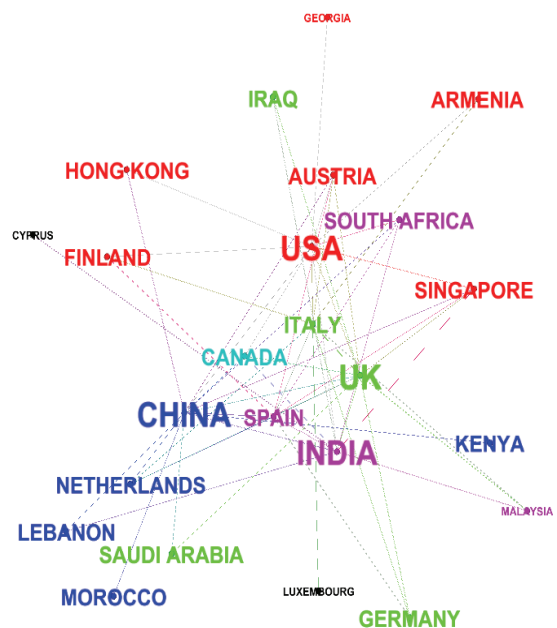
Author	Number of Publications	Total Citations	Affiliation	Themes Studied	Journals
Chen Y	6	49	University of Accounting and Finance, Shanghai 201620, China	Innovation ecosystems, Smart contract, Block chain, Applications of AI, Wireless sensor networks	Complexity, Digital Communication and Networks, IEEE Transactions and Medical Imaging, JMIR Medical Informatics, IEEE Access, International Journal of Distributed Sensor Networks
Lichtenthaler U	6	28	International School of Management, Germany	Artificial Intelligence, Digital Transformation, Agile Innovation, Integrated Intelligence	Journal of Business Strategy, International Journal of Innovation and Technology Management, International Journal of Service Science, Management Engineering and Technology, Journal of Strategy and Management
Liu C	6	3	Center for Drug Evaluation Research, US Food and Drug Administration, White Oak, MD, USA	Deep learning, Innovation, Technology	IEEE Vehicular Technology Magazine, Journal of Pharmacokinetics and Pharmacodynamics, Construction Innovation, Journal of Advanced Computational Intelligence and Intelligent Informatics, Journal of Engineering, Design and Technology
Wang Y	6	29	Office of Translational Science, Center for Drug Evaluation Research, US Food and Drug Administration, White Oak, MD, USA	Deep Learning, Artificial Intelligence, AI Adoption, Reiterative learning, Expert Systems	Journal of Pharmacokinetics and Pharmacodynamics, IEEE Access Social Science Computer Review, IEEE Journal of Biomedical and Health Informatics, NTT Technical Review Science China Information Sciences
Bai X	5	56	Huazhong University of Science and Technology, P. R. China	Block chain, Artificial Intelligence, Knowledge Management, Innovation, Water Management, Big Data	IEEE Network, PLOS One, Knowledge Management Research and Practice, IEEE Access, Applied Ecology And Environmental Research
Zhang X	5	12	CUHK Business School, Chinese University of Hong Kong, Hong Kong	Fintech, Nano star antennas, R-CNN	Information Systems Research, Bioengineering and Translational Medicine, IEEE Access, Journal of Advanced Computational Intelligence and Intelligent Informatics
Zhao X	5	12	Daegu Gyeongbuk Institute of Science and Technology, Republic of Korea	Open Innovation, Artificial Intelligence, Automation and Maintenance, Web Economy	Science, Technology and Society, Science China Information Sciences, Social Science Computer Review, Journal of Advanced Computational Intelligence and Intelligent Informatics, International Journal of Knowledge-Based Development

<Table 6> Most productive authors in AI and Innovation (Cont.)

Author	Number of Publications	Total Citations	Affiliation	Themes Studied	Journals
Li X	4	51	Huaqiao University, China	Artificial Intelligence Innovations, Aging, Nanowire	Journal of Informatics, International Journal of Technology Management, Nano Energy, Journal of Advanced Computational Intelligence and Intelligent Informatics
Parida V	4	107	Luleå University of Technology, Luleå, Sweden	Artificial Intelligence, Business Model, Smart Servitization	Journal of Business Research, Industrial Marketing Management, Research Technology Management
Wang X	4	66	The University of New South Wales, Australia	Wireless networks, Artificial Intelligence, Collaborative Design, Virtual Worlds	IEEE Vehicular Technology Magazine, Nano Energy, Boletin Tecnico/Technical Bulletin, Electronic Journal of Information Technology In Construction



<Figure 3> Country Wise Distribution of Articles on AI and Innovation



<Figure 4> Country Collaboration in AI and Innovation Research

Africa. A careful examination of country collaborations reveal that these are widespread and not linked to countries within a particular continent or within

neighboring countries etc.

4.7. Most Productive Institutions (RQ3)

<Table 7> lists the institutions across countries which have been instrumental in producing maximum research in the domain of AI and Innovation. The top three institutions in terms of number of contributions are Stanford University with 12 articles followed by Huazhong University of Science and Technology and Tsinghua University with 11 articles each. Positions three and four are occupied by University of California and Harvard University with 10 and 9 articles respectively. From the top ten institutions worldwide there are six from USA, three from China and one from Singapore. The table indicates that the most influential research in this field is coming from USA China.

4.8. Research Themes (RQ4)

A PageRank analysis was done to identify key themes charting the scholarly research structure of

<Table 7> Important Institutions for Research on AI and Innovation (RQ3)

Institutions	Country	Articles
Stanford University	USA	12
Huazhong University of Science and Technology	China	11
Tsinghua University	China	11
University of California	USA	10
Harvard University	USA	9
University of Oxford	USA	9
National University of Singapore	Singapore	8
University of Pennsylvania	USA	8
Harvard Medical School	USA	7
Taipei Medical University	China	7

AI and Innovation. PageRank analysis was done as it measures the prestige of the article reflected by the citations received by it from other highly cited articles (Ding and Cronin, 2011). Thus there is a possibility that an article, which is very highly ranked on global or local citations or both may not emerge as a prestigious article in PageRank analysis or vice-versa. Thus PageRank remains as an essential tool in bibliometric analysis to identify the must cite article within the pool of highly cited articles (Donthu et al., 2021).

In this review, <Table 8> shows five major clusters which emerged and report 10 of the most prestigious articles within each cluster.

Cluster 1: Technology for Innovation (n = 43)

Cluster 1 focuses on the theme of Technology for Innovation emerged as one of the two largest clusters (n = 43) with Markard and Truffer (2008) article titled “Technological innovation systems and the multi-level perspective: Towards an integrated framework” published in Research Policy received the highest score on PageRank which is 0.006474476 while the article doesn’t even figure in the list of top global and local citation list.

Cluster 2: Digital Economy, AI and Innovation (n = 43)

Cluster 2 emerged with focus on Digital Economy, AI and Innovation with 43 papers. The paper authored by Teece (2018) titled “Profiting from innovation in the digital economy: Enabling technologies, standards, and licensing models in the wireless world” published in Research Policy received the highest PageRank score of 0.008256864.

Cluster 3: Innovative business models (n = 36)

Cluster 3 focuses on Innovative Business models

with 36 publications on the mentioned theme. The article authored by Massa et al. (2017) titled “A critical assessment of business model research” shared the PageRank of 0.00251584 with another article authored by Rochet and Tirole (2003) titled “Platform competition in two-sided markets”

Cluster 4: Applications of Artificial Intelligence for Innovation (n = 26)

Cluster 4 focuses on the Applications of Artificial

Intelligence for Innovation with 26 publications. Top ten articles listed in the table show the same PageRank of 0.002421308. All the articles are addressing different domains for AI based innovations like Finance and Manufacturing systems.

Cluster 5: AI, ML algorithms (n = 22)

Cluster 5 focuses on the AI, ML algorithms with 22 articles. The top two articles share the PageRank of 0.003751666 for the articles titled “The ethics

<Table 8> Cluster Wise PageRank Analysis

Author(s)	Article Title	Journal	Year	PageRank
Cluster 1: Technology for Innovation (n=43)				
Markard, J., and Truffer, B.	Technological innovation systems and the multi-level perspective: Towards an integrated framework	Research Policy	2008	0.006474476
Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., and Truffer, B.	Technological innovation systems in contexts: Conceptualizing contextual structures and interaction dynamics.	Environmental Innovation and Societal Transitions	2015	0.005375901
Carlsson, B., and Stankiewicz, R.	On the nature, function and composition of technological systems.	Journal of evolutionary economics	1991	0.005187374
Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., and Rickne, A	Analyzing the functional dynamics of technological innovation systems: A scheme of analysis.	Research Policy	2008	0.004463157
Geels, F. W.	Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study	Research Policy	2002	0.004077723
Jacobsson, S., and Bergek, A.	Transforming the energy sector: the evolution of technological systems in renewable energy technology	Industrial and corporate change	2004	0.004077723
Bergek, A., Jacobsson, S., and Sandén, B. A.	Legitimation and ‘development of positive externalities’: two key processes in the formation phase of technological innovation systems.	Technology Analysis and Strategic Management,	2008	0.003278959
Markard, J., Raven, R., and Truffer, B.	Sustainability transitions: An emerging field of research and its prospects.	Research Policy	2012	0.00318704

<Table 8> Cluster Wise PageRank Analysis (Cont.)

Author(s)	Article Title	Journal	Year	PageRank
Coenen, L., and López, F. J. D.	Comparing systems approaches to innovation and technological change for sustainable and competitive economies: an explorative study into conceptual commonalities, differences and complementarities.	Journal of cleaner production	2010	0.002945931
Negro, S. O., Suurs, R. A., and Hekkert, M. P.	The bumpy road of biomass gasification in the Netherlands: Explaining the rise and fall of an emerging innovation system	Technological forecasting and social change,	2008	0.002831399
Cluster 2: Digital Economy, AI and Innovation (n=43)				
Teece, D. J.	Profiting from innovation in the digital economy: Enabling technologies, standards, and licensing models in the wireless world.	Research Policy	2018	0.008256864
Dellermann, D., Fliaster, A., and Kolloch, M.	Innovation risk in digital business models: the German energy sector.	Journal of Business Strategy	2017	0.007291118
Porter, M. E., and Heppelmann, J. E.	How smart, connected products are transforming competition.	Harvard Business Review	2014	0.006431306
Andriole, S. J.	Five myths about digital transformation	MIT sloan management re-view	2017	0.006115383
Doz, Y. L., and Kosonen, M.	Embedding strategic agility: A leadership agenda for accelerating business model renewal.	Long Range Planning	2010	0.005301501
Helfat, C. E., and Raubitschek, R. S.	Dynamic and integrative capabilities for profiting from innovation in digital platform-based ecosystems	Research Policy	2018	0.004941918
Davenport, T. H., and Ronanki, R.	Artificial intelligence for the real world	Harvard Business Review	2018	0.0040288
Lichtenthaler, U.	Beyond artificial intelligence: Why companies need to go the extra step	Journal of Business Strategy.	2018	0.003209023
Adner, R., and Kapoor, R.	Value creation in innovation ecosystems: How the structure of technological interdependence affects firm performance in new technology generations	Strategic Management Journal	2010	0.001655523
Teece, D. J.	Business models and dynamic capabilities	Long range planning	2018	0.000982609

<Table 8> Cluster wise PageRank Analysis (Cont.)

Author(s)	Article Title	Journal	Year	PageRank
Cluster 3: Innovative business models (n = 36)				
Massa, L., Tucci, C. L., and Afuah, A.	A critical assessment of business model research	Academy of Management Annals	2017	0.00251584
Rochet, J. C., and Tirole, J.	Platform competition in two-sided markets	Journal of the European economic association	2003	0.00251584
Baden-Fuller, C., and Haefliger, S.	Business models and technological innovation.	Long Range Planning	2013	0.001424233
Osterwalder, A., Pigneur, Y., and Tucci, C. L.	Clarifying business models: Origins, present, and future of the concept.	Communications of the association for Information Systems	2005	0.001252636
Raisch, S., Birkinshaw, J., Probst, G., and Tushman, M. L.	Organizational ambidexterity: Balancing exploitation and exploration for sustained performance.	Organization science		0.001181551
Andriopoulos, C., and Lewis, M. W.	Exploitation-exploration tensions and organizational ambidexterity: Managing paradoxes of innovation.	Organization science	2009	0.001181551
Morris, M., Schindehutte, M., and Allen, J.	The entrepreneur's business model: toward a unified perspective	Journal of business research	2005	0.001153073
McGrath, R. G	Business models: A discovery driven approach.	Long Range Planning	2010	0.001111191
Sabatier, V., Mangematin, V., and Rousselle, T.	From recipe to dinner: business model portfolios in the European biopharmaceutical industry.	Long Range Planning	2010	0.00086285
He, Z. L., and Wong, P. K.	Exploration vs. exploitation: An empirical test of the ambidexterity hypothesis.	Organization science	2004	0.000679392
Jacobides, M. G., Cennamo, C., and Gawer, A	Towards a theory of ecosystems.	Strategic management journal	2018	0.00063494
Cluster 4: Applications of Artificial Intelligence for Innovation (n = 26)				
Altman, E. I.	Financial ratios, discriminant analysis and the prediction of corporate bankruptcy.	The Journal of Finance	1968	0.002421308
Baesens, B., Setiono, R., Mues, C., and Vanthienen, J.	Using neural network rule extraction and decision tables for credit-risk evaluation.	Management Science	2003	0.002421308
Crook, J. N., Edelman, D. B., and Thomas, L. C.	Recent developments in consumer credit risk assessment.	European Journal of Operational Research	2007	0.002421308
Holt-Lunstad, J., Smith, T. B., Baker, M., Harris, T., and Stephenson, D.	Loneliness and social isolation as risk factors for mortality: a meta-analytic review.	Perspectives on Psychological Science	2015	0.002421308

<Table 8> Cluster wise PageRank Analysis (Cont.)

Author(s)	Article Title	Journal	Year	PageRank
Huang, C. L., Chen, M. C., and Wang, C. J. (Credit scoring with a data mining approach based on support vector machines.	Expert Systems with Applications	2007	0.002421308
Martens, D., Baesens, B., Van Gestel, T., and Vanthienen, J.	Comprehensible credit scoring models using rule extraction from support vector machines.	European Journal of Operational Research	2007	0.002421308
Abernathy, W. J., and Utterback, J. M	Patterns of industrial innovation.	Technology Review	1978	0.002421308
Boschma, R.	Proximity and innovation: a critical assessment.	Regional Studies	2005	0.002421308
Klepper, S.	Entry, exit, growth, and innovation over the product life cycle.	American Economic Review	1996	0.002421308
Scherer, M. U.	Regulating artificial intelligence systems: Risks, challenges, competencies, and strategies	Harv JL & Tech	2015	0.002421308
Cluster 5: AI, ML algorithms (n=22)				
Mittelstadt, B. D., Allo, P., Taddeo, M., Wachter, S., and Floridi, L.	The ethics of algorithms: Mapping the debate	Big Data & Society	2016	0.003751666
Gillespie, T	The relevance of algorithms	Media technologies: Essays on communication, materiality, and society	2014	0.003751666
Biggs, D., De Ville, B., and Suen, E.	A method of choosing multiway partitions for classification and decision trees	Journal of applied statistics	1991	0.002421308
Asheim, B. T., and Coenen, L.	Knowledge bases and regional innovation systems: Comparing Nordic clusters	Research policy	2005	0.002421308
McCullagh, P., Matzkanin, K. T., Shaw, S. D., and Maldonado, M.	Motivation for participation in physical activity: A comparison of parent - child perceived competencies and participation motives	Pediatric Exercise Science	1993	0.002421308
Barocas, S., and Selbst, A. D.	Big data's disparate impact.	California Law Review	2016	0.001975779
Burrell, J.	How the machine 'thinks': Understanding opacity in machine learning algorithms	Big Data & Society	2016	0.001975779
Beer, D.	The social power of algorithms	Information, Communication & Society	2017	0.001160425
Ananny, M., and Crawford, K.	Seeing without knowing: Limitations of the transparency ideal and its application to algorithmic accountability.	New media & society	2018	0.001160425

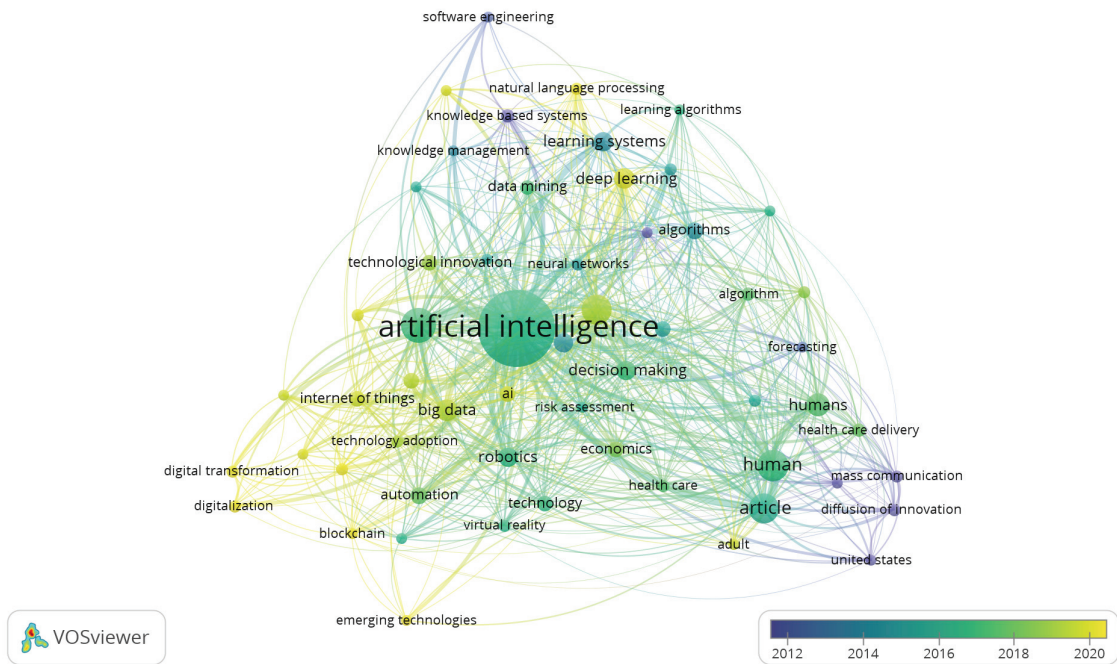
of algorithms: Mapping the debate” and “The relevance of algorithms” authored by Mittelstadt et al. (2016) and Gillespie (2014) respectively.

4.9. Keyword Co-occurrence (RQ4)

A keyword co-occurrence analysis (<Figure 5>) was done using all author keywords of 815 articles in VOS viewer to understand the key focus of AI and Innovation research during the period of study i.e. 1983-2021. The keyword co-occurrence network analysis shows a clear trend which indicate the evolution of Artificial Intelligence leading to Innovation research. In the duration between 2012 to 2014 the key research areas were software Engineering, knowledge based systems, mass communication, diffusion of innovation and learning systems. During the period 2014 till 2016 the AI and Innovation research centered

on decision making, risk assessment systems, humans, health care delivery, algorithms and forecasting. From 2016 till 2018 the research areas shifted to big data, artificial intelligence, neural network, innovation, economics, healthcare and robotics. From 2018 onwards the focus has been on Internet of Things, deep learning, digital transformation, digitalization, block chain, technology adoption, natural language processing and emerging technologies. The trend analysis from 2012 till 2021 clearly shows the advancement of the domain of Computer Science from software engineering to the Artificial Intelligence based systems being used for Innovation.

Articles shown in <Table 3> emphasize the fact that AI is being used for Innovation in different domains. Huang and Rust (2018) have published an article titled “Artificial Intelligence in Service”, Paschen et al. (2020) have published an article titled



<Figure 5> Keyword Co-occurrence

“Artificial intelligence: Building blocks and an innovation typology” which further corroborate the trend analysis done through keyword co-occurrence network.

Clusters created by application of PageRank algorithm also establishes co relation between Artificial Intelligence research and Innovation

V. Results and Reflections

The existing literature on AI and Innovation was examined to map the bibliometric aspects and intellectual structure of this field. The bibliometric analysis identified the most prolific and influential authors, countries, institutions, journals, articles, themes and topics of the AI being connected to Innovation research from 1983-2021. Specifically the four research questions framed in the beginning of the article were answered as:

- i. AI and Innovation research has grown steadily in the initial years before picking-up by 2011 and then growing exponentially since 2017 touching triple digit annually since 2019 onwards (RQ1).
- ii. IEEE Access has been the most productive journal. Paper titled “Artificial intelligence in service” has been the most cited paper both globally (322 citations) and locally (8) (RQ2)
- iii. Most productive author has been Chen Y with total 6 publications. The themes of his publication have been on Innovation Ecosystems, Smart Contract, Block Chain, Applications of AI and Wireless sensor networks (RQ3)
- iv. USA has been the highest contributor to AI and Innovation research with 23.7% articles. (RQ3)
- v. International hub of collaboration for AI and Innovation research has been United States followed by China, UK and India.(RQ3)
- vi. The PageRank analysis puts forth the key research theme across the 4 clusters which are (RQ4):
 - Cluster 1: Technology for Innovation (n = 43)
 - Cluster 2: Digital Economy, AI and Innovation (n = 43)
 - Cluster 3: Innovative business models (n = 36)
 - Cluster 4: Applications of Artificial Intelligence for Innovation (n = 26)
 - Cluster 5: AI, ML algorithms (n = 22)
- vii. The topics which have been the focus of study within AI and Innovation research over-time (RQ 4)
 - a. 2012-2014 : Software Engineering, Knowledge Based Systems, Mass Communication, Diffusion of innovation and learning based systems
 - b. 2014-2016: Decision Making, Risk Assessment Systems, Humans, Health Care Delivery, Algorithms and Forecasting
 - c. 2016-2018: Big Data, Artificial Intelligence, Neural Network, Innovation, Economics, Healthcare and Robotics
 - d. 2018-2020: Internet of Things(IoT), Deep Learning, Digital Transformation, Digitalization, Block Chain, Technology Adoption, Natural Language Processing, Emerging Technologies

It is evident from the above that AI applications have indeed led to innovation in various streams. Cluster 1 clearly depicts that Technology for Innovation has been a major theme followed by cluster 2,3 and 4 which put forth the theme of AI and Innovation in business application.

VI. Avenues for Future Research (RQ5)

Author's thought behind using the keywords AI and Innovation together was to reinstate the fact that AI is being used essentially for process and product innovation. As is evident from the analysis above that Artificial Intelligence and Innovation as a research area has grown rapidly in last one decade i.e. from 2011 onwards. The research areas have evolved in nature from basic software engineering research to contemporary use cases of Technology Adoption in state of art technologies under the larger umbrella of Artificial Intelligence and Innovation as also AI applied for innovation. The AI technologies for innovation is a larger umbrella which include Block Chain, IoT, Deep Learning, Neural Networks etc. Though there are evidences of scholarly research in AI and Innovation which have been studied in the bibliometric study, however it is evident from the population of research articles in the clusters created through PageRank analysis that the research articles are limited in number in different categories and there is a scope of publishing more articles. Artificial Intelligence and Innovation are intrinsically associated with application domains, thus there is a huge scope of application of AI and Innovation to various domains both from a research and a practitioner perspective. Quantitative research in AI and Innovation also should be brought to fore, this quantitative research should also address different application domains as stated earlier. Deployment of Artificial Intelligence and Innovation techniques need to be supported by the strategy team, thus there is research which can be focussed on the digital strategies of organizations in different domains.

The research questions which are being proposed by the authors on Artificial Intelligence and

Innovation research are:

6.1. Application of Artificial Intelligence and Innovation to Different Domains in Research and Practice

Artificial Intelligence is a large concept with many sub domains. Innovative business models may be researched upon across domains and technologies. Technologies like deep learning may be used extensively in complex sectors like Pharma, similarly combinations of technologies like IoT, robotics and block chain may be used in entertainment, training, manufacturing etc.

6.2. Quantitative Research in Varied Domains of Business

The bibliometric study has revealed a huge gap in terms of quantitative study in the domain of AI and Innovation research. It is recommended that deployment of AI based business models may be evaluated for relevance, effectiveness and from other statistical standpoints.

6.3. Involvement of Strategic Management Team

Deployment of AI technology for innovation is a decision which requires understanding of the current processes and technologies being used. This decision may also entail budgeting for the expenses and the decision to develop, outsource or buy the software solution. These aspects need to be a component of the digital strategy of an organization, Thus the buy in of the strategic level of management is imperative. Thus it is important for the future researchers to create a repository of such published papers which

provide quantitative and qualitative support to the decision makers so that the deployment of AI for innovation may be facilitated.

6.4. Design Thinking & Problem Solving Skills for AI and Innovation

Design Thinking has been considered to be an area of study which aids in problem solving and facilitates creative thinking. To further the AI and Innovation research it might prove to be beneficial to train the Design Thinking community vis-à-vis the plethora of possible solutions using AI for Innovation in different domains. Conversely it might also be a good idea to train the AI community in the intricacies of Design Thinking research. Thus the cross functional teams may present many innovative solutions across technologies and domains (Verganti et al., 2020)

6.5. Potential geographies, institutions and authors for collaboration

Author's recommendations (from the discussion of RQ3 -for geographies, institutions and authors) to collaborate in the domain of Artificial Intelligence and Innovation are-

- i. For individual collaborations authors should study Chen Y's publications as he is the most prolific author. The themes of his publication have been on Innovation Ecosystems, Smart Contract, Block Chain, Applications of AI and Wireless sensor networks (RQ3)
- ii. For country collaborations USA may be a potential collaborator as it has been the highest contributor to AI and Innovation research with 23.7% articles followed by China, UK and India

- iii. For probable institutional partnerships the top three institutions in terms of number of contributions are Stanford University with 12 articles followed by Huazhong University of Science and Technology and Tsinghua University with 11 articles each.

VII. Limitations of study

As all studies have limitations, in the enclosed study also limitations can be observed. Author's bias has inadvertently crept in the defining the search string for base data, Artificial Intelligence has been defined in various ways over time, and related technologies are also broad. Therefore, there is a limit to analyzing the overall research trend with only one keyword of AI

VIII. Conclusion

The paper is an effort by the author to present the evolution of work in domain of Artificial Intelligence and Innovation. During the initial studies as shown in the Introduction and Literature Review, there was a clear gap which emerged. The gap showed that there is a linkage between Artificial Intelligence and Innovation however it was discrete and spread out across publications. Author has made a conscious effort not only to create a tangible linkage between the two domains but also to identify the relationship as one being the means to the end of the other. Implying that Artificial Innovation is a vehicle for Innovation.

It is evident from the bibliometric study that Artificial Intelligence has evolved over the years as a means for innovation in different domains.

However, the number of publications indicate that the application of Artificial Intelligence leading to innovation are still in an embryonic stage. The reading presented above is a bibliometric study of the research published in the domain of Artificial Intelligence and Innovation during the period 1983 till 2021. Authors have used Scopus and Google Scholar for collating the base data on which the bibliometric analysis was carried out. Research questions raised at the beginning of the study have been answered using the analysis on the base data. Study of annual growth trend has indicated a slow but steady growth of the literature in the domain of Artificial Intelligence and Innovation, which is an indicator for the researchers to publish in this field. Study of important outlets indicated that leading outlets are technology based journals and not business and application oriented journals. This is a clear indication that the research of AI and Innovation is still restricted to realms of technology and business domains are yet to adopt the technology both in research and practice. The article titled “Artificial Intelligence in Service” authored by Huang and Rust (2018) is the most cited article in global as well as local citation list, this is indicative of the fact that researchers are indeed keen on applications of AI in service i.e. an automated process. Most productive

authors were also tabulated along with their research themes studied, these emerged as different aspects of AI and Innovation like Smart Contract, Block Chain, Deep Learning, Open Innovation etc. Most productive regions of research in AI and Innovation were unveiled which are USA, followed by China, UK and India. This finding has been further reiterated by listing of important institutions top ten of which are based in USA, China and one in Singapore. The PageRank analysis presented key clusters of AI and Innovation research which emphasized forays into innovative business models using technologies under the aegis of Artificial Intelligence, also the PageRank analysis show cased a clear cluster on the technical aspects of AI and Machine Learning algorithms. The clusters are not heavily populated showing the scattered nature of research in AI and Innovation. Research Themes in AI and Innovation have were studied which again showed a clear evolution of themes from study of software engineering to emerging technologies in the shown study period. Future research directions identified by the authors prod researchers towards more prolific research in the field of Artificial Intelligence and Innovation with focus on technologies, domains, strategy, qualitative and quantitate research.

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