

Citation Networks Analysis: A New tool for Understanding Science Dynamics with Implications Towards Science Policy

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ABSTRACT

The advancement of the scientific fields through accumulation of knowledge is tremendous so that in order to remain updated, the researchers are forced to rely on comprehensive surveys and literature reviews.^[1] Published articles are valuable resources which can be treated as a proxy measure of the volume of scientific activity and innovative researches in the scientific community. Many models of scientific progress had been postulated in the past and Kuhnian-model^[7] is regarded as a prominent one.

Keywords: Citation Network Analysis, Scientometrics, Science Dynamics, Science Policy.

In,^[7] Thomas Kuhn coined the term paradigm shift and argued that the period of normal sciences is occasionally accompanied by periods of anomalies which are in turn followed by the era of extra ordinary sciences and then resets again. Kuhnian model fails to explain the emergence of new fields as pointed out by Mulkey *et al.*^[2] and Whitley.^[3] Mulkey *et al.*^[2] argued that emergence of a new research network occurs through the invasion of other research areas over one which holds room for development where theories and techniques of the former are readily transferable for answering the unsolved questions in the latter.

This evolutionary branching theory of Mulkey *et al.* was supported by Perry and Rice^[4] and evidences in favour of

the same had been presented in their work. In the 20th century, tremendous increase has been witnessed in knowledge creation in almost all the research areas, though in varied rates. This could be attributed to advancement in computation and communication technologies which was the main driver of the 5th Kondratieff cycle.^[8] The advancements in software technologies, especially in visualisation and analysis of Complex networks have laid emphasis in the scientific citations analysis which could reveal the direction and rate of scientific progress.

Inspired by this advantage, T. Prabhakaran *et al.*^[9] as a case study, focused on analysis of an important research field, IT for Engineering with the objective of exploring the significance of Kuhnian model and also the concerned research field in the late 5th Kondratieff era. In,^[9] the flow of knowledge at individual work level is considered and the concept of flow vergence (divergence or convergence) is introduced. The flow divergence tendency of a work within a cluster indicates its cohesive potential to other research clusters. While convergence and passive flow indicate the tendency to grow incrementally within the confinement of the research area addressed by the cluster.

Thus divergence indicates the radical nature of work and convergence indicates incremental flavour. Results point out that most of the works and research fields (clusters) in an evolved network show a convergence dominant mode of growth and thus agree to Mulkey model. The

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occurrence of paradigm shifts is also identified in this work and hence the evidence towards Kuhnian model with the advantage of identification of the emerging fields is presented. The importance of network of publications analysis lies in the fact that, being a knowledge flow based approach, direct relationships between the intellectual works are reflected. In the online bibliometric analysis and visualization tool by Eugene Garfield, one can visualise the networks of publications as historiographs,^[12] which shows the historical evolution of the networks. Large network visualisation and analysis can also be done in a lot of other bibliographic management software packages. In,^[10] the potential of network analysis approach to identify (i) The main and critical flows of knowledge, (ii) Major Paradigm shift in the research area, (iii) Important works according to their positions and connectivity in the network of scientific publications which represents the knowledge landscape occupied by the research area and (iv) Crucial implications of the analysis for quick and efficient decision making, etc. are emphasised by the case study of Biotechnology for Engineering.^[10] The methodology used in this work is the complex network analyses which include centrality analysis and path analysis of the scientific literature collected over the time span January 1, 1999 to May 5, 2013. Here, the data from WoS undergoes a filtration process under the three level filter system. The analysis space (size of the corpus of literature) is decided by the three level filter system. Two of the filters are pre-process filters, which are provided by the WoS. They are said to be pre-process filters or preliminary filters because, they are used before data processing (in fact, data collection commences after this filtration process).

Time span of analysis is the first pre-process filter and Research area (which can be selected as an optional keyword in the advanced search provision) is the second pre-processor filter. After the data collection, the network creation is performed. In case of knowledge flow based analysis of networks, the isolated components play little role. So a third filter is imposed in order to remove the isolates. This is a post-processor filter or network filter. One of the widely used graph theoretic concepts for extracting the denser sub networks is k-cores. Using k-core ($k = 1$), isolated works are eliminated.

But the problem associated with the Kuhnian model to explain the formation and existence of a large number of different scientific fields and their interactions was overcome by the Cluster analysis. FV (Flow Vergence) index was devised to rank the clusters which were formed by LIF (Line Island Formation) algorithm.^[6] In this work, a method based on Flow Vergence gradient (FV gradient)

is devised to identify the pivot papers of paradigm shift accurately. This might reduce the need for the content analysis of the papers with high betweenness values to a considerable extent.

Implications for Science and technology policy makers

Paradigm shift (capability to connectivity model) and most of the radical innovations are identified from the path and centrality analysis. Policies to encourage the networked enterprise structures (academia industry funding agencies network) which lay special emphasis on proper interaction among members are anticipated.

Policies to promote research on management practices with special interest in networked knowledge structures of firm operation along with the scientific and technological arenas as indicated by the recent works should be formulated.

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