STRUCTURE OF RESEARCH COLLABORATION NETWORKS – CASE STUDIES ON MALAYSIA

SAMEER KUMAR

THESIS SUBMITTED IN FULFILLMENT
OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

ASIA-EUROPE INSTITUTE
UNIVERSITY OF MALAYA
KUALA LUMPUR

2013

UNIVERSITI MALAYA

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Registration/Matric No: QHA100003

Name of Degree: PhD

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STRUCTURE OF RESEARCH COLLABORATION NETWORKS – CASE STUDIES ON MALAYSIA

Field of Study: SOCIAL NETWORKING

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ABSTRACT

This study examines research collaborations in Malaysia from the perspective of networks. A research collaboration network is formed by connecting two researchers who have co-authored a research paper. Through three essay-based case studies, each representing a research question, topological properties of networks are investigated using social network analysis. In addition, some of the long-standing questions in research collaborations are answered, and an effective co-authorship strategy and a method to detect academic communities are proposed.

The first case study investigates research collaborations in the field of business and management in Malaysia. After manually disambiguating the authors, the network of 285 business and management researchers at the individual, institutional and international levels were examined. The study found that the popularity of researchers and the strength and diversity of their ties with other researchers had significant effects on their research performance. Furthermore, geographical proximity mattered in intra-national collaborations. Surprisingly, Malaysia has had relatively little collaboration with other ASEAN nations, although it is a prominent member and has an important agenda of educational cooperation with its member states. Internationally co-authored articles have been cited almost three times more frequently than locally co-authored articles. Based on these results, a strategy for co-authorship is suggested.

In the second case study, the size of the giant component of co-authorship networks was investigated in the four prominent engineering disciplines: electrical and electronics (EEE), chemical (CHEM), civil (CIVIL), and mechanical (MECH), involving 3675 scholarly articles, in which at least one of the researchers per article had a Malaysian address. Results revealed that well-formed giant components (size >50% of all nodes) were already present in EEE and CHEM disciplines, whereas they were at an undeveloped

stage in both CIVIL and MECH. However, those with larger giant components also had larger degree of separation (geodesic distance) between the nodes. Density of the nodes was negatively correlated with the size of the giant component. After the mid-1990s, both CHEM and EEE had a faster production of articles than the other two disciplines, corresponding with their well-formed giant components.

The third case study, collaborative patterns of Malaysia, was compared with another OIC country, Turkey, in the fast-developing field of Energy Fuels. The popularity, position and prestige of the authors in the network, as determined through centrality measures, had statistically significant effect on research performance. However, these measures were far more correlated with the research performance of the authors in the Malaysia network than in the Turkey network. Authors' degree ('deg-core') was applied to reach to the core of network, which in contrast to standard K-Core method, was found to capture more productive authors. A method to detect academic communities of productive authors by extracting *motifs* (large cliques) from the network is suggested. Finally, the cognitive structures of both countries using a 2-mode network representing research focus areas (RFAs) and prominent authors working in these RFAs were visualized.

ABSTRAK

Kajian ini mengkaji kolaborasi penyelidikan di Malaysia daripada perspektif rangkaian. Satu rangkaian kolaborasi akan wujud dengan menghubungkan dua orang penyelidik yang telah bersama-sama menghasilkan satu kertas penyelidikan. Berdasarkan tiga kajian kes berbentuk esei yang setiap satunya mempunyai satu persoalan kajian, maka sifat topologi rangkaian ini dikaji dengan menggunakan analisis rangkaian sosial. Selain itu, sebahagian persoalan yang telah wujud sekian lama dalam kolaborasi penyelidikan dapat dijawab serta satu strategi penulisan bersama secara efektif dan cara mengenal pasti komuniti akademik telah dikemukakan.

Kajian kes yang pertama telah mengkaji kolaborasi penyelidikan dalam bidang perniagaan dan pengurusan di Malaysia. Satu rangkaian yang terdiri daripada 285 orang penyelidik dalam bidang peniagaan dan pengurusan di peringkat individu, institusi, dan antarabangsa telah dikaji. Kajian mendapati bahawa populariti penyelidik, kekuatan serta kepelbagaian jalinan antara para penyelidik yang lain telah mempengaruhi prestasi penyelidikan mereka. Di samping itu, jarak kedudukan geografi yang berdekatan turut memberi kesan kepada rangkaian kolaborasi dalam negara. Walaupun Malaysia merupakan negara ahli ASEAN yang penting dan mempunyai agenda dalam kerjasama pendidikan, namun secara relatifnya tahap kerjasama Malaysia dengan ahli-ahli ASEAN yang lain adalah rendah. Artikel-artikel hasil penulisan bersama antarabangsa telah dipetik hampir tiga kali lebih kerap berbanding artikel-artikel penulisan bersama para penyelidik tempatan. Atas sebab ini, satu strategi untuk penulisan bersama telah dicadangkan.

Kajian kes kedua telah mengkaji saiz ‘giant components’ rangkaian penulisan bersama dalam empat disiplin utama bidang kejuruteraan, iaitu elektrik dan elektronik (EEE), kimia (CHEM), sivil (CIVIL), dan mekanikal (MECH). Kajian ini merangkumi 3675 buah artikel ilmiah yang mana setiap artikel itu mempunyai sekurang-kurangnya seorang

penyelidik yang beralamat di Malaysia. Dapatan menunjukkan bahawa 'giant components' (bersaiz > 50% daripada semua nod) sudah sememangnya wujud dalam disiplin EEE dan CHEM, manakala dalam disiplin CIVIL dan MECH pula, 'giant components' ini masih lagi belum berkembang. Walau bagaimanapun, bagi yang mempunyai 'giant components' yang lebih besar, darjah pemisahan atau 'geodesic distance' antara nod-nod juga adalah besar. Kepadatan nod-nod ini mempunyai hubung kait yang negatif dengan saiz 'giant component'. Selepas pertengahan tahun 1990-an, disiplin CHEM dan EEE lebih banyak menghasilkan artikel-artikel berbanding disiplin-disiplin yang lain. Ini adalah hasil daripada 'giant components' yang telah terbentuk dengan sempurna.

Kajian kes ketiga adalah perbandingan corak kolaborasi di Malaysia dengan sebuah negara OIC, iaitu Turki. Kajian ini tertumpu dalam bidang 'Energy Fuels'. Prestasi penyelidikan dipengaruhi oleh populariti, kedudukan, dan prestij para penyelidik di dalam rangkaian tersebut. Walau bagaimanapun, pendekatan ini hanya mempunyai hubung kait dengan rapat dengan prestasi para penyelidik dalam rangkaian Malaysia berbanding rangkaian di Turki. Ijazah atau kelulusan para penyelidik ('deg-core') yang bertentangan dengan pendekatan 'K-core', telah diguna pakai untuk mencapai teras rangkaian yang telah berjaya mengumpulkan lebih ramai penulis yang produktif. Kaedah mengasingkan kumpulan-kumpulan besar (*large clique*) daripada rangkaian untuk mengenal pasti komuniti akademik yang terdiri daripada penulis-penulis yang produktif telah dicadangkan. Akhir sekali, struktur kognitif kedua-dua buah negara telah dapat ditunjukkan dengan jelas dengan menggunakan rangkaian 2-fungsi yang mewakili bidang-bidang fokus penyelidikan (RFA) dan penulis-penulis utama yang terlibat dalam RFA ini.

DEDICATION

Dedicated to my late father SRI SWARNENDU VERMA

ACKNOWLEDGEMENTS

First and foremost, I would like to thank Associate Prof. Dr. Md Nasrudin Bin Md Akhir, Executive Director, Asia-Europe Institute, Dr. Azmi Mat Akhir, Deputy Executive Director (Academic), Asia-Europe Institute and Dr. Siti Rohaini Binti Kassim, Deputy Executive Director (Research & Services), Asia-Europe Institute, for their continued encouragement and for supporting my candidature for funding under the Brightsparks Scheme of University of Malaya.

I am indebted to my supervisor, Associate Professor Dr. Jariah Mohd. Jan with whom I have had an association since 2008. She not only provided the mentorship and expert guidance for my PhD work, but also inspired me, especially when I was emotionally drained by father’s sickness and eventual demise.

My association with AEI has lasted for more than four years, since I entered the International Master’s Program in 2008. Returning to school after working full-time for over 14 years, was not easy. It took me some time to adjust but once I did, I was pleased with my decision. I have been touched by the warmth and collegiality of the staff at what I proudly call "my Institute”. Our PhD room (the "Singapore room") on the third floor is just next to Dr. Azmi’s office. Occasional chats with Dr. Azmi often gave me renewed encouragement.

It is been over a decade since I decided to earn the PhD. My late father, Sri Swarnendu Verma helped me to keep this flame from extinguishing. But for his advice and the research atmosphere at the University, re-energized by Honorable Vice Chancellor, Tan Sri Dr. Ghauth Jasmon, I would probably have returned to my home country upon completion of my master’s program.

I am also thankful to my PhD colleagues for their friendship. Without them my PhD would have certainly lacked vitality. The PhD is a tough road to traverse, which not many would tread if they knew what lay ahead. These friends came from such diverse countries as Iran and Pakistan and we inspired and helped each other. They made this vibrant town even more so, and I will miss all of them.

I am indebted to my mother Sheela Verma, my wife, Neha Sinha and my son Tanmay Verma, who have been with me throughout this entire PhD journey. The last three years have been difficult for them, especially for Tanmay, who missed me immensely, while I was away in Malaysia.

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List of Common Abbreviations

SNA	Social Network Analysis
WoS	Web of Science
ISI	Institute of Scientific Information
SCI	Science Citation Index
SSCI	Social Science Citation Index
RQ	Research Question
CHEM	Chemical Engineering
CIVIL	Civil Engineering
EEE	Electrical and Electronics Engineering
MECH	Mechanical Engineering
BM	Business and Management
ASEAN	Association of South East Asian Nations
OIC	Organisation of Islamic Co-operation
9MP	Ninth Malaysia Plan
10MP	Tenth Malaysia Plan
RFA	Research Focus Area
KDV	Knowledge Domain Visualizations

List of Publications during PhD

Kumar, Sameer. "Analyzing Social Media Networks with Nodexl: Insights from a Connected World." Information Research-an International Electronic Journal 16, no. 2 (2011). *Indexed in ISI Web of Science Tier 2 (Q2)*

Kumar, Sameer. "The New Edge in Knowledge: How Knowledge Management Is Changing the Way I Do Business." Knowledge Management Research & Practice 10, no. 1 (2012): 99-101. *Indexed in ISI Web of Science Tier 2 (Q2)*

Kumar, Sameer. and Jariah Mohd. Jan. "Social Networks and the Business Value of Social Media." In International Conference on Humanities, Society and Culture (ICHSC 2011), 20, 12-16. Kuala Lumpur, Malaysia, 2011.

Kumar, Sameer. and Jariah Mohd. Jan. "Hubs as Catalysts for Geospatial Communication in Kinship Networks." International Journal of Social and Human Sciences 6, (2012): 548 -550.

Kumar, Sameer. and Jariah Mohd. Jan. ""I'll E-Mail You a Handshake": Is Social Media Making Us Virtual ?" In National Conference on Social Networking (NCSN 2012), 1-4. Hyderabad, India 2012.

Kumar, Sameer. and Jariah Mohd. Jan. "Mapping the Structure, Evolution and Geo-Spatiality of a Social Media Network." International Journal of Physical Sciences 7, no. 13 (2012): 2038-2051. *Indexed in ISI Web of Science Tier 2 (Q2) –JCR 2010*

Kumar, Sameer. and Jariah Mohd. Jan. "Social Media's Impact on Teenagers and Women." In International Conference on Libraries, Information and Society (ICOLIS 2012). Kuala Lumpur, Malaysia, 2012.

Kumar, Sameer. and Jariah Mohd. Jan. "Research Collaboration Networks of two OIC Nations: Comparing work in the field of 'Energy Fuels' in Turkey and Malaysia, 2009-2011" Scientometrics, (2013). *Indexed in ISI Web of Science Tier 1 (Q1)*

Kumar, Sameer. and Jariah Mohd. Jan. "On Giant Components in Research Collaboration Networks: Case of Four Engineering Disciplines in Malaysia." Malaysian Journal of Library and Information Science. (2013). *Indexed in ISI Web of Science Tier 3 (Q3)*

Kumar, Sameer. and Jariah Mohd. Jan. "Discovering Knowledge Landscapes: An Epistemic Analysis of Business and Management Field in Malaysia", In International Congress on and in Procedia – Social and Behavioural Sciences (2013) – *Indexed in Scopus*

Kumar, Sameer. Review of "Understanding Social Networks: Theories, Concepts and Findings." Information Research-an International Electronic Journal 18, no. 1 (2013). *Indexed in ISI Web of Science Tier 2 (Q2)*

Kumar, Sameer. and Jariah Mohd. Jan. "Mapping research collaborations in the business and management field in Malaysia, 1980–2010" Scientometrics (2013). *Indexed in ISI Web of Science Tier 1 (Q1)*

Case studies in the present PhD dissertation published in ISI-Web of Science Indexed journals

All three case studies coming out from the present thesis have been published in ISI Web of Science indexed journals:

1. Kumar, Sameer. and Jariah Mohd. Jan. "Mapping research collaborations in the business and management field in Malaysia, 1980–2010" Scientometrics* (2013). *Indexed in ISI Web of Science Tier 1 (Q1)*

   (Case Study 1 representing the Research Question -1)

   Online link to the article:
   http://link.springer.com/content/pdf/10.1007/s11192-013-0994-8

2. Kumar, Sameer. and Jariah Mohd. Jan. "On Giant Components in Research Collaboration Networks: Case of Four Engineering Disciplines in Malaysia." Malaysian Journal of Library and Information Science**. (2013). *Indexed in ISI Web of Science Tier 3 (Q3)*

   (Case Study 2 representing the Research Question -2)

   Online link to the article:
   http://ejum.fsktm.um.edu.my/ArticleInformation.aspx?ArticleID=1375

3. Kumar, Sameer. and Jariah Mohd. Jan. "Research Collaboration Networks of two OIC Nations: Comparing work in the field of 'Energy Fuels' in Turkey and Malaysia, 2009-2011" Scientometrics*, (2013). *Indexed in ISI Web of Science Tier 1 (Q1) –*
   Online link to the article:
   http://link.springer.com/article/10.1007/s11192-013-1059-8

   (Case Study 3 representing the Research Question -3)

**Scientometrics* is a foremost 'international journal for all Quantitative Aspects of the Science of Science, Communication in Science and Science Policy'. The journal is in ISI Web of Science Tier 1 (Q1), JCR 2011

** *Malaysian Journal of Library and Information Science* is a leading journal in South-East Asia and 'publishes original research articles in the field of library and information science (LIS) as well related domains that encapsulate information and knowledge'. The journal is in ISI Web of Science Tier 3 (Q3), JCR 2011

CHAPTER 1: INTRODUCTION

1.1 Background of the study

Academic institutions, researchers, and the academic community are embedded in complex networks that play crucial role in the development and evolution of learned societies. The social and cognitive processes that stimulate scientific knowledge have kept mankind curious for centuries (Racherla & Hu, 2010). Patterns of human interaction have remained a topic of significant interest in the field of social sciences during the last 50 years (Newman, 2003; Wasserman & Faust, 1994). The production and dissemination of scientific knowledge, grounded in cognitive science and psychology, often has a social context (Pepe, 2008). The social function through which scientists come together to collaborate contributes to the output of research community. Recent decades have seen phenomenal increase in research publications, which is attributed to increased interaction among researchers. The formal and informal channels through which the researchers collaborate are often facilitated by social networks. The success of scientific ties depends to a large extent on the strength of these relationships. An in-depth analysis of knowledge networks provides an opportunity to investigate its structure. For example, patterns of these relationships could reveal the mechanism that shapes our scientific communities (Racherla & Hu, 2010).

The study of social relationships is fundamental to social sciences. Social network theory provides an answer to the question of social order and an explanation of social phenomena (Borgatti, Mehra, Brass, & Labianca, 2009). As anthropologist Radcliff Brown wrote (Radcliffe-Brown, 1940),

> "..direct observation does reveal to us that these human beings are connected by a complex network of social relations. I use the term " social structure " to denote this network of actually existing relations" (p.2).

1.1.1 Research collaborations

Creating scientific communities is primarily a social function, where researchers associate from within their department and institution or from other institutions or countries and integrate their expertise to accomplish research goals. Collaboration is a process in which knowledge and innovation flow among scientists, and individual scientists thus acquire access to new “capital” directly through collaboration between individuals and indirectly through the collaborators of their collaborators (Yin, Kretschmer, Hanneman, & Liu, 2006). Research collaboration is a key mechanism that links distributed knowledge and competencies into novel ideas and research avenues (Heinze & Kuhlmann, 2008). In other words, research collaboration connects different sets of talent to produce a research output.

In recent years, the scientific community and policy analysts have become increasingly interested in research collaborations. There have been numerous initiatives to increase collaboration among individual scientists as well as between sectors – such as university and industry and to encourage international collaboration.(Katz, 1994).

Scientists communicate with one another to exchange opinions, share research results and write research papers (Katz & Martin, 1997). On the one hand, communication among scientists could start with a simple discussion that leads to collaboration on a research project. On the other hand, scientists may decide to collaborate with scientists with whom they are already acquainted, knowing well their ability to carry out a research project.

In another scenario, prospective collaborators can meet at conferences or at other forums and form an "invisible college" (Crane, 1972). These informal exchanges may lead scholars to find a shared interest in a topic and to make a decision to collaborate on a research paper. Hence, a variety of reasons could bring a group collaborators together.

A journal article is a tangible knowledge output. Authors who contribute to knowledge are agents of knowledge. Although authors are not aware of others beyond their circle, there is a wider network through which knowledge flows. It is like being caught in a traffic jam and seeing only the cars and buses. From a helicopter, it is possible to get a better view of the traffic. Network analysis is like a helicopter from which we are able to see what are seemingly invisible connections (Kadushin, 2011). Co-authored research papers are a one of the common unit of analysis by which to gauge research collaborations (Katz & Martin, 1997).

1.1.2 Network approach

According to the network approach, power (social power), a fundamental aspect of social structures, is inherently relational (Hanneman & Riddle, 2005). Unlike the conventional individualistic social theory that pays more attention to an individual's personal attributes than to his or her social circumstances (Knoke & Kuklinski, 1982) network analysis gives prominence to the relationship that one individual has with another. Attributes of entity are not ignored, but are rather seen in the context of the relationship. Network analysis in the form of citation analysis, co-authorship analysis, co-word occurrence analysis, and other indicators of knowledge production and scientific discovery have remained an important tool for bibliometric analyses. Among associations made off-line (not online such as those thorugh, for example, Facebook and twitter), co-authorship networks are arguably the only true representation of human acquaintance patterns for which numerous data points exist and a more precise definition of connectedness can be made (Newman, 2001c).

This study explicates research collaboration through a social network lens. In a social network, two entities (nodes) form a connection (edge) if a relationship exists between them. For example, a group of individuals can form a network if they are friends with one another. Likewise, airlines, roads, food webs, protein interactions, and the like could form networks. In similar fashion, in a co-authorship network, two authors form a connection if they have co-authored a research paper. Co-authorship networks are one of the the largest publically available form of social networks. Moreover, because these networks are based on bibliographic data, they are free from subjectivity, which is a common drawback in questionnaire-based network studies (Newman, 2004b). Although there is a growing debate over what constitutes research collaboration (Katz & Martin, 1997), one of the most verifiable ways to examine it is to look at co-authorships of research papers (Glänzel & Schubert, 2005). It goes without saying that those co-authoring a paper together cannot do so unless a fair degree of acquaintance exists between them (barring cases of *ghost* authorships).

Co-authorship networks, to a fair degree, represent the social and cognitive structures of an academic community. Network analysis is often used to identify authors who are central to the academic community being studied. Such studies provide information on how authors can control the flow of communication and resources in the community. It can generate a picture of how closely knit or fragmented an academic community is. If key authors cease writing papers, perhaps the academic community to which they belong may fall apart.

Price (1963) was one of the first to report that the number of collaborative journal articles was rising. The number of authors per paper depends on the discipline. Disciplines that are more experimental (e.g. high energy physics), tend to have more co-authors on a paper than those that are theoretical (e.g. mathematics) disciplines (Newman, 2004b). Experimental fields, which tend to be based more on observation than on theory, often require more assistance with laboratory experiments.

Several studies on co-authorship have emerged since the 1960s (Beaver, 2001; Glänzel & Schubert, 2005; Melin & Persson, 1996; Price & Beaver, 1966). Newman's work

(Newman, 2001a, 2001b, 2001c), used network topologies to investigate the local and global properties of co-authorship networks. Newman has prompted renewed scholarly interest in investigations of co-authorship from a social network perspective. Since Newman's work, numerous studies have been conducted on co-authorship networks in both the natural (Newman, 2004a) and social sciences (Moody, 2004). Some scholars have carried out interdisciplinary comparative studies (Newman, 2001c, 2004a). On the one hand, some researchers have selected few important journals (Hu & Racherla, 2008; Quatman & Chelladurai, 2008) while others have concentrated on a single one (Fatt, Abu Ujum, & Ratnavelu, 2010). On the other hand, some have looked at co-authorship from the perspective of multiple countries (Persson, Melin, Danell, & Kaloudis, 1997) or a single country (Harirchi, Melin, & Etemad, 2007). Several researchers have examined the popularity, position, strength, and diversity of ties and their association with research productivity (Kuzhabekova, 2011; Uddin, Hossain, Abbasi, & Rasmussen, 2012; Yan, Ding, & Zhu, 2010) and have then suggested co-authorship strategies (Abbasi, Altmann, & Hossain, 2011; Abbasi, Chung, & Hossain, 2011; Kuzhabekova, 2011). Researchers have also explored the important features of research collaboration, such as geographical proximity and assortative mixing to determine if physical distance and similarity can bring researchers together (Katz, 1994; Newman, 2002).

1.2 Problem statement

Although co-authorship networks have been studied from several perspectives, there is minimal research on Malaysia. At the 6th Malaysia Plan in 1991, one of the important agendas was to "establish a scientific and progressive society" (www.epu.gov.my). Toward this end, several Malaysia Plans have been undertaken to improve the nation's

R&D infrastructure and create first-class human resources. In addition to hundreds of private institutions, Malaysia has 20 public universities, five of which are research universities (RUs). In 2009, under the 9th Malaysia Plan (2006-2010), more than US $2.4 billion was allocated to the Ministry of Higher Education (MOHE) with the primary task of carrying out research in the hard sciences, social sciences, arts and humanities, and improving the quality of higher education (Abrizah & Wee, 2011). Universities, especially those in the public sector, have been preparing to increase their research output. MOHE, through the Malaysia Research Assessment Instrument (MyRA), recognizes papers indexed in the Thomson Reuters' Web of Science (WoS) and Scopus to empirically gauge quality research production by academicians and universities. Research is thus an important objective of the Malaysian government and a study such as this will provide valuable information about the country's research performance.

Following are the general objectives that encompass the three main main objectives and hence the three main questions:

1. In a prominent discipline, investigate research collaboration at multi-levels (individual, institution and international levels).
2. Answer some of the long-standing research question on research collaborations such as,
    a. Whether collaboration promotes research productivity
    b. Whether structural position of authors in the network has an effect on research productivity
    c. Whether geographical proximity matters in research collaboration
3. Suggest an effective co-authorship strategy based on the results
4. Giant components represent core of research activity in a community. In the context of Malaysia, using a discipline-wise comparative study, examine specific factors contributing to the formation of giant components.

5. Compare Malaysia with another country in a prominent discipline and examine the differences in the collaborative patterns of researchers.
6. Propose a method to reach out to the core of productive authors and detect communities of productive authors
7. Suggest a method to depict the cognitive structure of a research community that includes both prominent research focus areas and prominent researchers.

The overall objective is divided into three main objectives. The aims 1, 2 and 3 above refer to the 1 first objective; aim 4 refers to the second objective and aims 5, 6,and 7 refer to the third objective. The rationale of the 3 objectives are delineated below:

The three research objectives that correspond with the three research questions. Each research question represents a case study or essay on research collaborations in Malaysia. The purpose of the first research question is to conduct an in-depth examination of research collaboration networks of a social science-based research domain in Malaysia at individual, institutional and international levels in order to suggest an effective co-authorship strategy. In the second research question, one of the prominent topological features of network is applied to carry out a comparative study among prominent engineering-based research disciplines in Malaysia. In the third research question Malaysia is compared with another OIC nation, in a science discipline. Here I also suggest a method of identifying academic communities. The three essays represent distinct cases (as they have different datasets), yet are connected by its overall objective. Hence I also refer to them as essay-based case studies.

Table 1.1 depicts the research objective, the research question and the corresponding case study. More specifically, the research questions attempt to answer sub-questions, among others.

Table 1.1: Research Objectives, Research questions and corresponding case study of the present study

	Research Objective	Research Question	Corresponding Case Study
1	To carry out a detailed analysis of research collaborations in the discipline of business and management in Malaysia at individual, institutional and international levels, answer some of the longstanding research questions in the field and then suggest a co-authorship strategy	**RQ1** What is the state of research collaborations in the business and management discipline in Malaysia at the individual, institutional and international levels?	Case Study – 1
2	To examine the size of giant component, its association with other topological measures and pace of yearly paper production for a country-specific dataset pertaining to Malaysia of four prominent engineering	**RQ2** What is the size of giant component, its correlation with other topological properties and its relationship with the pace of paper production, in the country-specific dataset pertaining to	Case Study -2

	Research Objective	Research Question	Corresponding Case Study
	disciplines as per WoS subject categories: namely - chemical engineering (CHEM), electrical and electronics engineering (EEE), civil (CIVIL) engineering and mechanical engineering (MECH).	Malaysia of four prominent engineering disciplines as per WoS subject categories, namely - chemical engineering (CHEM), electrical and electronics engineering (EEE), civil (CIVIL) engineering and mechanical engineering (MECH)?	
3	To examine research collaborations in the area of ‘energy fuels’ from the lens of social networks by carrying out a comparative study of two OIC nations – Turkey and Malaysia and propose a method of community detection.	**RQ3** How do collaborative networks of Malaysia and Turkey, the two OIC nations, compare with each other in the field of energy fuels?	Case Study – 3

Figure 1.1 depicts how these three research questions are related.

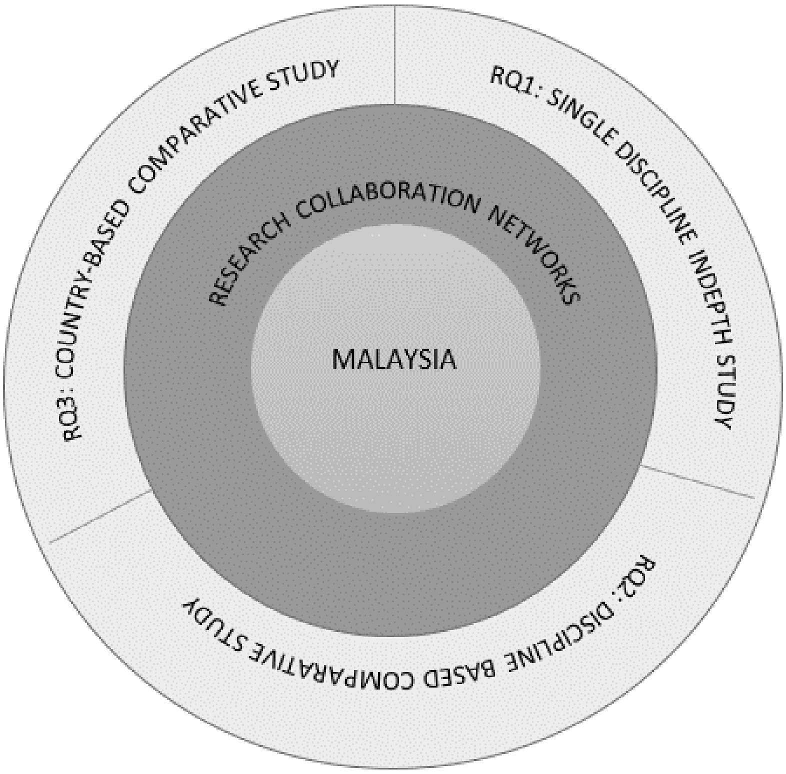


Figure 1.1: How the three case studies are related.

1.2.1 Research Question #1 (RQ1)

What is the state of research collaboration in business and management in Malaysia at the individual, institutional and international levels?

To answer this research question, a detailed analysis of research collaborations in the business and management (BM) discipline in Malaysia is carried out. 'Business' can be defined as a commercial enterprise that trades in goods and services, and 'Management' can be defined as any people-centric integrating activity. Given these definitions, it is almost impossible for one to exist without the other. The central concepts that encompass business and management are business, management, organization, and organizational behavior, among others. ‘Business and Management’, one of the most prominent social sciences disciplines (along with economics) is a growing discipline in Malaysia.

This research question has following sub-objectives and sub-questions:

1. Using bibliometrics and network analysis, examine research collaborations within the field of Business and Management in Malaysia at the individual, institutional, and international levels.
2. Using the acquired dataset answer long-standing questions in research collaborations such as:
   - 2.1. Are collaborative papers cited more often than individually authored papers? Are foreign-collaborated papers cited more often than locally co-authored papers?
   - 2.2. What is the effect of popularity, position, prestige, tie-strength, and diversity of ties among researchers in a co-authorship network on research productivity? More specifically, this research question attempts to answer the following sub-questions:
     - 2.2.1. What is the effect of popularity, position, and prestige of the authors in the network, as represented by its *Degree*, *Betweenness centrality*, and *PageRank*, respectively, on research productivity?
     - 2.2.2. What effect does the diversity of ties, as expressed through the *Structural holes measures* of *Efficiency and Constraint* have on research productivity?
     - 2.2.3. What effect does the strength of ties, as computed through *tie-strength* have on research productivity?
   - 2.3. Based on the degree of connections, what is the level of *Assortativity* between researchers?
   - 2.4. Does *geographical proximity* impact the frequency of collaboration among researchers?

3. Based on the results, suggest a co-authorship strategy for researchers.

1.2.2 Research Question #2 (RQ2)

What is the size of giant component, its correlation with other topological properties and its relationship with the pace of paper production, in the country-specific dataset pertaining to Malaysia of four prominent engineering disciplines as per WoS subject categories, namely - chemical engineering (CHEM), electrical and electronics engineering (EEE), civil (CIVIL) engineering and mechanical engineering (MECH)?

Most previous studies on giant components in co-authorship networks have been specific to subject area. Here, the size of giant component is calculated for a country-specific dataset pertaining to Malaysia of four prominent engineering disciplines as per WoS subject categories, namely - chemical engineering (CHEM), electrical and electronics engineering (EEE), civil (CIVIL) engineering and mechanical engineering (MECH). Being country-specific, it is understood that a majority of the authors would represent Malaysia, although there would be international counterparts with whom the Malaysian authors would have collaborated.

More specifically, this research question attempts to answer the following sub- research questions:

1. What is the size of giant components in the collaborative networks in the aforesaid four engineering disciplines in Malaysia, based on ISI Web of Science subject categories?
2. Is there any correlation between the degree, density, clustering coefficient and degree of separation between the nodes in the network and the size of giant components?

3. Does the pace of paper production has any relationship with the formation of giant component?

1.2.3 Research Question #3 (RQ3)

How do collaborative networks of Malaysia and Turkey, the two OIC nations, compare with each other in the field of 'energy fuels'?

Our world runs on 'energy' and access to affordable energy is essential not only for running modern industry but to meeting our own basic necessities - such as, providing electricity to our homes and running our cars. As the world economy expands, the energy demand is likely to increase, despite efforts to increase energy efficiency (Poole et al., 1992). The history of the Industrial Revolution proves that a nation's economic growth is inevitably linked to its energy supply. Energy fuels, remains an important and expanding research field; an April 2013 query in Web of Science indicates a more than threefold increase in the number of published papers since 2001.

Through the third research question, I examine research collaborations in the area of energy fuels through the lens of social networks by comparing two OIC nations: Turkey and Malaysia. Both countries are growing economies in Asia and Europe, with almost similar per capita income (PPP) and significant R&D investment in energy.

Prior bibliometric studies have rarely looked into discipline-based comparative studies that use social network analysis to understand collaborative patterns of authors in an academic community. Moreover, no studies, to our knowledge, have compared the scholarly networks of Turkey and Malaysia in the field of energy fuels.

This research question has the following sub-objectives and sub-questions:

1. Examine the topological properties of the collaborative networks of Turkey and Malaysia, and more specifically, attempt to answer the following research questions:
    1.1. Whether the giant components of the two networks follow 'small world' model?
    1.2. Based on Centrality measures who are the key researchers in the networks?
    1.3. What is the effect of degree (depicting popularity), closeness and betweenness (both depicting position) and PageRank (depicting prestige) on research performance?
2. Visualize the 'core' of researchers where most productive researchers could be located.
3. Investigate if researchers in the *motif* (large cliques) based communities are more productive than the rest of researchers in the giant component
4. Visualize prominent Research focus areas (RFAs) in the field of energy fuels and their association with prominent authors working in these RFAs.

1.3 Scope of research

This study examines the state of research collaboration in Malaysia from three perspectives (see Figure 1.1). Researchers in Malaysia publish their papers by presenting their work at conferences and submitting articles to research journals. These journals are published in both English and vernacular languages. Only a small number of these journals are indexed by the WoS databases. For example, in case study 1, the search restrictions for this research are articles indexed by WoS that have "Malaysia" as an address in the author address field and the subject of "business" or "management." For example, Researcher X has published 24

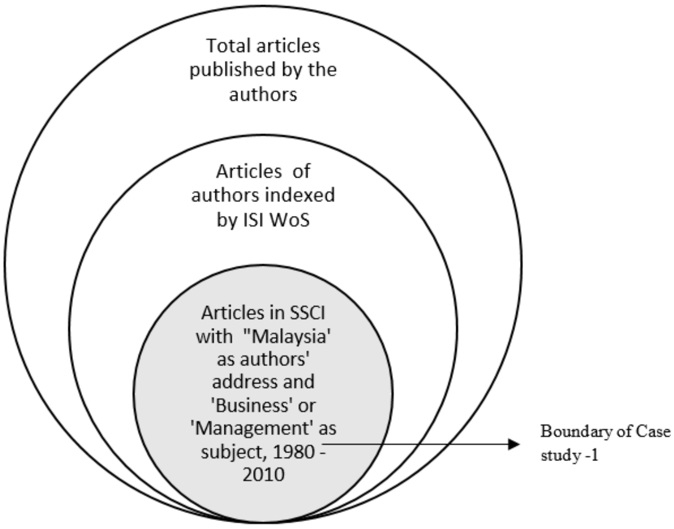


Figure 1.2: Scope of case study 1.

articles indexed by ISI WoS (four in the SCI database and 20 in SSCI database). The "Malaysia" address and "business" and "management" subjects for this author in the SSCI database filters the total to eight articles. Hence, only these eight articles of Researcher X become part of our study. Categories, as mentioned in the WoS SSCI database, are followed.

As an example, Researcher A has published 20 articles indexed by ISI Web of Science (4 in SCI database and 16 in SSCI database). "Malaysia" address and "Business" and "Management" subjects of this author in SSCI database filter out only six articles. Hence only these six articles are part of our study.. The two other case studies have similar limitations of scope.

In case study 1, although business and management are two distinct fields as per the ISI-categories (as of ISI WoS 2011), there are numerous overlaps between the two disciplines. In universities around the world, these two categories are found within a single university department. It is for this reason, when selecting a research domain I have considered these two disciplines together.

Case study 2 follows the WoS category for subjects. EEE, CHEM and MECH are the top categories based on the number of papers published. Although Environmental Engineering had more papers published than civil engineering (CIVIL), latter one is chosenas CIVIL is one of the more common engineering departments at universities in Malaysia and often environmental engineering is taken as a subset of civil engineering. WoS subject category are non-heirarchial and based on journal's title, its citation patterns, etc. (Leydesdorff & Rafols, 2009). They reflect the overall content of the journals pooled into them. A journal may be categoried into multiple categories depending on its multidisciplinary material. All articles get tagged with the categories at the journal level. For example, *Journal of Hazardous Materials* is categoried in Environment Engg., Civil Engg. and Environment Sciences, subject categories. Hence, all articles published in this journal, irrespective of its content, will be categoried in all these three categories. By categorizing the journals based on relevance (type of journals citing the journal) and not with hierarchy, WoS subject category handles the multi-disciplinary issue of the journals and articles quite effectively.

In case study 3**,** the three-year publication window (2009-2011) was used to capture recent collaborative patterns and identify the top collaborative authors. In co-authorship networks, several authors, after a certain period of activity, eventually cease to publish (Fatt et al., 2010). Known as *ghost* vertices, such authors remain frozen in time. I wanted to eliminate, or at least reduce, this effect in the present analysis. Moreover, because this studydoes not track the evolution of a co-authorship network, taking a larger window was redundant. Technically too, a 3-year period may be considered reliable for assessment of research performance in the hard sciences (Abramo, D'Angelo, & Cicero, 2012). There is always a possibility that some authors, for example, might not have co-authored a journal article but would have presented a paper at a conference. Hence, all five ISI Web of Science databases and all types of documents were considered for our analysis.

1.4 Significance of the study

The present study will help various stakeholders, from doctoral course applicants looking for an institution where they can find a thesis advisor to institutions in which high-volume and high-impact scholarly work output increases the institution's reputation and ranking (Serenko, Bontis, & Grant, 2009). Malaysia, under its 9MP and 10MP Malaysia Plans, now aspires to have its research universities (University of Malaya, University Putra Malaysia, University Kebangsaan Malaysia, University Technology Malaysia and University Science Malaysia) ranked among the best in the world. These universities are taking initiatives to improve their quality of education and especially their research. To this end, vice chancellors are working assiduously to improve faculty research output through research incentives and setting of Key Performance Indicators (KPIs). This study would assist government institutions and policy makers by providing further clues on research collaborations and topics of research interest.

One of the crucial assets of an institution is its reputation, and research is the cornerstone of an institution's reputation (Abrizah & Wee, 2011). Countries might use research productivity and scholarly communication data to benchmark and develop their academic policies (Serenko et al., 2009). Researchers could incorporate aspects of the co-authorship strategy suggested here to seek out beneficial associations and thus increase the likelihood that their research will be better received by their academic community.

Furthermore, the study would be of interest to scientometricians looking for a newer perspective on research collaborations networks, especially those that involve comparative study. It would explain whether or not centrality affects research performance or if geographical proximity still matters in intranational collaborations. New ideas on reaching out to the core of researchers, identifying communities of researchers and network visualization by dual-representation of prominent research areas and researchers, would provide a basis for continued research.

The research would benefit field researchers in the fields of business, management and energy fuels by revealing the best connected authors in the field, popular topics and the key researchers. A study such as this will also motivate researchers to conduct studies into lesser-known countries that seek to expand their horizons and contribute to the world's body of scientific literature.

1.6 Organisation of the thesis

In this chapter the rationale for the study is presented, the problem statement and the significance of the study.

In chapter 2, a literature review is presented. In chapter 3, I discuss the source data used for our analyses and the method applied in organizing the records and calculating social network metrics. Social Network Analysis is used for all the case studies. Data harvesting and related methods are discussed in separate sections for each research question.

In chapter 4, Bibliometric statistics is discussed and then co-authorship networks are analysed. The results of each case study are discussed individually. For the first research question, co-authorship networks at the individual, institutional, and international levels are analysed. Then I present the findings on the relationship and effect of Social Network Analysis measures on research productivity, the effect of geographical distance on frequency of collaboration, and assortativity due to authors' degree of connections. In the next section, based on the results, a co-authorship strategy is suggested. For the second research question the size of giant components, the correlation of other topological measures and the size of giant components, and the association of pace of yearly paper production on the size of giant component are ascertained For the third research question the topological analysis, effect of centrality measures on research performance, detecting the "core" of networks where most productive researchers are located, examining clique-based communities and finally, representing prominent authors and research focus areas using 2-mode network visualization are presented.

Chapter 5 summarizes the key findings. I conclude with the presentation of research limitations, contribution to the body of knowledge and directions for future research.

CHAPTER 2: LITERATURE REVIEW

This chapter discusses the research background of the study. The study integrates two distinct bodies of research, research collaborations and network approach to research collaborations, presented in two main sections of the literature review.

2.1 Research collaborations

The primary measure of research collaboration has long been joint authorship or co-authorship in a paper. Beaver (Beaver, 2001; Beaver & Rosen, 1978) presented a history of research collaboration, starting as early as 1800, when collaboration in papers was a prerogative of the French chemists. The study of research collaborations emerged from a larger field of Scientometrics. Hence, an overview of this field would provide a basis for better understanding of this field. Scientometrics involves “the quantitative methods of the research on the development of science as an informational process” (Nalimov & Mulchenko, 1969). Vassily V Nalimov coined the word Scientometrics (*Naukometriya*, in Russian) in 1960s and since then, it has been used to describe the study of science in terms of its growth, structure, inter-relationships and productivity (Hood & Wilson, 2001). During 1960s, Derek John de solla Price carried out some pioneering work on the quantitative indicators in formulating science policy, with classics such as Science Since Babylon (Price & Weber, 1961), Little Science Big science (Price, 1963) and an article in Science on ‘the Network of Scientific Papers’ (Price, 1965). Scientometrics overlaps heavily with Bibliometrics. According to Pritchard (1969), Bibliometrics is the “application of mathematics and statistical methods to books and other media of communication”. Bibliometrics has focused largely on the literature (i.e., papers, patents), the tangible output of science and technology in the public domain. However, there is much more to science, such as practices of researchers, the socio organisational structure, R&D Management, government policies, and the like, which are effectively covered by Scientometrics (Hood & Wilson, 2001). Due to the increased capacity of computer storage and faster processors, it is now possible to analyse and measure large document sets. Scientometrics focuses more on the measurement and analysis, leaning more towards policy studies. Bibliometrics, on the other hand, leans more towards library studies. The speciality is data driven, using archival records of scientific communication in the form of citations, addresses, substantive messages (i.e., keywords), and relational information to reconstruct patterns and identify the hidden characteristics of both authors and documents. Works of Kuhn (1996) and Price (1965) provided a link between philosophical issue of the growth of scientific knowledge and the sociological quest on that the production of knowledge. Kuhn emphasized the relations among authors working within paradigms and the growth of knowledge while Price highlighted the relationship between knowledge growth and document sets (Leydesdorff, 2001).

The statistical analysis of scientific literature began almost five decades before the pioneering works of Price. Lotka (1926) published his pioneering work on the frequency distribution of scientific productivity and concluded that "the number (of authors) making n contributions is about $1/n^2$ of those making one; and the proportion of all contributors, that makes a single contribution, is about 60 per cent." In short, few authors publish large number of papers and a large group of authors that publishes few or just one. Lotka's work on frequency distribution has taken a form of a lLaw, termed as Lotka's law of scientific productivity. Bradford (1985) and Zipf (1949) came up with their own studies on frequency distribution of journals and frequency of occurrence of words, respectively. In 1964, Goffman (1964) came up with their epidemic model, which compared the diffusion of ideas in a scientific community with that of spread of influenza virus in a population of people, which has an entry point, a peak, and a decline. In 1976, Price (1976) introduced the principle of cumulative advantage, where, for example, a paper which is cited many times is more likely to be cited again. This could be applied to authors or journals. For instance, if an author is a highly cited author, his or her new works would be more referenced compared to works of less cited authors; alternatively, a journal that has been frequently consulted is more likely to be used again compared to infrequently used journal. This idea of cumulative advantage is also known as *preferential attachment* or *rich-getting-richer* phenomenon (Barabasi & Bonabeau, 2003). I further deliberate on these ideas in my discussion on networks.

2.1.1 The rise of collaborative research

Collaborative research is becoming increasingly popular because of its various benefits. Governments encourage collaboration, as it provides avenues to solve complex scientific problems and promoting various political, economic, and social agendas. Co-authorship in research articles is considered to be a reliable proxy of research collaborations. Price (1963) first reported that the proportion of multi-authored research papers in research literature was rising. Large industrial projects, improvements in communication facilities led by information technology, and mobility of researchers created fertile ground for researchers to work in groups (Luukkonen, Persson, & Sivertsen, 1992; Price, 1963). Price (1963) noted that the trend towards co-authorship is ‘one of the most violent transitions that can be measured in recent trends of scientific manpower and literature’ (p. 89). A number of other studies have reported increasing trend in multiple authored papers in every scientific discipline within and across countries (Sonnenwald, 2008). Increasing specialization, changes in the institutional incentives for publication, along with host of other reasons brought about a marked trend toward co-authored articles.

Grossman (2002) examined the co-authorship in mathematical research, showing a similar rise in multiple authored papers from the 40s through the 90s. In the 40s, the percentage of single authored papers was as high as 91%, declining to 66% in the 90s. Grossman also found a steady rise in the number of 2-authored and 3-authored papers, proving increased collaboration among mathematicians in recent years compared to the 40s. While examining scientific authorship on *Chagas* disease,Gonzalez-Alcaide, Park, Huamani, Gascon, and Ramos (2012) found that collaboration among researchers had increased dramatically. Miro et al. (2012) identified similar increase in the collaboration patterns of Spanish emergency physicians in the period between 2005- 2009. The growth in the number of publications is being reported across various disciplines and different parts of the globe.

Sooryamoorthy (2011) found that the number of co-authored publications has grown in South African engineering research while the number of single authored papers decreased. Co-authorship generally differs in physical sciences and social sciences due to the experimental nature of the former. However, the recent trends in the rise of large scale data collection in social sciences replicates that of large labs, requiring the collaboration of multiple researchers, similar to that of physical sciences (Moody, 2004). Some areas in social sciences, such as ethnography, may be less co-authored compared to other areas, such as economics, where specialization and the ease of bringing a new person in the research team instead of learning a new material makes co-authorship an easier option (Moody, 2004).

2.1.2 Definition of research collaboration

Fishbaugh (1997) has defined collaboration as a formal body established by two or more autonomous partners, none of who is under contract to another but whose aim is to attain substantive or symbolic goals that no partner could achieve independently.

Other researchers have also attempted to define 'collaboration'. The fundamental aspects of these definitions are that individuals who differ in 'notable ways' or those with 'diverse interests' share resources and competences to achieve a research purpose or 'goal' (Amabile et al., 2001; Jassawalla & Sashittal, 1998).

Extending this definition of collaboration, research collaboration is a special form of collaboration undertaken for the purpose of 'research' (Bukvova, 2010).

Sonnenwald (2008) defined research collaboration as:

> "Human behaviour among two or more scientists that facilitates the sharing of meaning and completion of tasks with respect to a mutually-shared superordinate goal and which takes place in social contexts" (p.3).

Subramanyam (1983) defined research collaboration in a simpler way. According to him, collaboration in research "is a joint work on a project of two of more investigators who contribute resources and effort – both intellectual and physical" (p.34).

The definition emphasizes few important aspects of research collaboration. First, it is a joint work between two or more researchers, which involves mainly sharing of resources or intellectual expertise. Second, research collaboration has a goal. The goal may be to bring out a definite product in the form of a research article, for instance. It may also have individual goals, such as PhD scholar or junior scientist wishing to get a promotion through the positive outcome of the research (Sonnenwald, 2003). Third, the research takes place in a 'social context'. The last point is crucial, as in most cases, the scientists collaborate with others based on their personal choices.

2.1.3 Big science, little science

Price (1963) referred to larger 'team work' research collaboration as 'Big science' and small group collaboration as 'Little Science'. Big Science is the fall out of the industrial era where professionalism and increased knowledge brought forward large-scale researches (Beaver & Rosen, 1978). Quantitative work is more likely to be co-authored than is a non-quantitative work (Moody, 2004). Considering an example of non-quantitative work, in humanities, a lonely scholar still manages to produce a fair degree of research literature without the trappings of 'big science' (Subramanyam, 1983). In contrast to small collaborations where collaboration followed Poisson distribution, co-authorship in the giant collaboration followed a power law. Collaboration grew at a much faster rate after WWII, primarily due to giant collaborations (or teamwork). Governments in various countries have taken initiatives to bring together scientists through collaborative research programs at both national and international levels (Garg & Padhi, 2001). These are generally teamwork kind of research where the choice of who should be on the team may not necessarily be in the social domain. A formal selection board might be selecting researchers. One notices here that collaboration has two aspects – one that involves actual social function where researchers choose who they would like to work with (or 'little science') and 'teamwork' (or 'big science') where large number of researchers work on a research project but may not be free to select their research partners (Price, 1963).

One of the characteristics of 'big science' is the requirement of massive funding and large labs. Most research within the scope of 'big science' is conducted within physical sciences, such as 'high energy physics', whereas 'little science' research is conducted across a wide spectrum of soft sciences, from social sciences to humanities and arts. Beaver (2001) even argued that 'big science' should be considered as 'collaboration', as it falls outside the purview of researchers associating because of social function. 'Big

Science' studies are conducted primarily in the natural sciences or experimental fields.. In one of the early studies quoted by Garfield (1980), the percentage of multi-authored papers in social sciences, economics, and sociology was 17 – 25%, in contrast to 47 – 81% in gerontology, psychiatry, psychology, and biochemistry. This scenario is fast changing and a large percentage of papers are co-authored even in the social sciences. Nonetheless, collaboration with less number of researchers is characteristic of humanities, social sciences or theoretical sciences, such as, mathematics.

2.1.4 Issues with taking co-authorship as a unit of analysis

Katz and Martin (1997) pointed out few issues when considering co-authorship in a paper as the only means to evaluate research collaboration. For example, a researcher making a brilliant suggestion over a casual discussion may be instrumental in shaping the course of research more than days of labour-intensive work at the laboratory. In some situations, collaboration between researchers may not end-up in joint co-authorship in paper. For example, two researchers may work closely together but may choose to write separate papers to suit their audience. Furthermore, due to the complex nature of human interactions that take place between researchers over a period of time, the precise nature and magnitude of collaboration cannot be easily determined (Subramanyam, 1983).

Heffner (1981) divided collaboration broadly into two types – theoretical and technical. In theoretical kind of collaboration, the association is limited to rendering advice, ideas, or criticism whereas in the practical kind of collaboration, it encompasses tangible assistance in a research endeavour. In general, the researchers in 'technical' collaboration are cited in the author-list of the journal artiinvisiblecle while those who have given 'theoretical' assistance are cited in the acknowledgement section of the journal article. Measuring research collaboration through survey and observation may not be precise. For this reason, the use of co-authorship in journal articles is a more tangible and easier way to determine collaboration.

There are few other benefits to using co-authorship in paper as a proxy to research collaboration. Katz and Martin (1997) pointed out that one of the biggest benefits is that co-authorship in papers is ‘invariant and verifiable’. As co-authorship is based primarily on bibliographic records, one should be able to replicate the results given the same datasets. Second advantage is the scalability of sample size that could be analysed by this technique could be very large. Therefore, the results should be more statistically significant compared to those of qualitative studies, questionnaire based studies or case studies, for instance. Katz and Martin (1997) further point to the third and often overlooked advantage – that these studies are ‘non-reactive’ – meaning their measurement does not affect the collaboration process. However, Katz and Martin (1997) also mention that other researchers have suggested that although not immediately, the results of bibliometric study may affect the collaborative process over the longer term.

2.1.5 Authorship credit and ethics

‘Significant contribution’ is an important criteria for research collaboration and multiple authorship in paper is used as a proxy to measure the same. Bodies like APA and ICMJE have well-structured rules for an author to qualify as a co-author of a paper. According to APA guidelines (http://www.apa.org/research/responsible/ publication/index.aspx),

> Authorship credit should the individual's contribution to the study. An author is considered anyone involved with initial research design, data collection and analysis, manuscript drafting, and final approval. However, the following do not necessarily qualify for authorship: providing funding or resources, mentorship, or contributing research but not helping with the publication itself. The primary author assumes

responsibility for the publication, making sure that the data is accurate, that all deserving authors have been credited, that all authors have given their approval to the final draft, and handles responses to inquiries after the manuscript is published.

APA Ethical Principles of Psychologists and Code of Conduct (2002) specify who could be on the authorship list

(http://www.apa.org/research/responsible/publication/index.aspx)

8.12 Publication Credit

(a) Psychologists take responsibility and credit, including authorship credit, only for work they have actually performed or to which they have substantially contributed. (See also Standard 8.12b, Publication Credit.)

(b) Principal authorship and other publication credits accurately reflect the relative scientific or professional contributions of the individuals involved, regardless of their relative status. Mere possession of an institutional position, such as department chair, does not justify authorship credit. Minor contributions to the research or to the writing for publications are acknowledged appropriately, such as in footnotes or in an introductory statement.

(c) Except under exceptional circumstances, a student is listed as principal author on any multiple-authored article that is substantially based on the student's doctoral dissertation. Faculty advisors discuss publication credit with students as early as feasible and throughout the research and publication process as appropriate. (See also Standard 8.12b, Publication Credit.)

The APA code of conduct makes it clear that only those who have significantly contributed to the study could be on the authorship list. Those who have contributed little have to be appropriately 'acknowledged' in footnotes or in the acknowledgement section.

International Committee of Medical Journal Editors (ICMJE) requires all three criteria to be met by the researchers (Hwang et al., 2003):

> All persons designated as authors should qualify for authorship, and all those who qualify should be listed. Each author should have participated sufficiently in the work to take public responsibility for appropriate portions of the content. One or more authors should take responsibility for the integrity of the work as a whole, from inception to published article. Authorship credit should be based only on 1) substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; 2) drafting the article or revising it critically for important intellectual content; and 3) final approval of the version to be published. Conditions 1, 2, and 3 must all be met. Acquisition of funding, the collection of data, or general supervision of the research group, by themselves, do not justify authorship.

However, *honorary authorship* (also termed as 'guest authorship' or 'gift authorships') includes researchers who might not have provided significant contribution to the paper. Another extreme is *ghost authorships,* which fails to mention the names of those authors who had merit to be added in the authorship list of the paper. In other words, ghost authors are individuals who have contributed to the paper substantially but they may not want their names to be revealed or they may be in some kind of deal to have their name concealed from the author-list. Honorary authorship and ghost authorships are two extremes of scholarly malaise. Several studies have investigated these dual issues. One of the first serious discussion of honorary authorship appeared in the case study by Hagstrom (1965) in which he found that some publications had author names listed for purely social reasons.

Flanagin et al. (1998) received responses from 809 corresponding authors of articles published in 3 peer-reviewed journals in 1996, and found evidence that 19% and 11% of these papers involved honorary and ghost authorship, respectively. In another study on Cochrane reviews, Mowatt et al. (2002) found similar pattern of honorary and ghost authorships. They carried out a web-based self-administered survey on 577 reviews published in the Cochrane Library and found that 39% of the reviews had evidence of honorary authors, 9% had evidence of ghost authors, and 2% had evidence of both. Wislar, Flanagin, Fontanarosa, and DeAngelis (2011) conducted a cross-sectional survey of six high impact biomedical journals and found evidence of honorary and ghost authorship in 21% of the 896 research articles.

Medical journals stand for accountability, responsibility and credit (Mowatt et al., 2002), and the presence of substantial proportion of honorary and ghost authorship should indeed be a matter of concern among the medical fraternity. However, little literature is found on honorary authorship or ghost authorship in the sciences, and even fewer in the social sciences. Marusic, Bosnjak, and Jeroncic (2011) carried out a meta-analysis of 123 studies across disciplines (biomedical and non-biomedical), which showed that a pooled weighted average of 29% researchers reporting experience (their own or others') with misuse of authorship.

The trend of *honorary authorships* can be growing for many reasons. For example, some authors may include the name of a prominent researcher (or researchers) in the author list in order to impress editors and reviewers and also acknowledge moral and financial support (Riesenberg & Lundberg, 1990).

In honorary and ghost authorship, the idea of ‘significant contribution’ is not reflected in the author-list. In honorary authorship, someone who has contributed little or nothing gets to be an author. Similarly, a ghost author gets no credit for his contribution, as he/she is not on the author list.

In areas that involve a teamwork-kind of association, where there may be hundreds and sometimes even thousands of authors per paper, papers that are co-authored by large number of authors are often referred to as having *hyper authorship* (Cronin, 2001). The incidents of hyper authorship have been on a rise (Knudson, 2012). This issue becomes complicated because there is no way to know the contribution of each author. Have they all contributed equally? How many of the authors have actually sat down to co-write the paper and how may have contributed through lab work? These difficult questions cannot be answered just by looking at the author list. As a counter problem, Cronin (2001) suggested that authors be replaced by the list of contributors and recorded in the paper unambiguously.

Few studies have gone beyond the use of quantitative analytic techniques, supplementing them with qualitative method of survey research by directly asking the co-authors of papers to indicate their real nature of contribution (Pepe & Rodriguez, 2010). Birnholtz (2006) interviewed physicists (although not always, physicists are generally known to work in teams) and discovered that authors are grappling with what it means to be an 'author'.

Some research associations duly 'acknowledge' individuals who provide significant assistance on the paper, commonly referred as *sub-authorship*. Acknowledgements have gradually established themselves as a constitutive element of academic writing that indicates the changing socio-cognitive structure and work practices (Cronin, Shaw, & La Barre, 2003).

Cognitive partnering in the research world is now common, which is reflected also in the number of co-authorships and sub-authorships (Cronin, 2004). However, at times, both authorship and sub-authorship could fail to provide a full picture of collaboration. For example, Laudel (2002) interviewed scientists who were co-authors and those who were cited in acknowledgements on the content and reward of collaboration. He found that a vast proportion (about 50%) of collaborators was unreported through formal communication channels.

2.1.6 Order of authorship

In multiple authored paper, which is the unit of analysis for research collaborations, first authorship has a significant value. It is widely recognized that the first author provides a major contribution to the paper. In some disciplines, the author order is based on the alphabetical sorting of surnames; however, first authorship is considered important in most disciplines, as some landmark studies are known by their first author, lending support to the impression that by being the first author, he or she plays a pivotal role in particular research (Riesenberg & Lundberg, 1990). In essence, the order of authoring is an adaptive device, which symbolizes authors' relative contribution to research (Zuckerman, 1968).

The order of authorship has been changing over time. Drenth (1998) carried out a study to access the change in number and profile of authors who had contributed with articles to BMJ over a 20-year period and found a shift in hierarchical order of authorship and its change over time with senior authors (professors and chairpersons) moving to first authorship at the cost of other contributors, like consultants and lecturers. Fine and Kurdek (1993) cited APA's ethic committee policy on authorship of articles based on dissertations to determine the authorship credit and authorship order of faculty–student collaboration. The policy statement indicates that dissertation supervisors must be included as authors in such articles only if they have provided 'significant contributions' to the study. In such situations, only second authorship is appropriate for supervisors, since dissertation is an original study of the student; thus, first authorship is always reserved for the student.

ICJME also has similar criteria when dealing with authorship issues (Zaki, Taqi, Sami, & Nilofer, 2012). The issue of who should be the first author could get stormy at times, sometimes needing to be resolved in court (Abbott, 2002). In interviews with Nobel Laureates and comparisons of their name order practices, Zuckerman (Zuckerman, 1968) found that laureates exercise their *noblesse oblige* by giving more credit to less eminent co-workers as their eminence grows.

Hart (2000) indicated that authors mentioned various ways in which they listed their names in the co-authored paper, although a vast majority (46.9%) indicated that they listed the names according to the 'contribution' of each author. Some of the other methods that can be used include alphabetical order with intent to indicate an equal contribution (15.3%) or without intent to indicate an equal contribution (9.2%). Within authorship, Hart (2000) also mentioned the cases of 'helped' first authorship, where authors of 4 articles indicated that the first author was in line for tenure and promotion, thus the co-authors helped to further the individual cause by assigning him or her first authorship.

2.1.7 Benefits and motivations of research collaboration

Researchers collaborate for several reasons. The primary basis for research collaboration is that it brings individuals together to work on a project (i.e., research study) that could not be completed by a single author. Therefore, bringing together multiple talents is the hallmark of research collaboration. Theoretically, this is true, but we have already seen in two cases of honorary authorship and ghost authorship, that this may not always be the case. However, collaboration may still have a number of benefits. One of the most important reasons why researchers collaborate is to improve the quality of paper, thereby increasing the chances of acceptance in a journal. Presser (1980) found that multiple authored papers were more likely to be accepted for publication compared to single authored articles. In his studies, he found that PhD departments (departments conducting doctoral programmes) receive more favourable reviews compared to non-PhD departments. Citing a case, Presser (1980) found that solo papers written by PhD departments had 76.7% rejection rate compared to two-author papers where the rejection was down to 60%.

Beaver and Rosen (1979) investigated papers on the basis of journal prestige and found that prestigious journals contained more multi-authored articles. Collaboration also increases scientific credibility, as researchers get a chance to work with more researchers from diverse fields and backgrounds, producing a greater number of works of better quality (Sonnenwald, 2003, 2008). However, link between collaboration and quality is often debated. When Hart (2007) investigated whether co-authored articles did indeed lead to better quality articles using citations analysis, he found so such connection.

Beaver (2001) cited 18 potential reasons for why researchers collaborate, including access to expertise, sharing of resources, improved access to funds, professional advancement, learning the tacit knowledge, progressing more rapidly, tackling larger or bigger problems, enhancing productivity, getting to know people, learning new skills, satisfying curiosity, sharing the excitement of an area with other people, reducing errors, keeping focused on research, reducing isolation, education (i.e., student), advancing knowledge, but also having fun. With these 18 reasons, Beaver practically summarizes a large body of knowledge that examined reasons for which researchers collaborate.

Division of labour (Melin, 2000), where authors are in a position to divide their work among themselves, is an important reason why authors collaborate. For example, if three authors collaborate on a paper, one could focus on the literature review, the other on research design, and yet another on analysing the data. Research collaboration enables sharing of expertise and exchange of ideas (Katz & Martin, 1997; Melin, 2000). As more than one person is looking into the quality, accuracy, and meaning of the results, it increases scientific reliability and probability of success. In an empirical study, Hart (2000) received responses from surveying the authors of all multiple authored articles that appeared in two journals of academic librarianship and found that among the 9 potential benefits, improved quality of the article, co-author expertise, and value ideas received from the co-author and division of labour, were among the important reasons why authors collaborated.

Collaboration could potentially increase the total number of publications of a researcher. One of the most consistent findings in the literature has shown high degree of correlation between collaboration and research productivity (Katz & Martin, 1997; Subramanyam, 1983). Zuckerman (1967) interviewed 41 Nobel prize winners and identified a strong relationship between collaboration and productivity; Nobel laureates are more apt to collaborate compared to a matched sample of scientists. However, owing to strains resulting from prestige, collaboration ties (with most of these terminating) decrease soon after the award. Pao (1982) found that musicologists who collaborated the most were also most productive.

Landry, Traore, and Godin (1996) carried out an econometric analysis and showed that collaboration conducted within universities, industries, or institutions, may indeed increase academic productivity. However, productivity may vary according to the geographical closeness of the partners and their field of research. Landry et al. (1996) also found that collaboration between universities and industry was far more productive compared to collaborations with Universities or Universities and other institutions. S. Lee and Bozeman (2005) carried our one of the most significant studies examining the effect of collaboration and scientific productivity. S. Lee and Bozeman (2005) examined 443 academic scientists affiliated with university research centres in the USA and found that the net effect of collaboration in research productivity was less clear. The researchers conducted a 'fractional count' by dividing the number of publications by number of authors and found that number of collaborators is not a significant predictor of productivity. However, they concurred that their findings were conducted at an individual level while the major benefits of collaboration may accrue to groups, institutions and research fields.

Increase in the number of publications influences the researchers in the research community, thereby bringing them prestige. As the influence of researchers grows, other researchers show their interest in working with them, further increasing the number of publications. Collaboration brings in the cumulative effect that increases the popularity of the researcher. Popularity of a researcher here would mean the number of associations an author has, which may likely increase his or her influence in a research community.

Katz (1994) mentioned ten factors that promote collaboration, which are changing the pattern of funding; scientific popularity, visibility and recognition; rationalization of scientific manpower; the demands of complex large scale instrumentation; increasing specialization in science; the degree of advancement of a particular discipline; professionalization of science; the need to gain experience and train researchers; the desire to increase cross-fertilization of ideas and techniques; and decrease in spatial distance. However, Katz (1994) also stated that the above-mentioned factors derived from literature are far from complete, as research collaboration is a social process and that researchers have reasons to collaborate just as people have reasons to communicate.

Collaboration is a key mechanism for mentoring graduate students and key post-doctoral researchers. Pressure to publish (Morrison, Dobbie, & McDonald, 2003) for promotion and/or tenure-ship or to fulfil the publication requirement to remain in the job contract are strong motivations for collaboration.

Going beyond the benefits of individual authors, research collaborations could also benefit nations. Informal and formal collaboration could bring international co-operation even when relations between countries are strained (Cerroño & Keynan, 1996). It could also heal post war wounds by facilitating military research funds to be re-directed to peace-time applications (Sonnenwald, 2008). Scientific collaboration has several socio-economic benefits. It could spread the financial risk of research for businesses over the long term. By collaborating with developing countries, companies can hire scientists from developing countries at much lower rates prevalent in advanced countries (Sonnenwald, 2008).

However, collaboration may have certain disadvantages because it requires extra time to coordinate with all stakeholders involved and high costs that result from co-ordinating especially large multi-institutional collaboration (Cummings & Kiesler, 2007). Apart from this, the problems of assigning credit to the authors may dissuade some, as they may not feel 'recognised'. Research credit is an important currency in the career of researchers and not being given due credit would reduce accountability, which often slows down the research progress and lowers the quality of research finding (Heinze & Kuhlmann, 2008; Wray, 2006). Moreover, unethical practices, such as scooping of results or conducting clinical practices that may be banned in some countries but not prohibited in other countries, are some other negative aspects of research collaboration (Sonnenwald, 2008).

2.1.8 Types of collaboration

Research collaboration is categorised into various types, depending on the level of aggregation or models of working relationships, among others. For example, Subramanyam (1983) mentioned 6 different types of collaboration, the teacher-pupil collaboration, collaboration among colleagues, supervisor assistant collaboration, researcher-consultant collaboration, collaboration between organizations, and international collaborations. Teacher-pupil relation is the most common relationship in university-based set-ups where Professor provides guidance or supervision to the student and student does most of the bench work, leading to academic papers. In most cases, both students and professors share names as authors of these papers. Collaboration among colleagues happens when authors share the work as colleagues. Teacher-pupil relation may also be called a 'mentoring' relationship or model and collaboration among colleagues as a 'collegial' relationship or model (Hart, 2000). Just as model of relationship, research collaboration may also be grouped according to different levels of collaboration, which may be either within (or *intra*) or between (or *inter*) the two levels.

Studies have shown interest in various levels of collaboration; however, international and inter-sector collaboration have been of special interest. International collaboration among institutions (or individuals) belonging to different nations reveals the level of participation of a nation with other nations. Inter sector collaboration, such as between universities and industry, is gaining prominence, with a new model of triple helix that involves the study of research collaboration among three important stakeholders, university, government and industry. Different levels of collaboration and distinction between inter and intra forms (Katz & Martin, 1997) are mentioned in Table 2.1

Table 2.1: Different levels of collaboration and distinction between inter and intra forms (Katz & Martin, 1997)

	Intra	**Inter**
Individual	-	Between individuals
Group	Between individuals in the same research group	Between groups (e.g., in the same department)
Department	Between individuals or groups in the same department	Between departments (in the same institution)
Institution	Between individuals or departments in the same institution	Between Institutions
Sector	Between institutions in the same sector	Between institution in different sectors
Nation	Between institutions in the same country	Between institutions in different countries

Collaboration is also classified based on the disciplinary focus. Inter-disciplinary and multi-disciplinary are the most frequently used terms, although several terms have been used in the literature, such as inter-disciplinary, intra-disciplinary, cross-disciplinary, multi-disciplinary and trans-disciplinary. Interdisciplinary collaboration integrates the knowledge of two or more disciplines. Multi-disciplinary collaboration involves participation of two or more disciplines but does not involve integration. The thin line differentiating multi and inter disciplinary collaboration can be difficult to distinguish in practice, though.

2.1.8.1 International collaboration

International collaboration, as demonstrated through international co-authorship, , has been on a rise in both volume and importance (Leydesdorff & Wagner, 2008; Luukkonen et al., 1992; Narin, 1991; Narin, Stevens, & Whitlow, 1991) largely due to professionalization in science (Beaver & Rosen, 1978, 1979). The growth in international collaboration has been observed across disciplines as well as different countries and regions have also reported growth in international co-authorship (Teodorescu & Andrei, 2011; C. S. Wagner, 2005; Zheng et al., 2012). For example, recently, subjects such as psychology (Kliegl & Bates, 2011) have been reporting a substantial rise in the number of internationally co-authored papers.

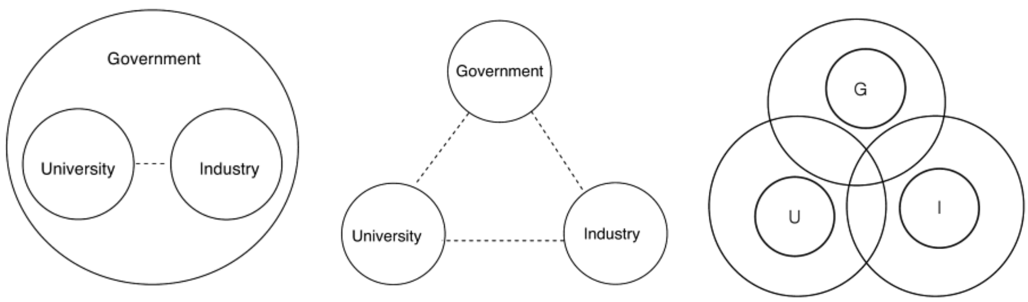
Three findings emerged from Frame and Carpenter (1979) early work on international co-authorship. Frame and Carpenter (1979) found that more basic fields had greater proportion of international co-authorships, larger scientific enterprise of a country, and smaller proportion of international co-authorship. Extra-scientific factors (such as geography, politics and language) play a strong role in determining who collaborates with whom internationally. Frame and Carpenter (1979) second finding indicated that larger the enterprise of a country, the smaller is the proportion of international co-authorship, which is in contrast with C.S. Wagner, Brahmakulam, Jackson, Wong, and Yoda (2001) finding that more scientifically advanced countries are more likely to collaborate more internationally. C.S. Wagner et al. (2001) applied tools from networks science to show that the growth of international co-authorship can be attributed to self-organizing phenomenon based on *preferential attachment* within the network of authors.

Two specific patterns are seen in international co-authorship, one patterns shows that more scientifically advanced countries seem to collaborate more internationally (C.S. Wagner et al., 2001) and second pattern indicates that smaller countries tend to collaborate more internationally (Luukkonen et al., 1992). Narin et al. (1991), while analysing publication, co-authorships and citations within 28 scientific fields related to various European community programs, reported two important findings, showing that internationally co-authored papers (more than 1 EC country) were cited twice as much as papers written intra-nationally and that the degree of international co-authorship does not seem to depend on country's size. International co-authorships differ across disciplines, but is seen to be more prominent in the natural sciences (Luukkonen et al., 1992). Areas such as climate research, such as seismology, require greater international co-operation and as such, these areas have seen more international collaboration.

2.1.8.2 Triple helix

Another important model of organisational collaboration involves University, industry and government interactions. Referred to as the triple helix model, industry initially operates as the locus of production, the government acts as an agency that guarantees stable interactions and exchange, and the university acts as the source of new knowledge (Etzkowitz, 2008).

Etzkowitz (2008) asserted that the path to a triple helix begins from two opposing viewpoints, a statist model, where the government controls academia, and industry and the laissez faire model, where the three helices work almost independently, interacting only modestly across strong boundaries (see Figure 2.1: a and b resp.). The new model suggests an active interaction among these three helices. In the triple helix field interaction model (see Figure 2.1: c), the three helices have their internal core and external field space. Core helps keep a distinct status on each helix, and it helps identify when the core is in danger of losing its identity. Field space depicts the interactions taking place among the helices.



a b c

Figure 2.1: The three models of university-government and industry interactions – a) Statist model b) laissez-faire model c) triple helix field interaction model (Etzkowitz, 2008)

Studies have looked at triple helix relations in various ways. For example, Heimeriks, Horlesberger, and Van den Besselaar (2003) presented an approach for researching the triple helix as a heterogeneous and multi-layered communication network in biotechnology field involving co-authorship, project collaboration and communication of information over the virtual network of web links. According to Etzkowitz and Klofsten (2005), triple helix comprises three elements. The first element assigns a prominent role to the university and industry in terms of innovation while perceiving government in a knowledge-based society. In the second element, the three helices collaborate equally, with innovation policy being an outcome rather than prescription from the government. In the third element, apart from their traditional roles, each helix "takes the role of the other", performing new roles in addition to their traditional function. For example, Universities that have been seen primarily as a source of human resources and knowledge are now looked to for technology as well. Several universities have developed organisational capabilities to formally transfer technologies. Interdisciplinary knowledge production involving the prominent helices inspire research collaboration and firm formation ventures (Etzkowitz & Dzisah, 2008).

2.2 A network approach to co-authorship

Using co-authorship to measure scientific collaboration has been a subject of significant interest since the 1960s (Beaver, 2001; Glänzel & Schubert, 2005; Melin & Persson, 1996; Price & Beaver, 1966). However, understanding research collaborations from the lens of social networks is a fairly young research area. In a co-authorship network, two authors (node) are connected if they have co-authored an article together (edge). If human social networks are narrowed down to ones for which we quantitative data exists, we are practically left with only a handful of them – two of these are a network of film actors (actors acting in a film together) and the network of researchers (researchers co-authoring a research piece together) (Newman, 2001c). Among these two networks, the one with true social function is probably only the researchers' network, as unlike film actor network, researchers mostly choose with whom they would like to do research and then pen down the results in the form of a co-authored research paper or artefact. These collaborations leave digital footprints in the form of bibliography, which can be effectively tracked and evaluated.

Co-authorship studies garnered renewed interest after Newman (Newman, 2001a, 2001b, 2001c) used social network analysis methods to investigate the macro and micro characteristics of large co-authorship networks. Barabasi et al. (2002) study that followed up Newman's 2001 work (Newman, 2001c) investigated the dynamics and evolution of co-authorship networks. Co-authorship networks have since been studied extensively in various ways and in several both the natural and social sciences (Lewison & Markusova, 2010; Moody, 2004; Newman, 2004a; Quatman & Chelladurai, 2008; Racherla & Hu, 2010; Uddin et al., 2012; Yan et al., 2010).

2.2.1 The evolution of networks field

We now understand that we live amid a web of networks – they are all around us - both as human networks and as entity networks (i.e., power grid networks, network of roads or organizational networks). Recent studies on large scale networks by two prominent physicists, Barabasi (Barabasi & Albert, 1999) and Watts (Watts & Strogatz, 1998), have provided new insights into the topologies of networks. Watts and Strogatz (1998) re-investigated Milgram's 1967 work (Milgram, 1967) on the 'Small-world problem' and found that the phenomenon of one entity reaching out to another in a few hops is also evident in several real world networks, from Hollywood film stars and Electric grids of western United States to neural network of worm c-elegans. Watts-Strogatz model suggests a single parameter model, which interpolates between an ordered finite dimensional lattice and a random graph (Albert & Barabasi, 2002) (see Figure 2.2).

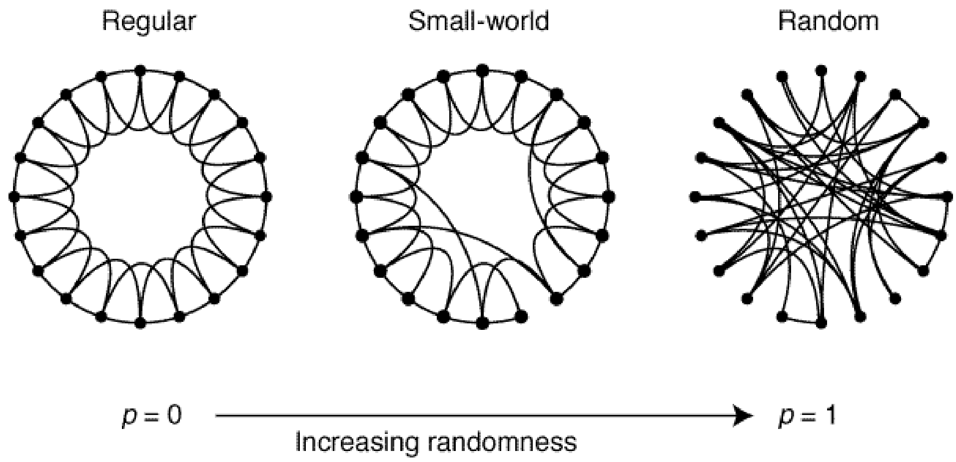


Figure 2.2 Watts-Strogatz model (Watts & Strogatz, 1998)

Close on the heels of Watts was Albert Lazlo Barabasi who discovered that the self-organising networks also have a *scale-free* property (Barabasi & Bonabeau, 2003). Barabasi ran a web crawl in the section of web and found that the web demonstrated a 'flocking' nature, as proportionately few Web pages had a large number of links and a large number of web pages had only a few links. This characteristic of 'hubs' (nodes with large number of links) in real networks follows a Power Law (Adamic, 2000) distribution. Power law distribution forms a linear scaling regime (straight line) on the log-log plot. Barabasi also found that web had a relatively small diameter of 19 at the time – meaning a random node on the web could be reached in a maximum of 19 hops (Albert, Jeong, & Barabasi, 1999).

Preferential attachment and *growth* are two prominent features of scale-free networks. Preferential attachment means that a node shows preference for node which it is better connected in comparison with its neighbouring nodes. Growth means that real networks also demonstrate the feature of adding more nodes and links over time. Scale-free networks model overturned the long standing random networks model of Erdos and Renyi (Erdős & Rényi, 1959, 1960), which postulated non-existence of hubs in a network.

Network transitivity and Community Structure (Girvan & Newman, 2002) are two other properties found in many networks.

In a social network, the stress is on the relationships between the actors. However, the attributes of the nodes are not ignored; rather, they are seen in the light of the relationships that the actors have among themselves. Moreno (1953), the founder of *Psycho-Drama*, was one of the first researchers to work in the area of social networks. During his time and many years after that, the field of social networks was known as *Sociometry*. Ever since Moreno, several researchers, e.g., Balevas, Kochen, Levi-Strauss, Linton Freeman (Linton, 1977) and Howard Aldrich (Aldrich & Zimmer, 1986), from diverse disciplines, like psychology, anthropology, sociology and business, have contributed immensely to our idea of social networks (Borgatti et al., 2009).

A developed set of mathematical algorithms, known as Social network analysis (SNA)(Wasserman & Faust, 1994), are applied for the analysis and visualization of networks. SNA is a sociological approach to discover the topological properties of a network. It has been used in various settings to examine different phenomena, from organisation behaviour (Borgatti & Foster, 2003) to the spread of obesity (Christakis & Fowler, 2007). The technique has been used to study the exchange of resources among actors (Haythornthwaite, 1996).

2.2.2 Social capital

Social capital can be defined as social networks that have value (Putnam, 2001) or resources made available through social relationships. Unlike other forms of capital, social capital inheres to the structure of relationships between and among actors (Coleman, 1988).

Mark Granovetter, in his highly cited work, 'Strength of Weak Ties' (Granovetter, 1973), claimed that tightly knit nodes (strong ties) could be redundant, as the same ideas and information pass between them over and again. However, the cohesive power of weak ties (acquaintances), which are outside the strong ties (or 'clump'), are sources of novel information. Burt (1997) found that in an ego-network (nodes -or alters- with direct ties to the focal node and links between the alters), an absence of a tie between the alters increases opportunities for the focal node in certain competitive settings. Burt (1997) termed these absence of ties in the ego network as *structural holes*. It is widely accepted that egos with several structural holes perform better (Borgatti et al., 2009; Burt, 1997).

Individuals gain social capital through their strong and weak relations and by virtue of their position in the network. Embedded or strong ties (Krackhardt, 1992) bring 'safety' whereas weak ties (Granovetter, 1973) bring 'effectiveness' and both complement each other. Just as with the competing views of strong and weak ties, two competing views, cohesiveness and structural holes, draw on the relationship between social network structure and social capital. Burt's theory (Burt, 1997) of structural holes suggests that the diversity of connections in an ego network is crucial to individual outcomes because they present more brokerage positions.

2.2.3 Co-authorship networks

Citations, co-citations, author co-citations, bibliographic coupling, co-word and co-authorship are the major indicators of scientific productivity and knowledge production that relate one entity with another – the idea which gives birth to our concept of 'networks'. In citation analysis, the emphasis is on the number of citations received by an article, journal or author, or which article cites which article. Bibliometric studies started to use the network right from the time Price (1965) published his classic paper on networks of papers. Co-authorship networks provide a copius and meticulously documented record of the social and professional networks of authors (Newman, 2004a), and their analysis could uncover certain aspects of the network, such as how fragmented or cohesive the knowledge community is or who are the best connected authors in that network. Whereas macro level properties look at the overall network, microlevel properties reveal the popular gatekeepers or prestigious authors in the network.

The earliest form of co-authorship in papers is evidenced through *Erdos Number* (Barabasi et al., 2002). Erdos was a famous mathematician who had written over 1300 papers, most of them co-authored with fellow mathematicians. A mathematician who had co-authored with Erdos directly had an Erdos number of 1. An author who collaborated with author who had directly co-authored paper with Erdos had an Erdos number of 2, so on and so forth. Hence a lower 'Erdos number' was a matter of status and a show of influence in the Mathematics research community.

However, Newman's 2001 study (Newman, 2001a, 2001b, 2001c) that examined the topological properties of co-authorship networks opened the floodgates for other studies in co-authorship networks. Newman's study analysed seven scientific collaboration networks comprising of scientists in biology and medicine (MEDLINE), physics (Los alamos e-print archive – physics and SPIRES), and computer science (NCSTRL) who had contributed papers over a five year period, from 1995 to 1999. Mean papers per author, authors per paper, number of collaborators, the size of a giant component, mean geodesic distance and clustering were some of the network aspects analysed. Newman found that all networks displayed the property of 'small-world', meaning that the authors in the scientific community investigated were typically 5 to 6 'hops' away from one another. The networks were also highly clustered, meaning that if two authors had a common partner, the probability of their collaboration was high. However, biomedical research showed lower clustering compared to other fields. Both author productivity and the degree of collaborations of authors followed a power law. Newman also found significant statistical differences between scientific communities, for example, the number of collaborations per paper in high energy physics was staggering and significantly higher compared to other fields.

Whereas, (Newman (2001a), 2001b), 2001c)) carried out analyses of static networks, Barabasi et al. (2002) conducted the analyses on evolving networks in mathematics and neuroscience journals from 1991- 1998. The networks were found to be scale-free and governed by preferential attachment. While the average degree increased in time, the node separation decreased. The numerical and analytical results underlined the crucial role of internal links in determining the observed scaling behaviour and network topology. Barabasi et al. (2002) determined that co-authorship networks represented a prototype of complex evolving systems, and the results could be useful in understanding other complex evolving systems, such as World Wide Web and other social networks. Neither one of the studies by Newman and Barabasi looked into path-based centrality measures, i.e., betweenness and closeness centralities. Co-authorship networks evolve over time, which was aptly demonstrated by Barabasi. Ever since his study, a number of other researchers have looked into the evolutionary dynamics of co-authorship networks (Gonzalez-Alcaide et al., 2012; Ozel, 2012b; Uddin et al., 2012).

In the same year as Barabasi's study (Barabasi et al., 2002), Otte and Rousseau (2002) conducted another study on applying social network analysis to examine co-authorship networks (see Figure 2.3 for an example of a typical co-authorship network). Otte and Rousseau (2002) pointed out that SNA is not a formal theory in sociology but a 'strategy' for investigating social structures. Using centrality measures, which included degree, closeness, and betweenness, the authors located the most central researchers in the field of Social network analysis. An important feature of co-author network analysis is to identify key authors in the network who are well positioned, popular and best connected (Fatt et al., 2010; Racherla & Hu, 2010; Ye, Li, & Law, 2013).

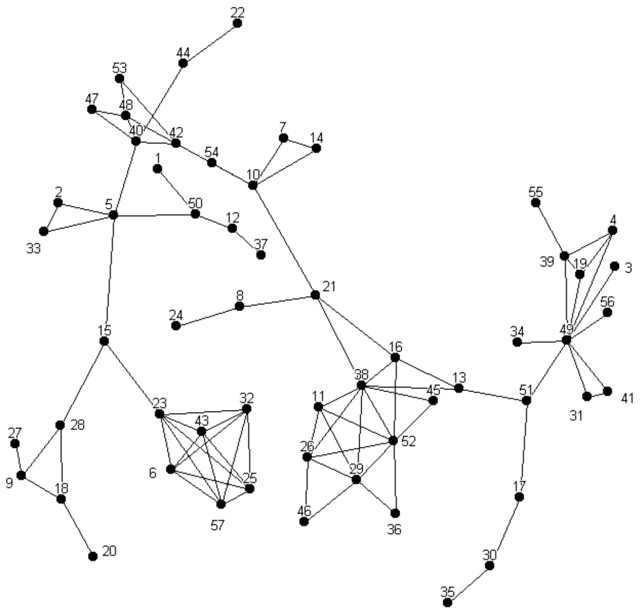


Figure 2.3 Typical co-authorship network (Otte & Rousseau, 2002)

Newman (Newman, 2001a, 2001b, 2001c) followed up his earlier work with analysis of co-authorship networks in biology, physics and mathematics (Newman, 2004a). Biological research, Newman found, had significantly more number of collaborators per paper compared to physics or math, which indicates its predominantly experimental nature of research.

2.2.4 Small world

Newman studies (Newman, 2001c, 2004a) reported that various co-authorship networks followed small-world pattern (see Figure 2.4). Several other studies have reported at least one of the most common properties of the network, a 'small world' property (Gonzalez-Alcaide et al., 2012; Kretschmer, 2004; Yan et al., 2010; Yin et al., 2006). For a network to possess the properties of a 'small-world' the presence of popular nodes (or 'scale-free' nature) is important.

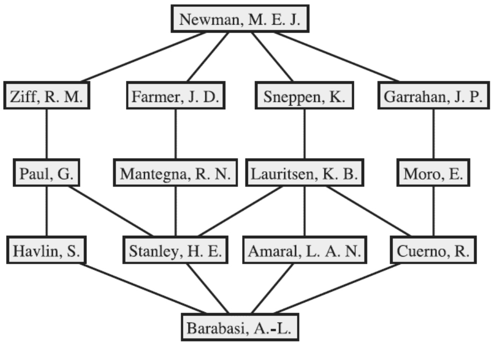


Figure 2.4 demonstration of small world. Shortest path between Mark Newman and AL Barabasi through collaboration network of physics papers (Newman, 2004a).

Yan et al. (2010) applied social network analysis on 18 core LIS journals in China to examine the macro and micro level properties of the network. Their study found the network to be both small world and possessing scale-free characteristics.

2.2.5 The size of giant component

Apart from examining 'small world' phenomenon in co-authorship networks, another characteristic that studies have commonly looked at included the size of giant component in a collaborative network. A giant component is the largest component of a network. The size of this component matters, as it could reveal how cohesive or fragmented a network is. A large giant component can signify, for example, that knowledge flows would be faster in this network. A giant component may also be indicative of 'core' field of research in the research community, and other components may indicate communities carrying out 'specialized' research (Fatt et al., 2010). Newman (2004a) found that the giant components of the biology, physics and mathematics networks were between 82% and 92%. Newman's earlier work (Newman, 2001c) also found that the size of giant components is anywhere from 57.2% (computer Science) to 92.6% (biomedical research).

In another work, Kretschmer (2004) found that the largest component covers 40% of nodes. While investigating a small network comprising 48 authors who had contributed papers to the COLLNET conference, Yin et al. (2006) found that the giant component comprised 66.6% of nodes. In yet another study, while examining the co-authorship network of LIS in China, Yan et al. (2010) found that the largest component comprised 48.87% of all authors. However, the largest component of research collaboration networks may not be as high as this (or above 40% as in the above studies). In a study, Yan and Ding (2009) detected that the largest component of LIS authors comprises just 20.77% of all authors.

2.2.6 Various aspects of co-authorship network studies

While Newman (Newman, 2001c, 2004a) took the entire bibliographic databases and carried out a comparative study of co-authorship patterns, others studied co-authorship patterns using important journals in a specific fields, such as chemistry (de Souza, Barbastefano, & de Lima, 2012), youth mentoring (Blakeslee & Keller, 2012), viticulture and oenology (Aleixandre-Benavent et al., 2012), electronic markets (Fischbach, Putzke, & Schoder, 2011), information retrieval (Ding, 2011), library and information systems (Yan et al., 2010), (Ardanuy, 2012), digital library (Liu, Bollen, Nelson, & Van de Sompel, 2005), information management (Graeml, Macada, & Rossoni, 2010), business process management (Reijers et al., 2009), solar cell technology (Larsen, 2009), tourism and hospitality (Hu & Racherla, 2008; Racherla & Hu, 2010), sport management (Quatman & Chelladurai, 2008), astrophysics (Heidler, 2011), and economics (Krichel & Bakkalbasi, 2006), among others. Most studies generally select prominent journals in the field and carry out analyses. However, some studies have concentrated only on single prominent journal in the field to carry out these analyses (Fatt et al., 2010; Hou, Kretschmer, & Liu, 2008). Some researchers have looked at co-authorship from the point of an association (Yin et al., 2006), research collaboratory (Pepe & Rodriguez, 2010), and geographical region (Persson et al., 1997). Several studies have focused on specific countries, e.g., China (Yan et al., 2010), Spain (Alcaide, Calatayud, Zurian, & Benavent, 2009; Ardanuy, 2012; Ovalle-Perandones, Perianes-Rodriguez, & Olmeda-Gomez, 2009), South Africa (Durbach, Naidoo, & Mouton, 2008), Turkey (Gossart & Ozman, 2009) and Iran (Fakhree & Jouyban, 2011; Harirchi et al., 2007). We notice a persistent lack of similar studies pertaining to Malaysia.

Co-authorship networks have been examined in a number of ways. Hennemann (2010) used co-authorship networks to trace the development of science and technology in China. The authors found that top universities are dominating the intellectual space and circulating knowledge. Going beyond the educational ambit, co-authorship networks convey important information about firm level collaborative patterns. Demirkan and Demirkan (2012) showed that biotechnology firms depend heavily on social network of researchers for the exchange and production of knowledge. They also found that firm-level patenting was closely linked to the ways in which researchers interacted. Co-authorship network analysis was used by a Brazilian Ministry as a tool for Strategic planning and capacity building. The researchers found that the visualizations of network data generated new insights, which allowed for better strategic planning, as they were able to locate key researchers and institutions participating in international scientific collaborations (Morel, Serruya, Penna, & Guimaraes, 2009). Co-authorship network has been used along with online social networks, tagging activities and face-to face contacts at three major conferences to gather online social interactions' interdependencies with the offline world (Barrat, Cattuto, Szomszor, Van den Broeck, & Alani, 2010).

Alcaide et al. (2009) used co-authorship network analysis to examine women participation in Spanish sociological journals. The study found predominance of male authors, with only one-fourth of total number of authors being women (Alcaide et al., 2009). The authors of the study suggested that this 'inequality' may be due to reduced number of women reaching the highest position in academic ranking (Alcaide et al., 2009). Ozel (2012a, 2012b) noticed that the cognitive demand of publishing in indexed journals has given way for cohesive collaborative teams, resulting in collaborative knowledge production and transfer. Authors may choose publication outlets. Gossart and Ozman (2009) used SSCI and Turkish ULAKBIM databases to construct co-authorship networks and found that while some authors publish mostly in international journals, others target national audience.

2.2.7 Author name disambiguation

Name disambiguation remains one of the unresolved issues in bibliometrics (Tang & Walsh, 2010). Due to inherent problems involved in disambiguating author names, some studies avoid the process while others indicate a method but do not elaborate on the resolution of the author name issues (Tang & Walsh, 2010). Kang et al. (2009) proposed a technique for acquiring implicit coauthors of the target author to be disambiguated and then a coauthor disambiguation hypothesis that the identity of an author can be determined by his/her coauthors, which has been examined and confirmed through different author disambiguation tests. Andreas, Dangzhi, and Tania (2009) have outlined a heuristic algorithm for disambiguating author names of publications on the basis of well-defined similarity measures among publications in which their names appear as authors.

2.2.8 Network visualization

Visualization forms an important component of network analysis. Visualization gives meaning to the analysis and both complement each other. Softwares like Pajek (Batagelj

& Mrvar, 1998), UCINET (Borgatti, Everett, & Freeman, 2002), SCI2 (Sci^2, 2009), and NodeXL (Smith et al., 2009) have an inbuilt network drawing function. These softwares have been extensively used in several co-author network studies (Gonzalez-Alcaide, Aleixandre-Benavent, & de Grande-Orive, 2010; Graeml et al., 2010; Olmeda-Gomez, Perianes-Rodriguez, Ovalle-Perandones, & Moya-Anegon, 2008; Velden, Haque, & Lagoze, 2010). Network drawing can be improved for better visibility using spring algorithms, such as Kamada-Kawai (Olmeda-Gomez et al., 2008; Ovalle-Perandones et al., 2009), Fruchterman- Reingold (Fruchterman, Reingold, & Science, 1991) and Harel-Koren Fast multiscale (Koren & Harel, 2004), among others.

2.2.9 Co-authorship network analysis at multi-levels

Co-authorship networks are used to explore collaborative patterns not only at individual levels, but also at institutional and national levels. Using data harvested from Scopus for the period from 1970 to 2009 in the field of 'steel structures', Abbasi, Hossain, Uddin, and Rasmussen (2011) presented an evolutionary dynamics of co-authorship networks at individual, institutional and national levels. While examining number of publications per capita in Ibero-American countries from 1973 to 2010, Lemarchand (2012) found exponential growth in total number of publications, the same as their national productivity. Lemarchand (2012) also noticed that the co-publications among countries grows quadratically against time. Olmeda-Gomez et al. (2008) examined intra-regional collaboration involving university-government's enterprise. By carrying out a co-authorship network analysis, Aleixandre-Benavent et al. (2012) found an increase in the degree of internationalization, yet a constant degree of domestic association. The authors used co-authored articles from web of science to examine the networking behaviour of three scientific domains in the region of Madrid. Their study found that networking moderately increased the number of links and participating actors. Public Universities recorded the largest number of links.

2.2.10 Scholarly communities

Scholars work in certain communities based on their research interests, and this could be at times deciphered by the network patterns (Girvan & Newman, 2002). Communities could play an important role in knowledge creation (Lambiotte & Panzarasa, 2009). Newman (2004a) presented an example of a research collaboration network at a private research institution, where the network appeared to be divided into sub-communities (see Figure 2.5). The underlying cognitive structure created by the scholars has also been extensively analysed (Boyack, Klavans, & Börner, 2005; Mane & Börner, 2004; Milojević, Sugimoto, Yan, & Ding, 2011). Research communities could be detected through cluster analysis or some other analysis. Perianes-Rodriguez, Olmeda-Gomez, and Moya-Anegon (2010) used data from 9 departments of Carlos III University and identified research groups based on factorial analysis and similarities in the choice of authors. Velden et al. (2010) carried out mesoscopic level study, which included network analysis and participant interviews in three areas in chemistry. The authors detected clusters, which they interpreted as an overlap between two distinct types of cooperative networks of groups of authors publishing in a research specialty.

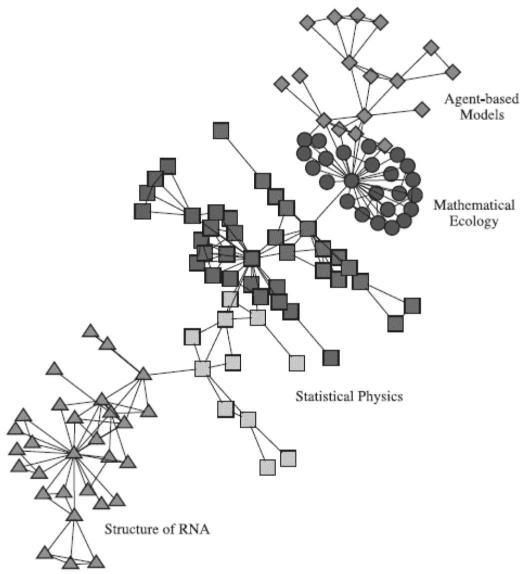


Figure 2.5 : Communities within a Co-authorship network (Newman, 2004a).

Another study identified research clusters using papers published between 2003 and 2007 in biomedical journal, *Archivos de bronconeumologia* (Gonzalez-Alcaide et al., 2010). Gonzalez-Alcaide et al. (2012) applied clustering methods to the dataset on Chagas disease extracted from the Medline databases to identify the research groups. Applying a threshold of five and more researchers, the authors detected 168 research groups. A large number of these researchers were from Brazil, the country that has been affected by this disease the most. Heidler (2011) combined scientometrics, quantitative network analysis and visualization tools with a qualitative network analysis approach to examine the cognitive and social structure of the elite collaboration network of Astrophysics. Ozel (2012a) used a novel method, which mapped actors from co-authorship network into a 'strategic diagram' of scientists in the Turkish management academia spanning the years from 1922 until 2008. Calling this a 'socio-cognitive' map, the author found that the leading local academicians have more social ties and diversified knowledge compared to the rest of authors. Hou et al. (2008) carried out combined analysis of social network analysis (SNA), co-occurrence analysis, cluster analysis and frequency analysis of words to reveal prominent collaborative field and collaborative centre of the collaboration network in journal Scientometrics. In yet another study, Reijers et al. (2009) identified the ‘hotbeds’ of Business Process Management research and mapped the progressive collaboration patterns within the BPM community.

Few established standard algorithms and modelling tools are used to detect academic communities (Girvan & Newman, 2002). Chinchilla-Rodriguez, Ferligoj, Miguel, Kronegger, and de Moya-Anegon (2012) applied different techniques, such as block modelling, kamada-kawai algorithm and standard bibliometrics, to study research group composition, structure and dynamics. Similarly, Kromer et al. (2012) had applied spectral partitioning to detect communities in a co-authorship network.

2.2.11 Assortative mixing

Assortative mixing or homophily is the tendency of entities to connect to ‘similar others’ (McPherson, Smith-Lovin, & Cook, 2001). Several factors could bring researchers together, such as, similar popularity, position, gender, nationality, and the like. A tendency to connect to dissimilar others, i.e., member of one gender associating with member of another gender, is called a ‘disassortative’ mixing. In preferential attachment, less connected nodes ‘prefer’ to connect to popular nodes, which is a form of disassortative mixing. Preferential attachment, a principle factor in network growth, is also displayed by scientific collaboration networks (Perc, 2010). Examining assortative mixing based on the degree of the node (or degree assortativity) have been carried out in co-authorship networks (Newman, 2004a). Recently, Pepe and Rodriguez (2010) carried out, in addition to degree assortativity, an in-depth analysis of assortative mixing by applying other discrete parameters, such as nationality, department, academic affiliation and professional position. However, studies on assortative mixing among authors, especially those involving discrete parameters, have been limited.

2.2.12 Comparative studies

Co-authorship studies have been applied in multi-field comparative studies. Nikzad, Jamali, and Hariri (2011) used indicators, such as the Collaborative Index (CI), Degree of Collaboration (DC) and Collaboration Coefficient (CC), to compare scholarly networks of Iranian papers in library and information science (LIS), psychology (PSY), management (MNG), and economics (ECO) in the ISI Web of Knowledge database during 2000-2009. They applied network analysis for the visualization of co-authorship networks. Interestingly, the study found that PSY had more multi-authored papers, yet its network was least dense. All of the above fields had co-authors mostly from the developed world, such as UK, US and Canada.

Even though co-authorship networks may belong to the same subject or field, they may show significant differences in collaborative patterns. Eblen et al. (2012) compared co-authorship networks using citations published from 1990 till June of 2011 in Cardiovascular Health Study (CHS) and Strong Heart study (SHS). Although belonging to similar epidemiological cohort studies, their collaborative patterns showed significant differences. CHS had thrice the number of authors compared to SHS, yet its networks were sparser, consisting of several components. The authors also pointed out that differences in factors, such as study population, study design, and funding, among others, can influence differences in these collaboration patterns.

Comparative studies on co-authorship strategies have been carried out in a number of ways; however, comparative studies in a given research field have rarely compared two nations directly. Such studies can bring out, for example, differences between two countries in researchers' collaborative patterns.

2.2.13 Correlation between centrality and productivity

While examining co-authorship networks, studies have found correlation between the centrality measures and productivity. Using a 20 year data from 16 journal in LIS, Yan and Ding (2009) constructed an evolving co-authorship network to calculate 4 centrality measures, closeness, betweenness, degree and pagerank centrality. They found that authors' centrality measures had significant correlation with citation counts. In their study, betweenness centrality had the highest correlation with the number of citations. Yan's another study in 2010 (Yan et al., 2010) also found that centrality ranking correlated highly with author's citation counts. Abbasi, Altmann, et al. (2011) examined normalized degree centrality, normalized closeness centrality, normalized betweenness centrality, normalized eigenvector centrality, average ties strength, and efficiency and found that only normalized degree centrality, efficiency, and average ties strength had significant influence on the g-index (as a performance measure). In a more recent study,Ye et al. (2013) applied SNA to the co-authorship network by examining articles published in six leading tourism and hospitality journals and found significant correlation between research collaborations and research outputs. Uddin, Hossain, and Rasmussen (2013) used co-authorship database of 'steel structures' to examine the influence of degree, betweenness and closeness centralities on citation count and tie-strength. Their study found that degree and betweenness centralities influence both citation count and tie-strength. Closeness centrality did not significantly affect these factors.

Some studies have suggested co-authorship strategies based on the effect of centrality measures on research performance (Abbasi, Altmann, et al., 2011; Kuzhabekova, 2011). However, co-authorship strategies need to encompass other determinants to provide a wholesome strategy. For example, apart from looking at just effect of centrality measures on research performance, other determinants, such as frequency with which collaborated papers are cited and the role of local and foreign partners could provide clues for better and more complete co-authorship strategy. This is systematically missing in the literature, especially from the Malaysian context.

2.2.14 Co-authorship and citation behaviour

Some studies have shown that co-authorship reveals citation behaviour of authors. Fischbach et al. (2011) examined co-authorship networks of researchers publishing in Electronic Markets, particularly the International Journal of Networked Business (EM). Among others, the study found that co-authored papers were cited more compared to those authored individually. In their study, Ding (2011) found that highly cited authors generally do not co-author with each other but frequently cite each other. Krumov, Fretter, Muller-Hannemann, Weihe, and Hutt (2011) analyzed the correlation of (three- and four-node) network motifs with citation frequencies using two large-scale data sets, CiteSeerX and DBLP, and found that the average citation frequency of a group of authors depends on the motifs these authors form.

2.3 Organisation of Islamic Co-operation (OIC) nations, Turkey and Malaysia, in the field of 'Energy Fuels'

The three research questions representing the three case studies deal with three disciplines or fields of research. Case study 1 deals with business and management discipline, case study 2 deals with engineering disciplines in Malaysia and case study 3 deals with the field of 'energy fuels'. The first two case studies focus on the structure, whereas the third case study emphasises both the structure and field (energy fuels). Apart from this, the third case study is also a comparative study between two OIC (Malaysia and Turkey) nations. Hence, a research background in the field of ‘energy fuels’, OIC, Turkey and Malaysia becomes pertinent here.

Most of the world’s energy supplies come from fossil (i.e., coal, natural gas and crude oil) and nuclear energy sources (Dresselhaus & Thomas, 2001). However, due to fast depletion of fossil fuels reserves and thus escalating oil prices along with environmentally damaging effects, such as GHG (Greenhouse gas) emissions, fervent efforts have been made to find alternate sources of energy that would be cheaper, more sustainable and environmentally friendly (Sopian, Ali, & Asim, 2011). Renewable energy, such as hydroelectric power, wind power and solar power, do not produce CO_2 or other greenhouse emissions, although they have their own limitations. For example, wind power relies on wind farms that require expensive turbines that may interfere with radar in addition to leaving a negative ecological footprint (https://www.gov.uk/onshore-wind-part-of-the-uks-energy-mix). Biomass power is emerging as a promising renewable energy source. Biomass is produced by green plants (algae, trees and crops) where energy of sunlight is stored in chemical bonds (McKendry, 2002). Biofuels and hydrogen fuel cells are also being considered as powerful alternatives that could run our cars instead of oil. We cannot do away with conventional forms of energy. The right solution may be to make efficient use of conventional energy and expand the use of renewable technologies. This requires governments’ actions at various levels and international co-operation. I are amid energy crisis and the climatic concerns of global warming due to inefficient use of conventional energy is at its height.

In the recent times, quite a number of bibliometric studies have been carried out in the field of energy fuels, and these studies have looked at this field from various perspectives. Very recently, S. U. Hassan and Haddawy (2013) studied the field of energy while introducing a new quantitative measure to gauge knowledge flows between countries.

Using publication and patents data to study the field of solar cells , Huang, Dong, and Chen (2013) found unbalanced performance and regional differences in research collaborations at individual and country-levels. International collaborations showed best performance in Huang's study; however, Asian countries, such as Japan, Taiwan and China, had a high ratio of domestic collaboration, higher than the average ratio of international collaboration. A bibliometric study on Solar Photovoltaic industry in the U.S. identified early technology focus in different areas within this field and determined potential technology pathways in the renewable energy domain (Vidican, Woon, & Madnick, 2009). While investigating research collaboration networks in wind power and solar cells, two of the most promising technologies for "green" growth. Sakata, Sasaki, and Inoue (2011) found that geographical distance, international policies and maturity of technologies, among others, have a significant effect on research collaboration.

Glänzel and Thijs (2011) conducted the analysis on the broader field of Energy and fuels. In this study, the authors examined energy and fuels subject category based on core documents, extending this notion through the combination of citation-based and textual links. The authors detected seven clusters, including renewable energy, cover batteries and electricity storage, and theoretical aspects, such as mathematical modelling, among others. Other bibliometric studies have been carried out in energy fuels areas. Quite understandably, these have focused on renewable energy, such as solar power research (Dong, Xu, Luo, Cai, & Gao, 2012; Jang, Chen, Chen, & Chiu, 2013), hydrogen energy (Tsay, 2008), fuel cells (E. Hassan, 2005), wind power (Sanz-Casado, Garcia-Zorita, Serrano-López, Larsen, & Ingwersen) and biomass (Thomas, 1992).

OIC or Organisation of Islamic Co-operation is an association of 57 Muslim-majority nations. Although OIC nations hold about two-thirds of world reserves of crude oil and natural gas, they lack necessary technology and R&D to process these resources (Series, 2012). Turkey and Malaysia are two prominent OIC nations. Malaysia is about one-third the size of Turkey in terms of both geographical area and population, yet its per capita consumption of energy is significantly higher than that of Turkey. Malaysia had 2557.8 kgoe/a (kilogramme of oil equivalent per capita) in contrast to Turkey's 1445.1 kgoe/a per capita consumption of energy (World Development Indicators, 2012). As many OIC nations are blessed with rich reserves of conventional energy, little effort has been made to harness renewable energy (Sopian et al., 2011). However, both Turkey and Malaysia are making impressive strides in harnessing renewable energy. Turkey, for example, is a leading OIC nation in the production of wind and hydroelectric power (Series, 2012), whereas Malaysia is a major producer of photovoltaic panels (Sopian et al., 2011).

Both Turkey and Malaysia have realized early that a highly skilled talent base or robust human capital, which lies at the core of innovation, is imperative for their country's economic development. For example, under the *Wawasan 2020* project, Malaysia has allocated significant financial resources to improve its R&D infrastructure and create first-class human resources. Research and development within OIC member countries are particularly important, as they help in gaining competitive advantage over other OIC member states. By creating new knowledge and technological innovation, research in Science and Technology provides is the key toward an innovation-driven economy (SESRIC, 2010). Both Turkey (0.74) and Malaysia (0.63) have above average R&D intensity % (R&D spending in %age to the GDP) among OIC nations, which is still much lower than the World average (1.78%) (SESRIC, 2010). The quantum of academic research is adequately reflected through scientific publications. As per WoS 2009 data, OIC nations produced 63,342 articles, of which Turkey and Malaysia contributed 31% and 6.2% respectively (SESRIC, 2010). The latest Web of Science SCI records showed that both countries are also undertaking significant research in the field of energy fuels. The subject area of energy fuels includes both conventional and non-conventional energy sources and encompasses research in areas such as renewable energy, fuel, biomass, petroleum geology, global warming, and green energy, among several others. Given the interdisciplinary nature of research today, studies in energy fuels are relevant to other subject areas, from Mechanics and Thermodynamics to Mathematics and Public Administration.

2.4. Chapter conclusion

In this chapter, relevant literature on both research collaborations and research collaboration networks were presented, while identifying research gaps in the process. The first section deliberated on the history of research collaborations, ethical issues, factors, perceived benefits and the various dimensional and organisational types of research collaborations. The second section dealt with the network approach to research collaborations. Here, first the literature on the evolution of networks field, its common topological properties, and its application to research collaborations were reviewed. Next, various aspects of co-authorship, social capital, assortative mixing and centrality measures effect on research performance were reviewed. Specific literature on OIC and energy fuels relevant to Case study 3 is reviewed in the last section. In the next chapter, I discuss the research methods employed for this study.

CHAPTER 3: RESEARCH METHODS

This study examines research collaborations in Malaysia from the perspective of networks. Three essay-based case studies have been chosen, each representing a research question. All the case studies have Social network analysis as the main research method. In this chapter, I begin with the description of the social network analysis metrics used in the study. I then delineate data sources, additional research methods, author disambiguation, and tools used for each case study.

3.1 Social network analysis

Social network analysis (SNA) is applied to the characteristics of co-authorship networks. SNA uses an established set of mathematical algorithms to map and analyze relationships among entities (Wasserman & Faust, 1994). In network analysis, the attributes of the entities are not ignored, but rather seen in the light of the relationship the nodes have with one another. Several key structural measures and notions in SNA are the result of researchers' insights into empirical phenomena and are driven by social theory(Wasserman & Faust, 1994). Social network methods have been developed over the past seven decades as an integral part of development in social theory, empirical research, maths and statistics (Wasserman & Faust, 1994).

3.1.1 Constructing a co-authorship network

A network of researchers can be constructed if two researchers co-author a scholarly paper together. In this case, scholars would form the nodes and the paper they have co-authored would represent the link between them.

For example, if four authors,

$V_1 = [a,b,c,d]$, co-write a paper, the co-authorship links they form is,

E_1 = [[*a*,*b*],[*a*,*c*],[*a*,*d*],[*b*,*c*],[*b*,*d*],[c,d]].

Again when *c* co-writes a paper with *f*, V_2 = [*c*,*f*], the link is represented as E_2 = [*c*,*f*]. Similarly, when *d* co-writes a paper with *b* and *i*, V_3 = [*d*,*b*,*i*] the links are represented as E_3 = [[*d*,*b*], [*d*,*i*],[*b*,*i*]].

The lines between the nodes in a co-authorship network are undirected, symbolizing mutual relationship. This could be graphically depicted as in Figure 3.1.

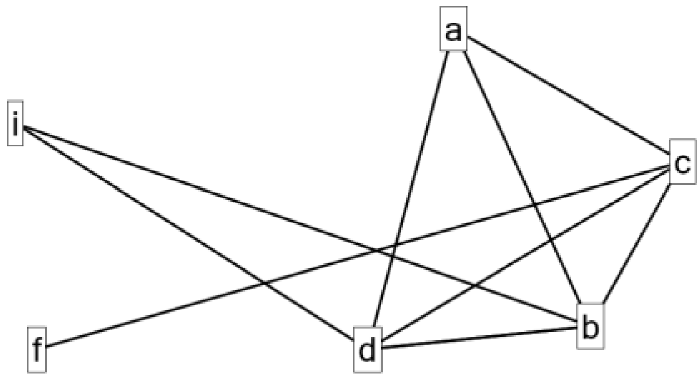


Figure 3.1: An example of co-authorship network

If two authors wrote a paper together, a weight of one was accorded to their relationship. When they co-authored two and more times, their edges were merged to give a weight to their relationship. For example, if A and B co-authored a paper three times, only one edge line still passes between them, but the edge would carry a weight of three. Optionally, higher weights could be visualized by thickening the edge between A and B. The edge value does not get fractioned based on the number of authors in the paper.

3.1.2 The evaluation of topological characteristics of a network

Topological characteristics of the network are evaluated at two levels: the global or macro level and the local or micro level. At the global level, by calculating density, geodesic paths, clustering coefficients and degree distribution, the overall features of the network are revealed. Global properties indicate the concentration of authority, control and other resources within the network (Yan et al., 2010). At the local level, measures such as degree, betweenness, closeness and PageRank centralities reveal the properties of individual nodes. Centralities indicate the influence of actors in terms of their popularity, approachability, brokerage power and prestige. The social behaviour of authors is governed by opportunities, which in turn determine the influence of actors in the network (Yan et al., 2010).

A *path* is the sequence of vertices 'walked' from one edge in the network to another edge. A *geodesic distance* is the shortest path between a specified number of nodes. It is possible that there is more than one geodesic path between two vertices at any particular point in time.

A *component* is a set of nodes joined in such a way that any single random node in the network could reach out to any other random node by "…traversing a suitable path of intermediate collaborators" (Newman, 2004a) (p.5202). A giant component is the component having the largest number of nodes. In a network, initially most nodes either exist in isolation or in small clusters. Then, when new vertices and edges are added, the network grows dynamically to a tipping point, also known as the percolation level, at a special value of probability:

$$P = 1/n \qquad (1)$$

where n is the number of vertices above which a giant component forms (Newman, 2007). In a co-authorship network, a giant component can reflect the group in which the main or central activity is taking place.

Clustering coefficient, C, is also known as 'transitivity' and more accurately as the 'fraction of transitive triples'(Wasserman & Faust, 1994). Mathematically, clustering coefficient is calculated as:

$$C = \frac{3 \times no.of\ triangles}{no.of\ connected\ triples} \qquad (2)$$

where the number of triangles represents trios of nodes in which each node is connected to both others, and connected triples represent trios of nodes in which at least one node is connected to both others (Barabasi et al., 2002; Newman, 2004a).

The *density* of a network, *G*, indicates the number of links in the network in ratio to the maximum possible links. The density, *D*, of an undirected network P (cooperation network in which the relationship is mutual) with n vertices is expressed as (Otte & Rousseau, 2002),

$$D = \frac{2 * (\#L(P))}{n(n-1)} \qquad (3)$$

Degree is the most common and probably the most effective centrality measure to determine both the influence and importance of a node. A degree is simply the number of edges incident on the vertex. Mathematically, degree k_i of a vertex is

$$k_i = \sum_{j=1}^{n} g_{ij} \tag{4}$$

where g_{ij}= 1 if there is a connection between vertices *i* and *j* and g_{ij}= 0 if there is no such connection (Otte & Rousseau, 2002).

Betweenness centrality of a vertex *i* is the fraction of geodesic paths that pass through *i*, which could be mathematically represented as

$$b(i) = \sum_{j,k} \frac{m_{jik}}{m_{jk}} \tag{5}$$

where m_{jk} is the number of geodesic paths from vertex *j* to vertex *k(j, k ≠ i)* and m_{jik} is the number of geodesic paths from vertex *j* to vertex *k*, passing through vertex *I* (Linton, 1977; Otte & Rousseau, 2002)

Closeness centrality of a vertex *i* is the average geodesic distance from every other node in the network. Mathematically, this is computed as

$$c_i = \sum_j d_{ij} \tag{6}$$

where d_{ij} is the number of edges in the geodesic path from vertex *i* to vertex *j* (Otte & Rousseau, 2002)

PageRank is a link analysis algorithm (Page, Brin, Motwani, & Winograd, 1999) that measures the relative importance of nodes within the network. PageRank works on the premise that having links to page *p* from important pages, is a good indication that page *p* is important one too. PageRank was proposed initially for digraphs. However, it can be calculated for a unidirectional graph, such as the co-authorship network, by making each edge bidirectional.

3.2 Measuring research performance

Research performance of an author involves, in general, two parameters – number of papers produced by an author and the total number of citations received by the papers written by the author. 'Fractionalised counting' and 'whole paper' counting are two common ways to see productivity of author in terms of number of paper produced. In factionalized count, a paper is divided by the number of authors and each author is then accorded a fractionalised value. In whole paper counting a paper is accorded a value of one irrespective of the number of authors in the paper. Similar, fractionalised counting has been suggested for citations too. When an author writes paper, he or she is a 'producer' and his paper gets cited, it is 'consumed' based on how much relevant it is to the literature in context. Hence, number of paper and times cited are two different aspects of productivity, one indicating a quantity and the other indicating the quality. Some measures like the *h-index* have a special algorithm that computes both quality and quantity in one index, however, recent papers have also raised specific issues with this system (Bornmann and Daniel 2007). Several other variants of h-index, such as *g-index, p-index* and *d-index* (Di Caro et al. 2012; Karpagam et al. 2011) also have been suggested. In this study, however, the classic method of paper and citations count of each author to check research productivity have been used. I use whole paper counting to accord quantity count to the authors.

3.3. Lotka's law of scientific productivity

Lotka (1926) investigated the frequency distribution of author productivity among chemists and physicists and found that the number of authors writing *n* articles is about $1/n^2$ of those writing one paper, and the proportion of all authors that make a one-paper contribution is about 60%. Since publishing his findings, Lotka's measures are now established as Lotka's Law of Scientific productivity (Talukdar 2011). Lotka's Law is a kind of 80:20 rule, stating that a few authors write the much higher number of papers. Mathematically, this is denoted by

$$f(k) = \frac{C}{k^{\beta}} \quad (7)$$

where $f(k)$ denotes the number of authors with k publications. C and β are computed using the maximum likelihood method (Rousseau & Rousseau, 2000). Lotkasofware developed by the Rousseau and Rousseau (2000) have been used to check if the research productivity of authors in our two datasets fitted Lotka’s Law.

Apart from the common research methods that are applied to three case studies, there are certain data sources and certain research methods that are specific to the case studies. These are delineated underneath.

3.4 Research Question 1

The essay-based case study representing RQ1 is focused on examining the state of research collaborations in the Business and Management discipline in Malaysia at the individual, institutional and international levels.

3.4.1 Data harvesting

WoS database has been used to carry out our analyses. Because Business and Management as a discipline often falls within the purview of the social sciences, the SSCI (Social Sciences Citation Index) database of the WoS was queried for a 30-year period, from 1980 to 2010.

The SSCI database was queried as of January 2011. The total number of documents in the business and management categories was 245 records, which consisted of articles

(209 documents), reviews (10 documents), letters (4 documents), corrections (1 document), proceedings paper (10 documents), book reviews (6 documents), editorial materials (3 documents), and note (1 document). The records were futher skimmed to include only ‘Articles’ as the study focus is only to include artifacts that represent prominent new research.. Thus, 209 harvested records fell into multiple WoS categories. However, because journals published by the “Academic Journals” publishing house have been disqualified by MyRA (http://www.ippp.um.edu.my/images/ippp/doc/myRA%20II.pdf, Section C, Publications), all articles published by the said publisher were removed. This narrowed our record set further to 160 records. Admittedly, the dataset is small, but it fully represents all the peer-reviewed articles indexed in the well-recognized indexing system, the WoS. Additionally, a smaller record set gave us the added advantage of cleaning the data meticulously by hand. These categories account for articles that fall under Business and Management subjects and might also be tagged with other subject categories. For example, an article might be in the main category of ‘Planning & Development’ but would be also tagged in the Business or Management category because it may also have business or management relevance.

Data is saved in delimited form and imported into spreadsheet software, MS-Excel. Cleaning the data was done by checking bibliographic data provided in the WoS. When uncertain, a cross-check was made to the actual journal abstract or article. Wherever available, an online check to the author’s curriculum vitae (CV) was also done. This minimized data redundancy and errors by thoroughly cleaning the records.

Author name disambiguation is a difficult task to resolve because some authors, during different times in their careers, represent themselves with different name variations. For example, sometimes they write their full name and sometimes they choose to just refer to themselves with initials and surnames. Although indexing databases, such as WoS and

Scopus are now standardizing author names, analysts still encounter earlier bibliographic data with author name variations that are difficult to disambiguate. Another issue is with authors that have names that are identical to other authors. This is difficult to detect, especially when the subject area of the authors is the same. Authors also move from one institution to another, or they may represent more than one institution simultaneously. These realities further complicate the problem because they could incorrectly relate authors and their publications. If authors have the same name but are actually two different individuals, not identifying them separately would combine the publications of the two, as if only the publications belonged to just one author. Similarly, if the same author with a different name variation could be taken as a different author, his or her publications could be distributed using a different name variation.

For large datasets the issue becomes about reducing errors due to name variations to a minimum, and several algorithms have thus been written. Newman (2001c), who conducted a co-authorship analysis with massive datasets, presented his results without data cleaning, by giving upper and lower limits. In microanalysis such as the present study, the effort is to create the most accurate datasets. The only practical way to accomplish this task is to clean the data manually. Using manual cleaning, each record is checked for anomalies.

Prior to 2008, WoS only indexed the initials and surnames of the authors, rather than full names. This made it difficult to identify authors while removing the possibility that someone having a similar or identical name as another might be mistaken for someone else. For example, at first look, ‘Ahmad, N.’ and ‘Ahmad, N.’ are identical names for the same person.

However, investigating their full names reveals:

a. Ahmad, N. -- Ahmad, Nursilah
b. Admad, N. -- Ahmad, Nobaya

With the authors' first names, one is now sure that they are two different authors. Those with the same names and belonging to same institution, faculty, or department are considered in our dataset as the same author. Where names are the same but they belong to different institutions, or when names were similar (with slight variance, such as Ramesh, M.Y. and Ramesh, M.) but both belonged to the same department and institution, such records were investigated by checking for full names. However, because WoS only indexed surnames and initials prior to 2008, actual article abstracts from journal websites for articles published before 2008 were reviewed. I also had to check the websites of journals, authors, or institutions to gain further details. The possibility also exists that authors with the same names but representing different institutions might actually be the same person. This can be the case for two reasons. First, they might be representing more than one institution, and second, they might have moved to another institution and therefore now represent a new entity. Manually checking a bibliography can identify the multi-representation of authors. Inter-person identity can distinguish authors from one another. For this reason, one of the ways an author can be discriminated from others with similar names, especially when dealing with larger datasets, is to identify his or her co-authors (Kang et al., 2009).

Apart from author name variations, authors' institutional representation was the next largest issue to resolve. Prior to 2007, WoS did not explicitly identify each author with his or her institution. Hence, the only way authors' institutional representation could be ascertained was to look into the actual bibliography of each paper from the journal's website and connect each author and institution. Some authors, mostly university faculty members, moved from one institution to another. For these authors, it was difficult to pinpoint the institution to which they belonged at the time their articles were written, especially when an author's CV was not online. Many of the authors who had publications prior to 2000 were no longer active and their email addresses (if any) were invalid. For publications prior to 2000, some publishers did not identify authors with their respective institutions even on the actual papers. In such cases, alternate methods were tried such as searching the author's other publications on the web and WoS. In most cases, this exercise was successful, and I was able to allocate the correct institution to each author.

3.4.2 Additional research methods

Efficiency and Constraint: In the assessment of social capital, *efficiency* is a measure that conveys the proportion of 'impact each ego is getting for each unit invested in using ties' and *constraint* measures the extent to which the ego is invested in people who are invested in other ego's alters (Abbasi, Chung, et al., 2011). To calculate *Author Tie Strength*, total number ties of each node was divided by the degree centrality of the node(Abbasi, Altmann, et al., 2011).

Degree Assortativity: Two of the major characteristics of a network are preferential attachment and growth (Barabasi & Bonabeau, 2003). Preferential attachment takes place when low-degree nodes associate with high-degree nodes, earlier defined as the rich-getting-richer phenomenon or *Mathew effect* (Kadushin, 2011). Assortative mixing, although based on the preferential attachment paradigm, is slightly different in its concept. It involves connections with similar others. In a network, there is a high probability that popular authors would associate with other popular authors in the network. It is also quite probable that less popular nodes, for example, new PhD candidates, would likely associate with someone popular in the field, such as a professor.

Here the Degree Assortativity Coefficient is calculated using Newman's formula (Newman, 2002), which uses the Pearson correlation coefficient on the degree of authors at either side of the edges:

$$r = \frac{M^{-1}\sum_i j_i k_i - \left[M^{-1}\sum_i \frac{1}{2}(j_i + k_i)\right]^2}{M^{-1}\sum_i \frac{1}{2}(j_i^2 + k_i^2) - \left[M^{-1}\sum_i \frac{1}{2}(j_i + k_i)\right]^2}, \qquad (8)$$

where j_i, k_i are the degrees of the vertices at the ends of the ith edge, with $i = 1 \ldots M$. r must be in the range of –1 and 1, where –1 depicts complete disassortativity and 1 depicts complete assortativity.

Geographical Proximity: Collaboration becomes easier with Geographical proximity or *propinquity* (Kadushin, 2011) due to the tacit nature of knowledge (Ponds, Van Oort, & Frenken, 2007). Other studies have found that Geographical proximity between institutions is an important factor in promoting research collaboration (Havemann, Heinz, & Kretschmer, 2006). Fewer than 20 years ago, Katz (1994) empirically calculated the distance between institutions represented by authors of four different nations. They found that in intra-national collaboration, Geographical proximity played an important role. Over these past 20 years, several technological advances have closed the distance gap between researchers. Here, I investigate whether geographical proximity still matters in intra-national collaboration. For this, only associations between two authors who were affiliated with a Malaysian institution are included. The distance between two cities was calculated by using an application available at http://www.distancefromto.net and was then cross-checked with actual geographical maps

3.4.3 Tools used

The edgelist was manually fed into NodeXL, a free MS-Excel template for exploring networks (Smith et al., 2009). Calculation of graph metrics and visualization were both carried out using NodeXL The ‘efficiency’ and ‘constraint’ values of individual authors were calculated using a built-in function in UCINET software (Borgatti et al., 2002).

3.5 Research Question 2

The essay-based case study representing RQ2 is focused on examining the factors that may affect the size of giant component in the country-specific dataset pertaining to Malaysia of four prominent engineering disciplines as per WoS subject categories, namely - chemical engineering (CHEM), electrical and electronics engineering (EEE), civil (CIVIL) engineering and mechanical engineering (MECH).

3.5.1 Data harvesting

The WoS subject categories were followed when extracting the data set of each discipline. During 3rd week of June 2011 All the 5 databases in the WoS were queried, namely - SCI-Expanded, SSCI, A&HCI, CPCI- S, CPCI-SSH for all years in the disciplines of electrical and electronics engineering (EEE), chemical engineering (CHEM), civil engineering (CIVIL), and mechanical engineering (MECH) with Malaysia as the address of at least one of the authors in each article.

Following search query was used for EEE:

> Address=(Malaysia), Refined by Document Type=(ARTICLE) AND Subject Areas=(ENGINEERING, ELECTRICAL & ELECTRONIC), Time span=All Years. Databases=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH.

Similar queries were followed for the other three disciplines.

In the ISI WoS database, records were found from 1973 to June 2011 (about 38 years). Again, as research articles are prominent artifacts of new research, only 'Articles' have been included in the study.

The data from WoS was downloaded in blocks of 500 records (maximum download allowed by WoS at a time). For two subject categories (EEE, CHEM) which had records over 500, the records were appended by removing the 'EF' in the mid files to make one complete file for each category.

Although, to be termed a giant component, it is not mandatory for the largest component to have a certain percentage of size of total *n*; for this study, the largest component was considered *well-formed* giant component only if it contained a majority (>50 percent) of the total *n* of the network (see Figure 3.2).

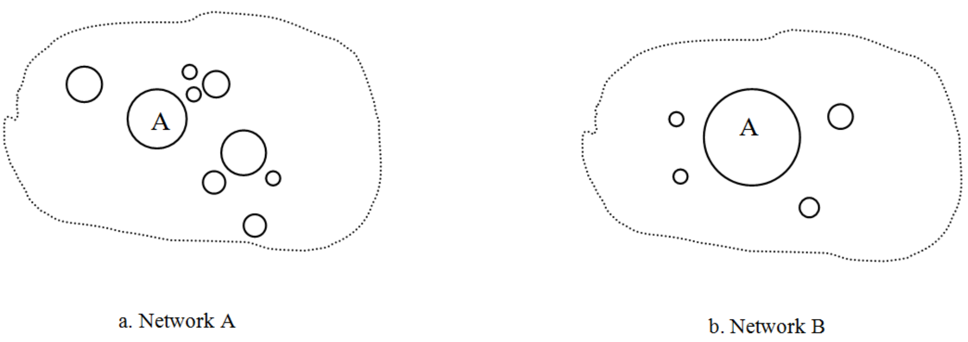


Figure 3.2: In (a) component A is the largest component, but not a *well-formed* giant component as per our classification. In (b), component A is the largest component and a *well-formed* giant component (component possessing majority of vertices).

3.5.2 Tools used

Construction of co-authorship network was carried out using Sci2 (Sci^2, 2009) and visualization using GUESS, which is inbuilt in Sci2. .graphml file of coauthorship network created in Sci2 was imported into NodeXL for the calculation of network topologies (Smith et al., 2009).

3.6 Research Question 3

The essay-based case study representing RQ3 is focused on examining how the collaborative networks of Malaysia and Turkey, the two OIC nations, compare with each other in the field of 'energy fuels'.

3.6.1 Data harvesting

All artifacts (all forms of published documents) were harvested during May 2012 from the ISI Web of Science (WoS) databases SCI-EXPANDED, SSCI, A&HCI, CPCI-S, and CPCI-SSH. The date range chosen was 2009−2011, with the subject area being 'Energy Fuels' and with the country affiliation of at least one author of each paper being 'Turkey' or 'Malaysia'. Two distinct datasets were created, one for Turkey and one for Malaysia.

For simplicity, I refer to artifacts as 'articles' in the present paper. The datasets sets of Turkey or Malaysia may be at times be mentioned simply as 'Turkey' or 'Malaysia'.

The following query was used to harvest the Malaysia dataset:

//

Address=(Malaysia)

Refined by: Web of Science Categories=(ENERGY FUELS) AND Publication Years=(2011 OR 2010 OR 2009)

Timespan=All Years. Databases=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH.

//

A similar query was used to extract the Turkey dataset.

Thomson Scientific has made internal disambiguation efforts on a massive scale (Smalheiser & Torvik, 2009) to reduce errors resulting from name variations of same author and different authors having the same name. Records were further checked manually for issues with author names. Recent records also have more accurate author-institutional identification and a separate field for the full name of the author in the bibliometric records. These qualities made it easier to disambiguate the names to the best extent possible.

3.6.2 Tools used

Sci^2 (Sci^2 2009) software was used to construct the co-authorship network. The resulting Graphml file was then imported from Sci^2 to NodeXL (Smith et al. 2009) for topological analysis and visualization.

3.7 Chapter conclusion

This chapter included six parts. The first part dealt with Social Network Analysis, which is the principal research method applied for all the three case studies. Here various macro and micro level graph metrics applied in the studies were described. The second and third parts explained about research performance measurement and Lokta's laws of productivity. The next three parts – each part referring to the specific case study – described data sources, harvesting queries used, author disambiguation process, additional research methods and tools used in the study. The the next chapter I present the results got from the study and analyse the same.

CHAPTER 4: RESULTS AND ANALYSIS

The previous chapter dealt with the research methods applied in the study. This chapter presents the results and analysis where an attempt is made to answer the three research questions of this study.

4.1 Research Question 1

Here the results and analysis of Research Question 1 (RQ1), which represents Case Study 1, are presented. RQ1 is restated here:

What is the state of research collaborations in the Business and Management Discipline in Malaysia at the individual, institutional and international levels?

This research question has following sub-objectives and sub-questions and are answered one by one.

4.1.1 Examining research collaboration at individual, institutional and national levels

This section attempts to describe the following sub-objective and answer the following sub-question of RQ1:

a) Using bibliometrics and network analysis examine research collaborations within the field of Business and Management in Malaysia at the individual, institutional, and international levels.

b) Are collaborative papers cited more often than individually authored papers? Are foreign-collaborated papers cited more often than locally co-authored papers?

Among the 379 authors in the dataset, they produced 160 research articles from 1980 to 2010. Published papers remained low until 2007. The noticeable surge in the number of papers published came after 2007 (see Figure 4.1.1). In some years, research production was non-existent.

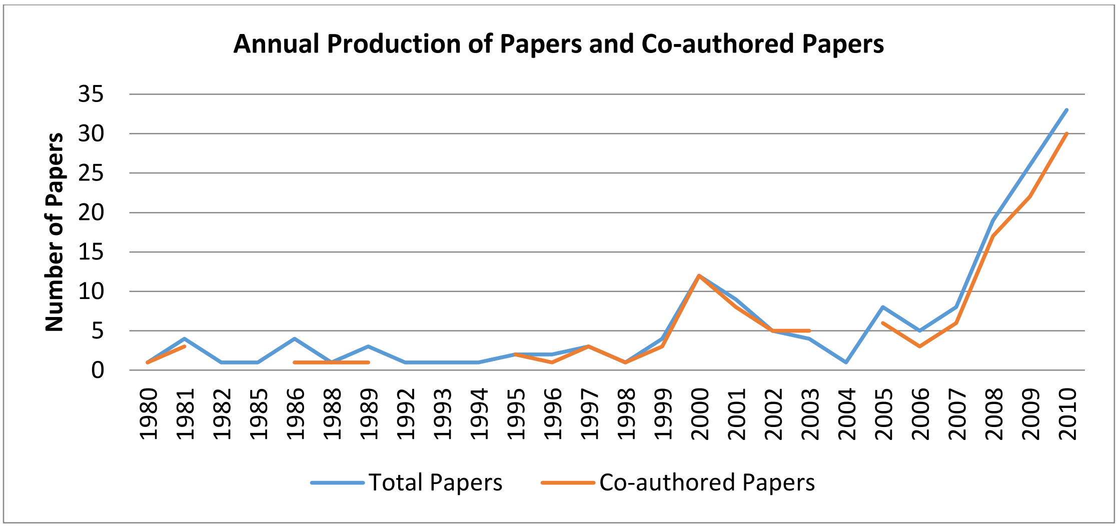


Figure 4.1.1: Year-wise production of articles

4.1.1.1 Author collaboration per paper

Twenty-one authors never collaborated with any other author in the dataset. There are 29 solo-papers, 64 two-author papers, 48 three-author papers, 17 four-author papers, 1 24-author paper and 1 49-author paper. Only 18.12% of the papers were written by solo authors, with the remaining 87.88% resulting from collaborative activity. The two papers with the significantly large number of authors were the result of large international studies and can be considered good examples of *hyper authorship* in the social sciences. Between 1980 and 1990, 1991 and 2000, and 2001 and 2010, the average number of authors per paper was 1.66, 2.33, and 3.00, respectively. These statistics demonstrate a steady increase in the number of authors collaborating on a paper. Solo papers have been cited two times on average and collaborative papers have been cited 4.12 times on average.

Although the number of collaborative papers increased, the number of solo papers also increased. Regression analysis was applied to check if collaboration on papers led to an increase in the number of papers produced. The percentage of collaborative papers produced per year (independent X variable) was checked for an association with the number of papers produced per year (dependent Y variable). The results revealed a correlation coefficient (R^2) value at 0.31 and P value > 0.05, which rejects our hypothesis that collaboration has led to an increase in the number of papers published.

4.1.1.2 Author productivity

A total of 338 authors published just one paper individually in the dataset. Thirty authors published two papers each, six authors published three papers each, two authors published five papers each, two authors published six papers, and one author published seven papers. Abdullah, M. is the author who produced seven papers, followed by Agus, A. and Fong, C.O. with six papers each, and Husain, M. and Yusof, S.M. with five papers each.

It is generally observed that a few authors in a research community publish a significant number of papers and a large number who publish just a few or one paper. This is also known as 80/20 rule, Zipf's Law, or Power Law. Lotka (1926) observed this phenomenon when investigating the publication frequency of physicists and chemists. Now known as Lotka's Law, this law postulates that the number of authors writing n articles (or contributions) is $1/n^{\beta}$ of those writing one article (c = 1). The β value in most cases is two. Lotka software developed by Rousseau and Rousseau (2000) was used to check if author productivity conformed to Lotka's Law. The value of β must be between with 1.27 and 3.29 to confirm Lotka's Law. The software gave a β value of above 3.29, which did not confirm a fit with Lotka's Law. However, looking at the frequency of the papers' patterns, it is clear that a large number of authors have published one or two papers and just a handful of authors have published three or more papers. This demonstrates a resemblance to Power Law to a fair degree. Some authors happen to collaborate more as other individuals preferentially attach to them. This preferential attachment might occur because of an individual’s popularity (already well connected with others) in the research domain or due to some other factor (Newman, 2002; Pepe & Rodriguez, 2010). Such popular researchers increase collaborative ties at a faster rate than their counterparts, a phenomenon also known as the *rich getting richer* (Barabasi & Bonabeau, 2003). Studies have also found a relationship with research productivity and other discrete parameters such as academic rank (Abramo, D'Angelo, & Di Costa, 2011) and well-being at work (Torrisi, 2013).

4.1.1.3 Overall co-authorship network

There are 358 vertices (unique authors), forming 1,760 edges (1,729 unique edges and 31 edges with duplicates), representing individuals who have collaborated at least once with another author. The network of Business and Management researchers (BM network) has developed over time. From just 13 edges during the 1980 to 1990 timeframe, the network gradually added another 51 edges during the 1991 to 2000 period. However, the real proliferation in edges occurred between 2001 and 2010 (see Figure 4.1.2). During this period, the network added 1,696 edges.

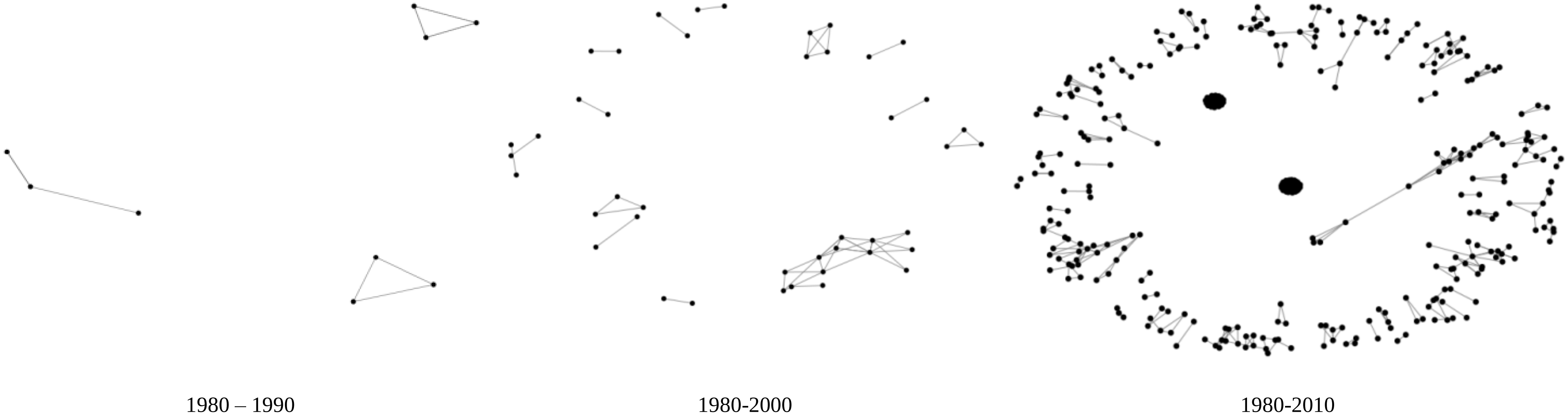


Figure 4.1.2: Dynamics of network formation

The co-authorship network of BM researchers in Malaysia is deeply fragmented. A giant component is the component possessing the largest number of nodes in the network. In the BM network, a giant component of any meaningful size has not yet formed. From among 94 connected components, the largest component has 49 vertices, and the second largest component has 24 vertices. The third, fourth, fifth and sixth, and seventh largest components have 17, 8, 8, and 6 vertices, respectively. There are 42 components with two nodes each, 28 components with three nodes each, 12 components with four nodes each, and six components with five nodes each.

The majority of studies concerning co-authorship networks tend to investigate networks that have well-established giant components (Newman, 2001c). Calculating global and local metrics is generally carried out only for the giant component. But, how does one deal with networks that are fragmented and have no presence of a well-formed giant component? Complicating the issue in our case is the presence of two hyper-authored network components. These hyper-authored articles present one of the largest hurdles when analyzing co-authorship networks. In a small network such as ours, such hyper-authored papers completely highjack the centrality scores, giving heavy biases to the results. Hence, these two network components, that is, those with hyper-authored papers are excluded, and the network is analysed excluding these two components (G1 and G2). The number of papers after excluding the hyper-authored papers is reduced from 160 papers to 158 papers. For all analyses henceforth, only these 158 papers are taken into account. This also reduces our vertices from 358 to 285 and edges from 1,760 to 308.

Graph metrics are presented in Table 4.1.1. The network has the maximum geodesic distance (diameter) of five, average geodesic distance of just 1.2, and a high clustering coefficient of 0.586. This low average geodesic distance is due mainly to high fragmentation and the absence of a giant component of any meaningful size. A low average geodesic distance, coupled with a high clustering coefficient, nonetheless, confirms the network's small-world nature (Watts & Strogatz, 1998). In a small-world network, any random vertex could reach another random vertex in a small number of hops. Several co-authorship networks have demonstrated the properties of small-world (Newman 2004; Yan et al. 2010).

Table 4.1.1: Topological properties of the BM network

Description	**Statistics**
Total number of unique authors	285
Unique edges	277
Edges with duplicates (repeat relationships)	31
Total edges	308
Connected components	92*
Vertices in the largest component	17
Maximum geodesic distance (diameter)	5
Average geodesic distance	1.2
Graph density	0.0071
Clustering coefficient	0.586
Mean degree	2
Mean betweenness	0.937
PageRank	Max: 2.732 Min: 0.452
Closeness centrality	**
Assortativity coefficient	0.463

*After excluding two components formed due to two hyper authored articles.
**Computation excluded due to high fragmentation of network.

The degree distribution shows the fit of the exponential model in the log-log diagram at $R^2 = 0.87$, which is quite good and resembles a scale-free network model to a good extent. In a scale-free network model, some nodes have large connections, whereas the majority of nodes have just a few (Barabasi & Albert, 1999). In our BM network, just 17 nodes have four to nine connections (or 6% of the total number of nodes). In contrast, 268 authors have between one and three connections (or 94% of the total number of nodes).

The third largest component (G3) is the effective largest component, which has been formed organically. This component forms a network of 17 authors who have 35 unique relationships among them (Figure 4.1.3). One of the advantages when drawing a graph with few vertices is the clarity with which one can see the interplay of nodes and vertices. The first relationship in the network was started by Agus, A. and Abdullah, M. in the year 2000. The network flourished in the year 2000, adding a total of 21 relationships. In 2001, 2007, and 2008, 7, 6, and 1 relationship(s), respectively, were formed. However, in 2009 and 2010, none of the authors co-authored a paper within the dataset. All of the authors in the group belong to Malaysian public institutions. Abdullah, M. and Husain, N. have the largest degree of connectedness: nine and eight, respectively. Among them, they have co-authored four papers together. They are the stars of this network and are holding the component together. If they were to become inactive for some reason, the component would break into pieces, disconnecting the flow of knowledge and resources in the component.

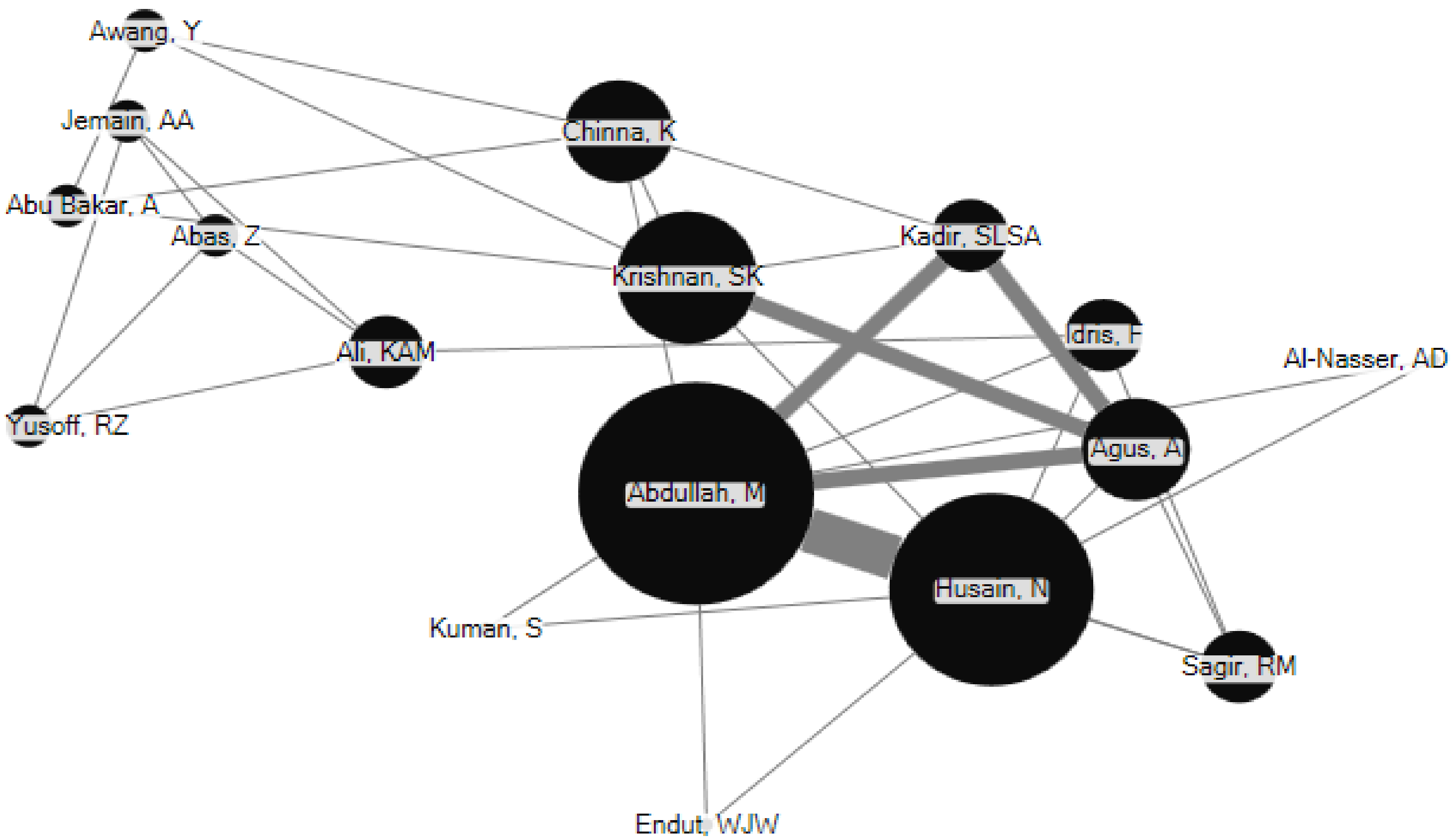


Figure 4.1.3: Visualization of effective largest component. Node size is based on degree centrality, while the thickness of lines depicts the strength of the relationship.

Several other components having between seven and eight nodes show developing relationships (such as G5, G6, G7). In G5, Yusof, S.M. has a degree of seven and has produced five works with 17 citations. In G6, Ahmed, Z.U., Johnson, J.P., Mohamad, O., and Tan, B. have a nice relationship, with between 20 to 31 citations to their works. In G15, Fong, C.O. and Srinivasan, V. have co-authored papers, which have been cited 78 and 74 times, respectively. These two authors are the most highly cited authors in the entire BM network.

4.1.1.4 Top authors based on centrality scores

Associating popularity, position, and prestige of authors with their research productivity has been a subject of several co-authorship network studies. Here, first top authors based on prominent centrality measures were investigated. Three centrality measures—*Degree, Betweenness Centrality*, and *PageRank*—were used to gauge popularity, position, and prestige, respectively, of the researchers. Due to the network's heavy fragmentation and the absence of a well-formed giant component, *Closeness Centrality*was not calculated Computations of graph metrics and the ranking of top authors based on these metrics and research productivity are given in Table 4.1.2.

Table 4.1.2: Top 20 authors based on centrality scores and research performance

Degree		Betweenness		PageRank		No. of Works		Citations	
Abdullah, M	9	Idris, F	48	Yusof, SM	2.735	Abdullah, M	7	Fong, CO	78
Husain, N	8	Abdullah, M	41	Abdullah, M	1.987	Fong, CO	6	Srinivasan, V	74
Yusof, SM	7	Ali, KAM	39	Ahmed, ZU	1.911	Agus, A	6	Yahya, S	50
Ahmed, ZU	7	Husain, N	31.083	Tan, LP	1.788	Yusof, SM	5	Kingsman, B	50
Krishnan, SK	6	Yusof, SM	18	Husain, N	1.786	Husain, N	5	Martinsons, MG	36
Zain, M	5	Krishnan, SK	15.5	Zain, M	1.604	Wong, ESK	4	Chong, PKC	36
Johnson, JP	5	Ahmed, ZU	12	Ang, CL	1.596	Williams, G	4	Ahmed, ZU	31
Agus, A	5	Chinna, K	11.917	Sambasivan, M	1.596	Sufian, F	4	Guiltinan, JP	31
Chinna, K	5	Zain, M	6	Wong, CY	1.467	Ahmed, ZU	3	Rejab, IB	31
Ang, CL	4	Tan, LP	5	Rasiah, R	1.467	Tan, LP	3	Rodgers, WC	31
Musa, G	4	Ang, CL	4	Ali, H	1.467	Wong, CY	3	Nambiar, JM	24
Sambasivan, M	4	Sambasivan, M	4	Devlin, JF	1.467	Rasiah, R	3	Gelders, LF	24
Idris, F	4	Musa, G	3	Larbani, M	1.459	Devlin, JF	3	Vanwassenhove, LN	24
Ali, KAM	4	Abu Bakar, N	3	Arshad, R	1.452	Krishnan, SK	3	Ramasamy, B	24
Abu bakar, n	4	Arshad, r	3	Othman, r	1.452	Kadir, slsa	3	Goh, kw	24
Sagir, RM	4	Othman, R	3	Musa, G	1.42	Srinivasan, V	3	Yeung, MCH	24
Kadir, SLSA	4	Fong, CO	3	Abu Bakar, N	1.42	Zain, M	2	Johnson, JP	23
Dinnie, K	3	Agus, A	2.25	Johnson, JP	1.349	Ang, CL	2	Agus, A	21
Melewar, TC	3	Johnson, JP	2	Krishnan, SK	1.337	Sambasivan, M	2	Mohamad, O	20

It was found that several authors in the top 20 of all three centrality measures also perform very well in terms of research productivity. Fifteen authors in the top 20 category in terms of the number of works published are also among the top in at least one of the other centrality scores. Citations, however, were substantially less correlated with the centrality measures. Abdullah, M., Yusof, S.M., and Ahmed, Z.U. are the top-ranked researchers in terms of their structural positions in the BM network. However, only Ahmed, Z.U., holds the top rank in all centrality measures and finds his place as a top-ranked author in terms of both the number of works published and citations. Authors such as Idris, F. and Chinna, K. are also very well positioned structurally, but do not appear in the top 20 rank in terms of research productivity. Srinivasan, V., who is top ranked both in terms of number of works and citations, does not feature in any of the top 20 centrality ranks. This amply supports the argument that although being structurally well positioned increases the chances of better research productivity, it is no guarantee that this will definitely be the case. Indeed, there are authors who are not structurally well positioned but are nevertheless highly productive. In networks where there is a well-established giant component, star authors in the giant component may also be well known among a large number of authors in the network. However, in the BM network, given its highly fragmented nature, it is less likely that these top performers will also be well known among a large proportion of authors in the network.

4.1.1.5 Institutional collaboration

Of the 111 institutions involved in inter-institutional collaboration, 49 are in Malaysia. Fifteen belong to public universities, 13 to private universities and colleges, nine to government institutions, eight to private companies, and four to other institutions. These Malaysian institutions have collaborated with 62 foreign institutions, the majority of which are universities or colleges.

With 34 authors, UPM (For full names of institutions' acronyms, see appendix) has the maximum number of authors represented in our dataset, followed by 23 each from UM and UKM, 20 from USM and 15 each from UTM and UUM. The top five slots in terms of the number of unique authors and articles produced are occupied by public universities in Malaysia, which also happen to be designated by the Malaysian Ministry as Research Universities. This may be likely due to additional resources the government provides exclusively for research to these institutions. For the few authors who had multiple affiliations, the most recent and the first affiliation of the author were taken.

Author order is another important element in paper authorship. In most cases, the first author is an individual who puts in the major work to complete the paper (Bhandari, Einhorn, Swiontkowski, & Heckman, 2003). A country-based, first authorship analysis shows a healthy figure of 103 of the 131 multiple-author paper representations (78.62%) have an author representing a Malaysian institution as the first author's affiliation. This implies that most of the articles written are led by a Malaysia-based researcher. This is an important finding because harvesting the data from the SSCI database only had Malaysia as one (or more) of the addresses of authors in the Business and Management field. Thus, authors who are from Malaysia are actually in the driver's seat when it comes to writing articles in the Business and Management field. UM had 15 first-authored papers, followed closely by UKM and UPM with 14 and 13 papers, respectively.

When constructing a network that relates to collaboration between institutions, the institutional affiliation of the authors is replaced as nodes. Creating this type of a network helps us to understand the collaboration taking place between institutions both at the domestic and international levels. All three centrality measures—Degree, Betweenness, and PageRank—rank the five research universities (RUs) among the top five, which correlates perfectly with not only the number of works but also with the total number of citations (see Table 4.1.3). The average correlation between centrality measures and number of works is 0.90, with Betweenness Centrality recording a maximum correlation at 0.93. Correlation of centrality measures with citations is 0.78, with Betweenness Centrality again topping at 0.81. UPM emerges as the star institution, coming in as the first position in all centrality measures and also delivering top research performance. When slicing the network, 17 connected groups were discovered. Of these, 71 institutions formed a giant component, which was led by the five research universities. The second largest component has 10 institutions lead by Monash University's Malaysia campus (Monash).

Table 4.1.3: Top 20 institutions based on centrality scores and research performance. See *Appendix* for the full names of the institutions' acronyms.

Degree		Betweenness		PageRank		No. of Works		Citations	
UPM	20	UPM	1303.121	UPM	5.339	UKM	44	UPM	153
UTM	16	UKM	875.931	UTM	4.093	UPM	41	UM	121
UKM	14	UTM	795.602	USM	3.401	UM	40	UKM	111
UM	13	UM	699.752	UM	3.351	USM	21	USM	108
USM	13	USM	457.660	UKM	3.347	UTM	21	UTM	75
UUM	9	Univ Nottingham	384	Monash	2.293	UUM	17	Stanford Univ	75
UiTM	8	UUM	337.212	UUM	2.178	UNiM	10	Univ Lancaster	52
UNiM	7	UNiM	333	UNiM	2.142	UiTM	9	Catholic Univ Leuven	48
Monash	7	Univ S Australia	201	UiTM	2.001	UTAR	7	UNiM	41
Univ S Australia	6	MMU	175.224	Monash Univ	1.610	Univ Nottingham	5	Univ Osaka Prefecture	38
IIUM	5	UiTM	149.333	Kianan Univ	1.459	Catholic Univ Leuven	4	City Univ Hong Kong	36
UTAR	5	UNIMAS	136	Univ S Australia	1.428	Monash	4	Asia Pacific Ctr Org Dev	36
Univ Nottingham	5	IIUM	108.341	IIUM	1.372	OWW Consulting	4	Ft Hays State Univ	31
MMU	5	UTAR	82	MMU	1.366	Stanford Univ	4	St Cloud State Univ	31
Monash Univ	5	Cardiff Univ	69	Catholic Univ Leuven	1.298	UMS	4	Univ Kentucky	31
Qatar Univ	4	Univ Bath	69	UTAR	1.254	Ft Hays State Univ	3	Old Dominion Univ	26
Univ Western Ontario	4	Univ Manchester	69	Univ Nottingham	1.158	IIUM	3	Rubber Res Inst Malaysia	24
Ft Hays State Univ	4	Univ Lancaster	69	Ft Hays State Univ	1.126	MMU	3	Open Univ	24
Old Dominion Univ	4	Aston Univ	52.150	Qatar Univ	1.115	MSU	3	SAS Malaysia	24
Stanford Univ	3	Qatar Univ	46.667	UNIMAS	1.057	Nanyang Technol Univ	3	Univ Western Ontario	20

Of the total of 308 edges, 106 edges are formed intra-institutionally. UKM leads the pack with 31 edges, followed by UPM with 18 edges; UM with 13 edges; USM with 10 edges; UUM with nine edges; and UTM with seven edges. A total of 69 edges are formed within Malaysia (excluding intra-institutional links), 101 links are formed between Malaysian institutions and foreign institutions, and 32 links are formed exclusively between foreign institutions. Both inter-institutional associations and intra-institutional associations are depicted in the same network diagram in Figure 4.1.4.

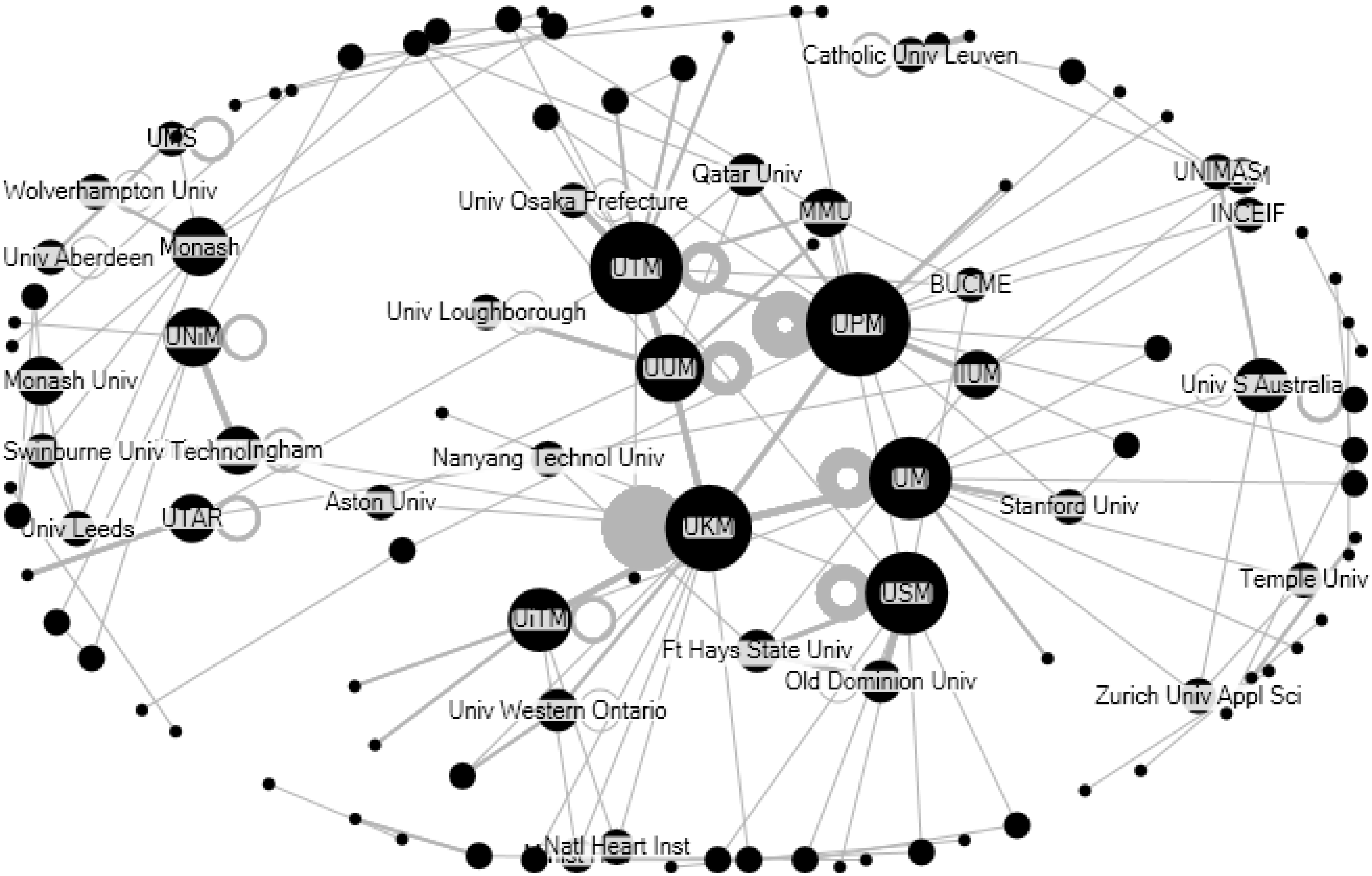


Figure 4.1.4: Inter-institutional collaborations. The size of the vertex is based on degree centrality. The rings next to the vertex depict intra-institutional collaborations. The thickness of the lines depicts the strength of the collaboration.

Intra-institutional associations (or self-loops) are depicted via rings next to the node. Results show that Malaysian authors either prefer to work intra-institutionally, which may be the result of being in close Geographical proximity or with foreign authors, which may be to seek more varied expertise.

The strength of the relationship is determined based on the number of times authors from two institutions have collaborated. Repeat relationships may again be due to the Geographical proximity of the institutions or because the author(s) of one institution have some kind of research link with the author(s) of another institution. UM and UKM have five collaboration links, followed by UUM and UTM (four connections) and UKM and UUM (four connections). Among the total of 111 links that the five research universities have extended outside their institutions, about 23% have been within these research universities. This demonstrates a fair degree of collaboration among the research universities.

4.1.1.6 International collaboration

International scientific collaboration has witnessed dramatic quantitative and structural change since the last decades of the 20th century(Glänzel & Schubert, 2005). Better communication channels are blurring national borders, making research more globalized. Collaboration with international counterparts can occur because authors obtain better opportunities to share resources and expertise. Collaborative research depends both on technology and bureaucracy; however, authors often play down the latter and use it constructively to achieve their goals(Shrum, Genuth, & Chompalov, 2007). Of the 131 co-authored papers, 63 had at least one foreign co-author (an author with a non-Malaysian institution address). Of these 38 papers had one foreign address per paper; 20 had two foreign addresses per paper; and five had three foreign addresses per paper. Of the 15 papers co-authored between 1980 and 1998, 13 (75% of total papers) included foreign collaborators. In 2007, the foreign co-authored paper share fell to its lowest point, at about 17%. The foreign co-authored paper share stood at 37% in 2010. The statistics do not show any year-on-year percentage increase of foreign co-authored papers. However, the total number of foreign co-authored papers has seen a steady increase. In 2008, seven papers were foreign co-authored, rising to nine in 2009, and 11 in 2010. In total, 17 countries have collaborated with Malaysia researchers during the last 30 years.

A network diagram (see Figure 4.1.5) is drawn to illustrate international collaboration between nation-states. Authors' country affiliations are illustrated as nodes and edges are constructed if the two authors have co-authored a paper together.

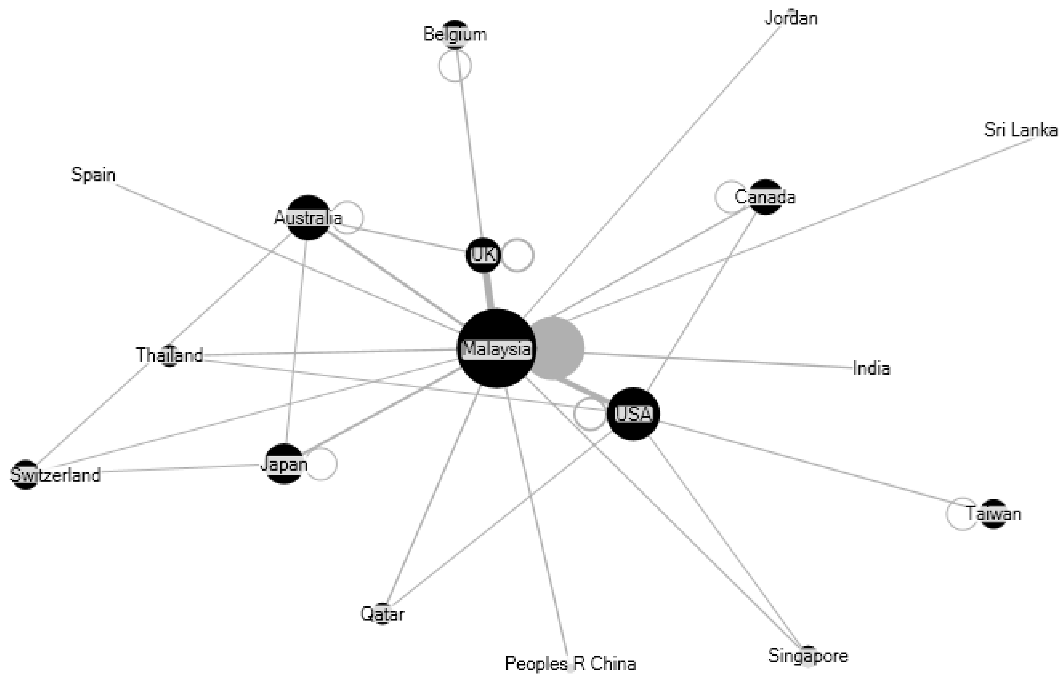


Figure 4.1.5. International collaboration. The node size is based on degree centrality. The rings around the nodes depict intra-national collaboration. The thickness of lines depicts the strength of the collaboration.

Table 4.1.4 displays the centrality measures of countries that have collaborated with Malaysia, sorted on the basis of top centrality scores. The results show that centrality measures are correlated with research productivity. The correlation coefficient determined a high level of correlation between centrality measures and research productivity. Both the number of works and number of citations had an average correlation coefficient of 0.90. This means that the nation-states that have collaborated with Malaysia have given the country rich dividends for both parameters of productivity—the number of works and citations. The People's Republic of China is the only country that performs poorly in centrality measures but has given good research benefits to Malaysia. In terms of the strength of each collaboration, developed nations such as the UK (33 edges), the US (23 edges), Australia (nine edges), and Japan (seven edges) are Malaysia's top partners. The strength of collaboration (in terms of repeat collaborations) between Malaysia and other countries is depicted in the Figure 4.1.5. It is interesting to note that countries with strong relationships form connections with other countries associated with Malaysia, thus, giving them high centrality scores. ASEAN is an association of 10 countries in Southeast Asia, which has an agenda of educational co-operation (http://www.asean.org/archive/publications/ASEAN-Charter.pdf accessed 7th February 2013, Article 1, Purposes, Number 10). However, collaboration within the ASEAN countries has been significantly less robust when compared with the nation-states with which Malaysia has preferred to collaborate. Thailand and Singapore are the only ASEAN countries with which Malaysia has collaborated (see Table 4.1.4). Interestingly, large ASEAN countries such as the Philippines and Indonesia have not collaborated with Malaysia. For the Philippines in particular, Vinluan (2012) found low research productivity when compared with Malaysia and other Southeast Asian countries. Collaboration with institutions in the Philippines and international institutions was also fewer.

Table 4.1.4: Top 20 countries that have collaborated with Malaysia based on centrality scores and research performance

Degree		Betweenness		PageRank		No. of Works		Citations	
USA	8	USA	18	USA	1.996614	UK	36	USA	208
Australia	6	Australia	1	Australia	1.353733	USA	21	UK	132
Japan	5	Japan	0	Japan	1.105944	Australia	8	Peoples R China	60
UK	4	UK	0	Canada	0.891731	Japan	5	Japan	52
Canada	4	Canada	0	UK	0.874553	Belgium	4	Belgium	48
Switzerland	3	Switzerland	0	Switzerland	0.861776	Canada	3	Canada	20
Taiwan	3	Taiwan	0	Belgium	0.68979	Taiwan	3	Qatar	12
Belgium	3	Belgium	0	Taiwan	0.68251	Singapore	3	Australia	9
Qatar	2	Qatar	0	Qatar	0.639075	India	3	Singapore	8
Thailand	2	Thailand	0	Thailand	0.639075	Peoples R China	3	India	7
Singapore	2	Singapore	0	Singapore	0.639075	Qatar	2	Sri Lanka	1
India	1	India	0	India	0.396631	Thailand	2	Jordan	1
Sri Lanka	1	Sri Lanka	0	Sri Lanka	0.396631	Switzerland	1	Taiwan	0
Spain	1	Spain	0	Spain	0.396631	Sri Lanka	1	Thailand	0
Jordan	1	Jordan	0	Jordan	0.396631	Spain	1	Switzerland	0
Peoples R China	1	Peoples R China	0	Peoples R China	0.396631	Jordan	1	Spain	0

Of a total of 131 collaborative papers, 61 papers are not cited and the rest of the 70 papers have been cited from one to 50 times. Locally co-authored papers (papers with no co-authors having a foreign affiliation) were cited 1.75 times, on average, when compared to 6.31 citations per paper received for foreign co-authored papers. It is interesting to note that internationally co-authored papers are cited well over three times more often than locally co-authored papers. Other studies have noted this trend. For example, Narin et al. (1991) found articles authored by researchers affiliated with institutions in more than one EC country were cited twice as much as papers authored by researchers working at a single institution within a single country. A study by Glänzel and Schubert (2001) also found a similar correlation between international co-authorship and citations. A developed nation collaborating with a developing nation may help the latter garner more citations. Developed nations could very well benefit in similar terms. Glänzel, Schubert, and Czerwon (1999) found that citation 'attractivity' of publications demonstrates that international scientific collaboration benefits both less-advanced and highly industrialised countries. The pressure to publish (Leung, 2007) could also be prompting some authors to look for more international co-authors on papers, because it may improve their chances for positive comments during the publication review process (Hart, 2000). It is also probable that researchers deem internationally co-authored papers of relatively higher significance than the locally co-authored ones and thus might cite them more often.

4.1.2 Correlation between SNA measures and research productivity

This section attempts to answer the following sub-questions of RQ1:

What is the effect of popularity, position, prestige, tie-strength, and diversity of ties among researchers in a co-authorship network on research productivity? More specifically, this research question attempts to answer the following sub-questions:

a) What is the effect of popularity, position, and prestige of the authors in the network, as represented by its Degree, Betweenness centrality, and PageRank, respectively, on research productivity?

b) What effect does the diversity of ties, as expressed through the Structural holes measures of Efficiency and Constraint have on research productivity?

c) What effect does the strength of ties, as computed through tie-strength have on research productivity?

In addition to the three centrality measures, SNA measures relating to social capital, that is, tie strength and structural holes measures (efficiency and constraint) of individual vertices, are included to determine their relationship with research productivity.

A triad is the basic building block or molecule (Kadushin, 2011) of relationships. For overall SNA measures' association with research productivity, all authors who had at least a degree of two (triad and above) were included. Such an exercise also provided better measures of structural holes.

Spearman Rank Correlation Coefficient was calculated for each SNA measure with two performance measures—the number of works and citations—to understand the level of association between these variables. All measures, except betweenness centrality, which is not significantly correlated with citations, have a significant correlation with both the number of works and citations. It was found that the number of works were more strongly associated with SNA measures than with citations (see Table 4.1.5). Yan and Ding (2009) also measured the impact of degree, betweenness, closeness, and PageRank centrality measures of an evolving co-authorship network on citations and found a significant relationship. Abbasi, Altmann, et al. (2011) reported similar results when correlating SNA measures with four performance measures such as number of works, citations, g-index and h-index. Constraint was negatively correlated with both the performance measures.

Table 4.1.5: Spearman Rank Correlation coefficient between SNA measures and performance measures: Number of works and citations

	Degree	*Betweenness Centrality*	*PageRank*	*Vertex Tie strength*	*Efficiency*	*Constraint*
No. of works	0.696*	0.569*	0.671*	0.591*	0.628*	-0.673*
Citations	0.169**	0.082	0.186**	0.528*	0.240*	-0.212*

*Significant at 0.01 levels
** Significant at 0.05 levels.

I next examined the effect of which SNA measures had a significant effect on performance measures. For this, multiple regression analysis was applied, where SNA measures were independent variables (X) and each performance measure was a dependent variable (Y). The results, presented in Table 4.1.6, show Degree, Vertex Tie strength, and Efficiency to have a significant effect ($P < 0.05$) on the number of works. However, only Vertex Tie Strength had a significant impact on Citations ($P < 0.05$). Several interpretations could be made here. First, the greater the number of connections established, the more an author benefits professionally. Second, the strength of relations or repeat relationships is perhaps the most important activity that an author could perform, as it would not only improve his or her number of publications, but also the number of citations attributed to his original work. Third, diverse connections will improve the author's chances for productivity. Similar results have been reported by both Abbasi, Altmann, et al. (2011) and Kuzhabekova (2011). This signifies that authors would be better off associating with just one author in a group of authors who are linked to one another, than having links with all of the authors in that particular group.

Table 4.1.6. Multiple regression analysis of the effect of SNA measures on research performance

	No. of Works				Citations			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
Intercept	-3.086	0.521	-5.923	0.000	-21.654	10.459	-2.070	0.040
Degree	0.473	0.061	7.796	0.000	0.756	1.217	0.621	0.535
Betweenness Centrality	-0.002	0.007	-0.354	0.723	-0.191	0.139	-1.371	0.172
PageRank	-0.110	0.243	-0.451	0.652	-2.452	4.879	-0.503	0.616
Vertex Tie strength	1.812	0.184	9.873	0.000	26.242	3.683	7.125	0.000
Efficiency	2.894	0.346	8.357	0.000	7.814	6.951	1.124	0.262
Constraint	0.003	0.271	0.012	0.991	-4.115	5.434	-0.757	0.450

4.1.3 Degree assortativity

This section attempts to answer the following sub-question of RQ1:

Based on the degree of connections, what is the level of Assortativity between researchers?

The overall degree assortativity of the BM network is 0.463, which indicates positive assortativity. This means that authors tend to collaborate with those who have a similar number of connections. Between 1980 and 1990, the degree assortativity was 0.158, which grew to 0.392 from 1990 to 2000, and increased again to 0.424 from 2001 to 2010. This increase correlates with the increasing number of authors in the network. Newman (2002) found human networks such as co-authorship networks and networks of film stars to be assortative, whereas non-human networks such as World Wide Web (WWW) and protein networks to be disassortative. Disassorative mixing or preferential attachment is more likely to be caused based on the feeling of trust, whereas assortative mixing is the result of being alike in some way.

4.1.4 Geographical proximity

This section attempts to answer the following sub-question of RQ1:

Does geographical proximity impact the frequency of collaboration among researchers?

The co-authorship edge list was replaced with the city in which the author's institution was located (see Table 4.1.7). Of the 172 intra-national co-authorship links, it was found that more than 70% of the collaborations originated from the same cities in which the authors' institutions were located. The collaborations tapered off as the distance increased, with a slight surge at 300 km, where found 14 collaborations (about 8%) were found.

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Table 4.1.7. A portion of code sheet that represents authors' affiliated cities, their collaboration links, and Geographical distance

Author Edge1	Author Edge2	City of Author Edge1	City of Author Edge1	Distance in kms
Arumugam, V	Abu Bakar, N	*Penang*	*Johor*	489.13
Safa, MS	Abu Bakar, N	*Selangor*	*Johor*	268.90
Yahaya, SY	Abu Bakar, N	*Kedah*	*Johor*	540.20
Moin, NH	Salhi, S	*Kuala Lumpur*	*Kuala Lumpur*	0
Ali, KAM	Jemain, AA	*Selangor*	*Selangor*	0
Ali, KAM	Yusoff, RZ	*Selangor*	*Kedah*	286.40
Ali, KAM	Abas, Z	*Selangor*	*Kedah*	286.40
Jemain, AA	Yusoff, RZ	*Selangor*	*Kedah*	286.40

Regression analysis was carried out to determine if distance played a significant role in the frequency of collaboration. Taking distance as the independent variable (X), and frequency of collaboration (Y) as the dependent variable, I found a *P* value < 0.05, confirming a significant dependence of frequency of collaboration on Geographical distance. A line fit plot demonstrates frequency and predicted frequency of two-way collaborations (see Figure 4.1.6). Even in the age of electronic communication systems, Geographical proximity plays an important role, at least in intra-national collaboration. Several practical reasons explain this phenomenon; for example, it is convenient to interact with individuals who are in close physical proximity, such as working at the same institution as colleagues or students. A large percentage of collaborations are centred in the Kuala Lumpur−Selangor region, where the majority of institutions are located.

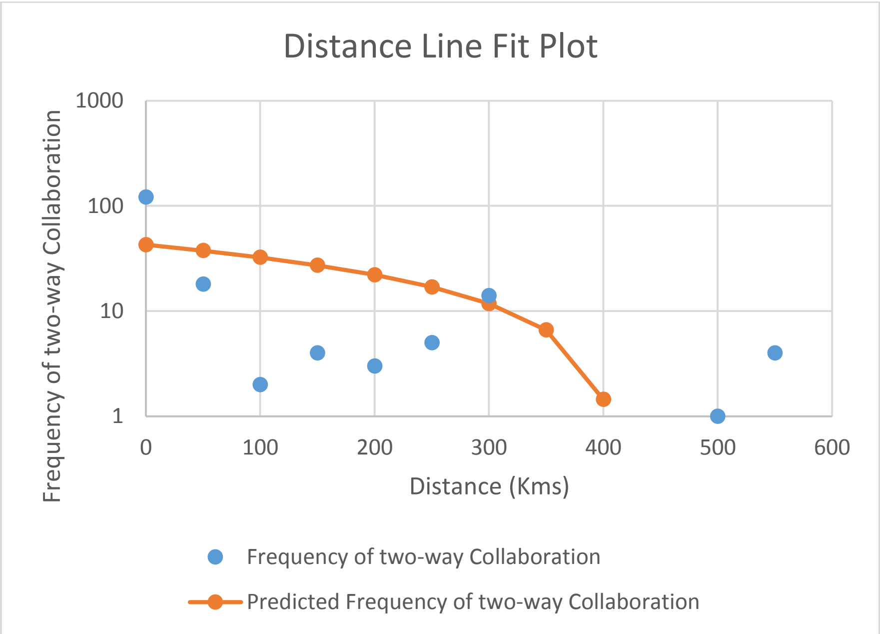


Figure 4.1.6: Line fit plot of distance between authors and frequency of collaborations

4.1.5 Co-authorship strategy

The final sub-objective of the RQ1 is re-stated here:

Based on the results, suggest a co-authorship strategy for researchers

Three important results emerged from this study, which provides sufficient grounds to propose a co-authorship strategy to researchers. First, whether collaboration actually leads to an increase in the number of papers is unclear from our dataset. Nonetheless, what is amply clear is that collaborative papers were cited more frequently than—almost twice as often as—individually authored papers. Second, the number of connections, the strength of ties, and the diversity of ties has a significant effect on research productivity. Third, internationally co-authored papers were cited several times more often than locally co-authored papers. Collaboration could thus be a strategy in and of itself, because it is seen that collaborative papers are cited more often. Having an author with a foreign affiliation, however, could prove to be an even better strategy. These papers were cited several times more than those written only with local co-authors. Furthermore, the influence of SNA measures on research productivity suggests that having many connections through co-authorship, co-authoring repeatedly with the same author, and aligning with only one additional author within a group of authors who already know one another, could be a multifaceted strategy that would likely improve the research productivity of authors.

4.2 Research Question 2

Here the results and analysis of Research Question 2 (RQ2), which represents Case Study 2, are presented. RQ2 is restated here:

What is the size of giant component, its correlation with other topological properties and its relationship with the pace of paper production, in the country-specific dataset pertaining to Malaysia of four prominent engineering disciplines as per WoS subject categories, namely - chemical engineering (CHEM), electrical and electronics engineering (EEE), civil (CIVIL) engineering and mechanical engineering (MECH)?

This research question has specific sub-questions and I attempt to answer each, one by one, as I progress with the description of results.

Summary of analysis of the 4 subject categories is given in Table 4.2.1. EEE has the maximum number of papers, followed by CHEM, MECH and CIVIL. The ratio of number of papers with the number of distinct authors is in the range of 1.59 to 1.73 for EEE, CHEM and MECH, but a good 2.12 for CIVIL, which means that although CIVIL had relatively more authors in the network, they have produced lesser number of papers. Number of authors per paper and author productivity (average number of papers per author) is fairly consistent across the four subject categories. Authors wrote about 2 papers each and average paper had about 3 co-authors each. Figure 4.2.1 and 4.2.2 show the distribution of papers per author and authors per paper, respectively.

In the co-authorship network of CHEM (see Table 1), a total of 1247 research articles had 1985 authors, who had 4710 collaborative links between one another. There were only 14 isolates or authors in CHEM who have never collaborated with any other authors in the dataset. Similarly, the number of articles, nodes, edges, and isolates of EEE, MECH and CIVIL are given in Table 4.2.1.

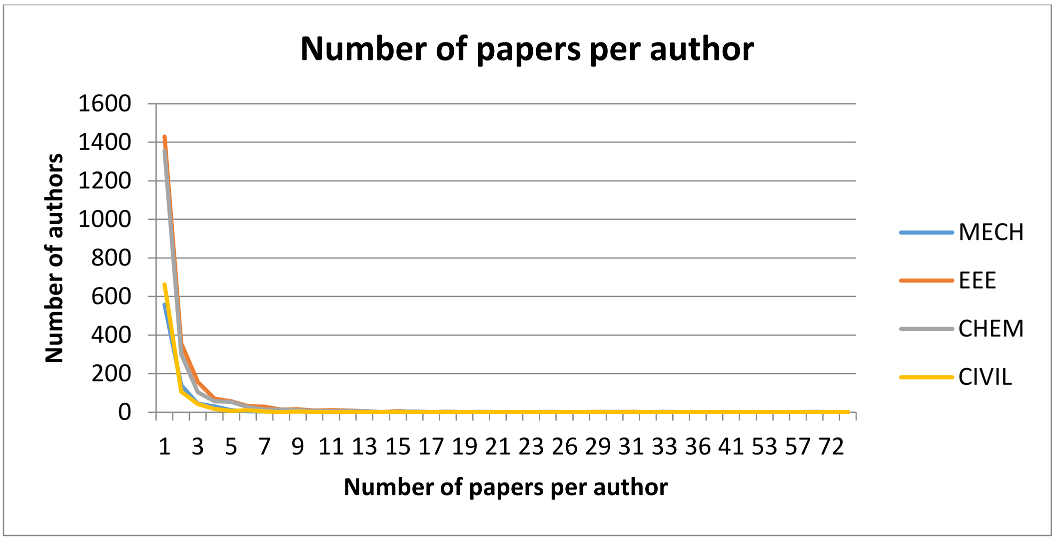


Figure 4.2.1: Number of papers per author (or research productivity) shows majority publishing just 1 paper (mode is 1)

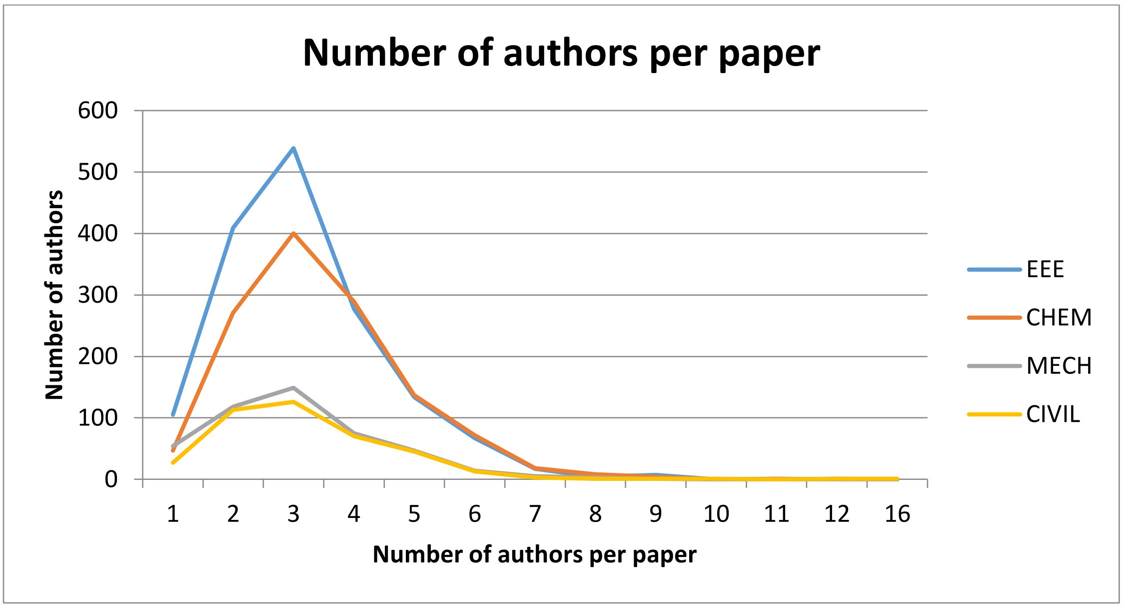


Figure 4.2.2: Number of Authors per paper. The mode of authors per paper is 3 for all the categories.

4.2.1 Topological properties of the various networks

Calculation of the total number of components, average degree of each node, the density of network, clustering coefficient of the network and average and maximum geodesic distance of nodes in the network was next done.

The authors of all four disciplines had an average of 4 collaborators each. A long tail depicts skewed degree distribution - majority of the authors had between 2 to 4 collaborators and few authors had a large degree of collaboration. An author in EEE had as high as 107 collaborators. Figure 4.2.3 shows the chart of degree of collaboration in the 4 disciplines.

Table 4.2.1: Summary of the analysis of four subject categories

	CHEM	**EEE**	**MECH**	**CIVIL**
No. of Papers	1247	1560	466	402
Average papers per author	2.16	2.22	1.76	1.51
Average authors per paper	3.44	3.17	3.05	3.21
Average degree of Collaborators per author	4.74	4.28	3.71	3.75
No. of Nodes (number of distinct authors)	1985	2210	809	855
No. of Edges	4710	4759	1502	1604
Isolates	14	24	10	12
Number of components	163	215	132	173
Average Geodesic Distance	5.52	6.39	3.69	2.67
Maximum Geodesic Distance (Diameter)	14	17	13	9
Average Clustering Coefficient	0.791	0.739	0.756	0.755
Density (Disregarding weights)	0.0024	0.0019	0.0046	0.0044
Nodes in the Largest component	1269	1338	107	57
% Size of Largest component.	63.93	60.30	13.27	6.66

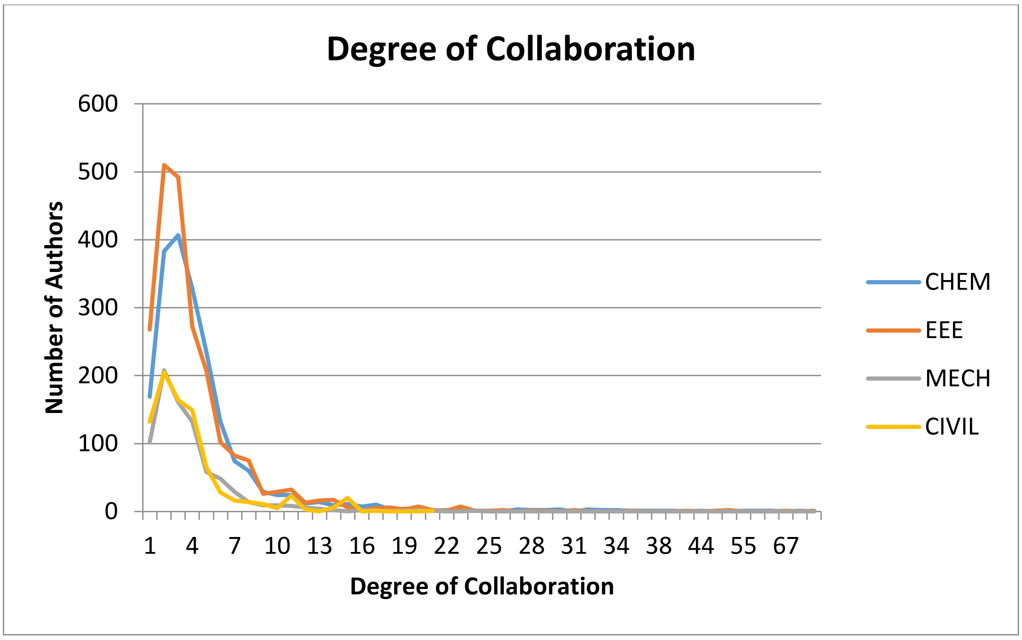


Figure 4.2.3: Degree of collaboration of authors. Mode for CHEM is 3 and for EEE, MECH and CIVIL, it is 2

4.2.2 Small-world

The degree of separation between any two random authors in the largest component had an average distance of about 6, confirming their 'small world' character. In a 'small world' model, any two random nodes are at shorter distance from each other (Watts & Strogatz, 1998). Interestingly, MECH and CIVIL had average degree of separation as 3.69 and 2.67 respectively, when compared to their bigger counterparts EEE and CHEM, which had average degree of separation at 6.39 and 5.52 respectively.

In simple terms clustering coefficient determines the probability of A connecting to C, if A and B and B and C are already connected. The clustering coefficient of all subject categories was found to be fairly similar, hovering around 0.7, which means that there is about 70% chance, in all these disciplines, for the nodes to form a clique.

The density was found to be low for larger networks (EEE - 0.0019 and CHEM – 0.0024) and relatively higher for small networks (CIVIL – 0.0044 and MECH – 0.0046). The average degree and density of a network are indicative of connectivity of the network. Higher connectivity would result from more collaboration between the actors, thus causing faster diffusion of information through such networks.

4.2.3 The size of the giant component

This section attempts to answer the following sub-question of RQ2:

What is the size of giant components in the collaborative networks in the aforesaid four engineering disciplines in Malaysia, based on ISI Web of Science subject categories?

Giant components of well-formed size have been formed (see Table 1) in CHEM (63.3%) and EEE (60.30%) disciplines. In the MECH and CIVIL disciplines, the size of largest component is at 13.27% and 6.66% respectively, hence still small to be considered a well-formed giant component.

The dense central part of the network explicitly reveals giant components of EEE and CHEM disciplines. Visualization of the 4 co-authorship networks is presented in Figures 4.2.4 to 4.2.7.

Figure 4.2.4: Visualization of co-authorship network of Electrical and Electronic engineering (EEE) WoS subject category. Large connected component in the middle shows the presence of *well-formed* giant component

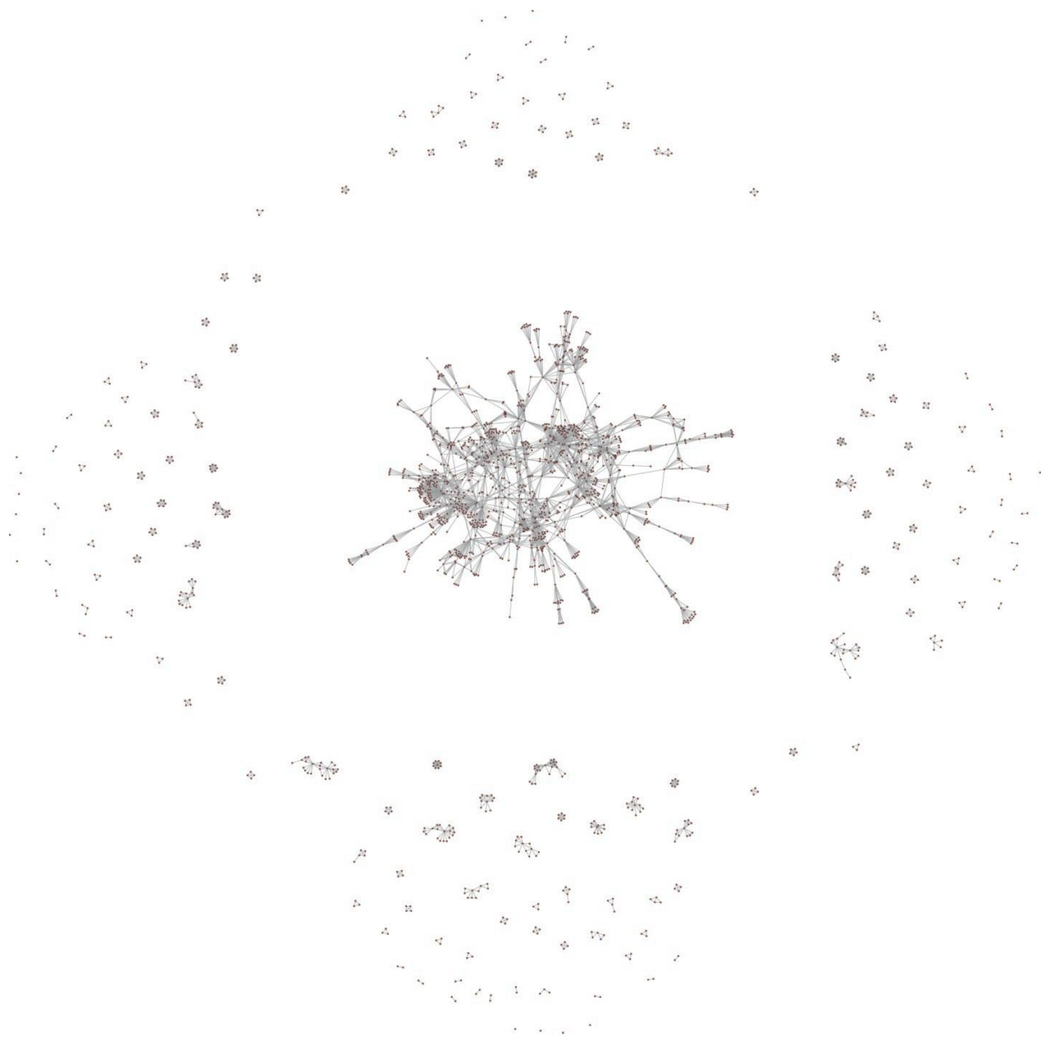


Figure 4.2.5: Visualization of co-authorship network of Chemical Engineering (CHEM) WoS subject category. Large connected component in the middle shows the presence of *well-formed* giant component

Figure 4.2.6: Visualization of co-authorship network of Mechanical Engineering (MECH) WoS subject category. There is no distinct *well-formed* giant component seen as yet.

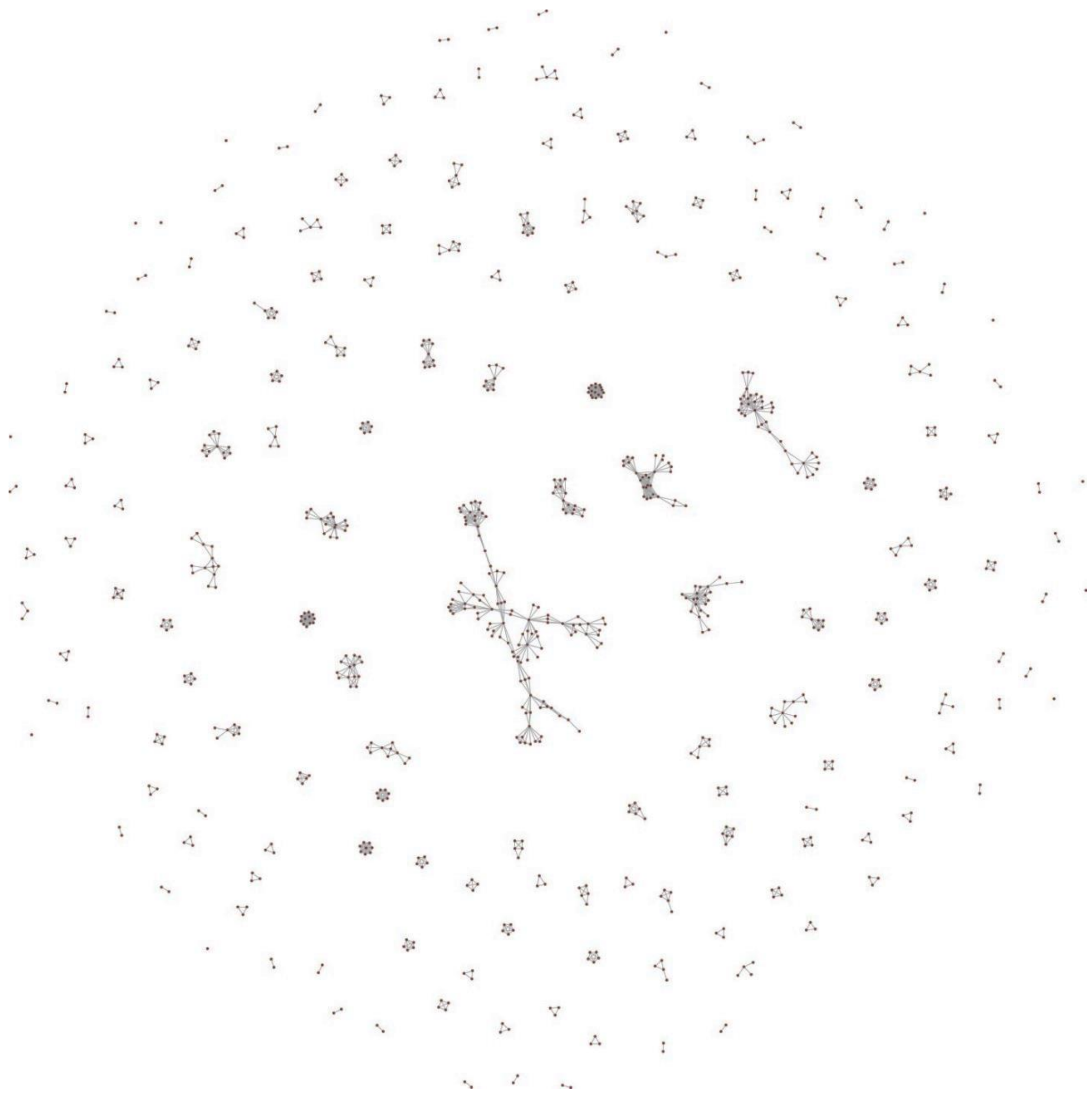


Figure 4.2.7: Visualization of co-authorship network of Civil Engineering (CIVIL) WoS subject category. There is no distinct *well-formed* giant component seen as yet.

4.2.4 Correlation between graph metrics and size of the giant component

This section attempts to answer the following sub-question of RQ2:

Is there any correlation between the degree, density, clustering coefficient and degree of separation between the nodes in the network and the size of giant components?

Interestingly, there is a negative correlation between density of a network and the size of giant component (see Table 4.2.2). Networks of CIVIL and MECH are denser than the other 2 networks, yet their giant components are smaller in size (see Table 4.2.1). One possible explanation for this is that as the network grows the number of possible connections increase proportionately, thus, making the network sparser. There is a positive correlation between the average degree and the size of the giant component (see Table 4.2.2). However, when it comes to clustering coefficient, A weak, yet positive, correlation is seen with the size of the giant component. The number of nodes and edges has a positive correlation with the size of the giant component. The average degree of separation (average geodesic distance) positively correlates with the size of giant component (see Table 4.2.2). When the network is small, the average degree of separation between any two random nodes is also small due to high fragmentation and smaller giant component. As the network grows, the formation of giant component, which has large number of nodes inter-connected in a single component, increases the distance of separation between nodes.

Table 4.2.2: Correlation matrix of various graph metric

	Number of Nodes	*Number of edges*	*Average Degree*	*Average Clustering Coefficient*	*Average geodesic Distance*	*Density*	*Size of giant component*
Number of Nodes	1						
Number of edges	0.99	1					
Average Degree	0.87	0.92	1				
Average Clustering Coefficient	0.13	0.24	0.60	1			
Average geodesic Distance	0.95	0.94	0.78	0.04	1		
Density	-0.99	-0.99	-0.86	-0.10	-0.95	1	
Size of giant component	0.98	0.99	0.93	0.30	0.95	-0.97	1

4.2.5 Pace of paper production and size of giant component

This section attempts to answer the following sub-question of RQ2:

Does the pace of paper production has any relationship with the formation of giant component?

Over the years there has been clear increase in the number of articles across all four disciplines (see Figure 4.2.8). All disciplines were almost in the same position until about 1996, after which both EEE and CHEM added articles faster than the other two. This greater proportion of increase in EEE and CHEM networks corresponds to the formation of giant components in these networks. With new paper production there are authors who repeatedly write papers with their existing co-authors in addition to the large proportion of new players who enter the scene. Increase in paper production, thus, directly increases in the number of nodes and edges in the network.

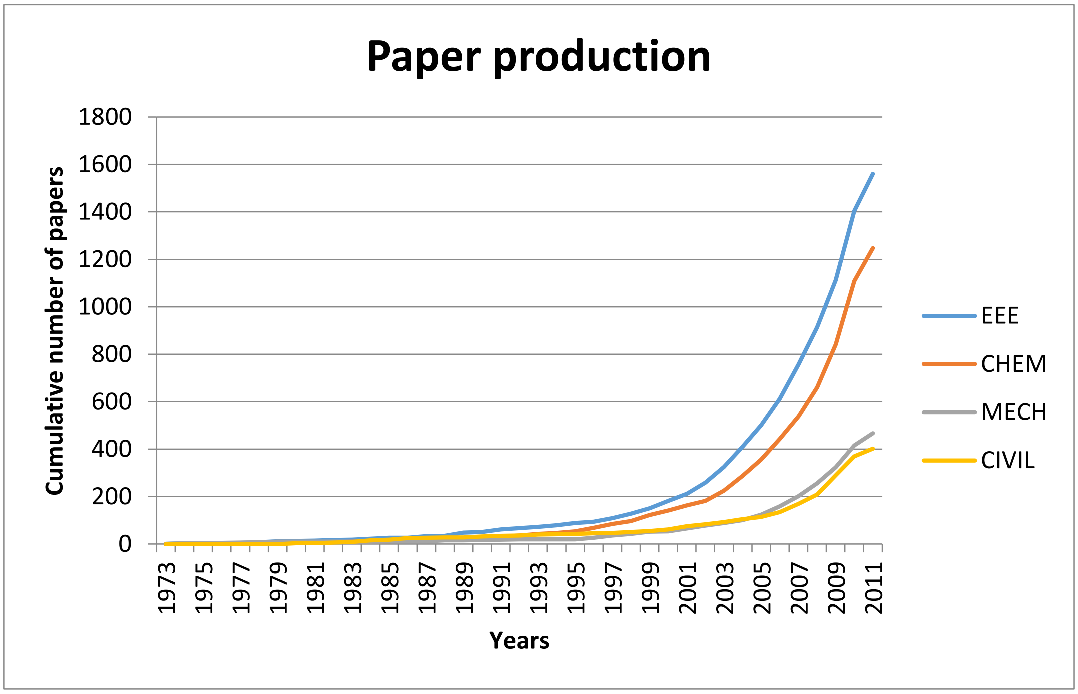


Figure 4.2.8: Cumulative increase in number of research articles in the four engineering disciplines over time.

(Till around mid-90s all disciplines were having similar paper production, after which EEE and CHEM have added papers faster than MECH and CIVIL. Corresponding to this faster paper production, giant Components have formed in EEE and CHEM, whereas they are still not evident in MECH and CIVIL)

4.2.6 Possible causes of the formation of giant component

As stated earlier, a positive correlation is seen between the number of nodes (and edges) in the network and the size of the giant component, within the context of these four engineering disciplines. However, looking from another perspective, just the existence of a large number of nodes (authors) in a network cannot be the sole reason for the formation of a giant component. For example, MECH has 809 nodes; yet, the largest component is just at 13.27% even after over three decades of activity. Even a very small network of just 48 researchers of COLLNET (Yin et al., 2006), a dedicated research forum of scientists studying scholarly collaboration networks, had a largest component possessing 32 nodes or 66.6% of the total network. Hence, just the presence of large number of nodes is no guarantee that a giant component would exist in such networks. It may be that scientific network possessing a large number of nodes, but nodes working separately in diverse sub-disciplines, would still keep the network fragmented for a long time. Engineering disciplines have dedicated sub-disciplines. For example, Mechanical engineering may have 'complex mechanics' and 'micro-mechanical science' as two separate divisions or sub-disciplines. In Universities, these sub-disciplines are sometimes enshrined as separate departments within the faculty. Such categories within a discipline can lead to fragmentation as researchers generally have favorable circumstances to collaborate with fellow researchers within their research divisions. One way to see faster formation of giant component is by fostering collaboration between these sub-disciplines. After all, it takes just one edge to bring two components or clusters of researchers together. Additionally, unlike random networks, collaboration in real-world networks, such as, co-authorship network, follows a certain pattern, also known as *preferential attachment*

(Newman, 2002). As such, some nodes attract connections by virtue of these nodes being already well connected or due to some other kind of *assortative mixing* (Newman, 2002).

There seems to be no particular cause for the formation of giant components. Although, rise in the number of research articles or increase in collaboration among researchers might play an important role, they cannot be standalone reasons for the formation of giant components. Rather, a variety of causes working in tandem may be responsible for the formation of giant components.

4.3 Research Question 3

Here the results and analysis of Research Question 3 which represents Case Study 3, are presented. RQ3 is restated here:

How do collaborative networks of Malaysia and Turkey, the two OIC nations, compare with each other in the field of 'energy fuels'?

This research question has specific sub-objectives and sub-questions and I attempt to describe and answer each, one by one, as I progress with the description of results.

The Turkey dataset returned 2,150 authors who have published 1,658 articles in 79 journals. Citations per paper averaged 5.82. The Malaysia dataset returned 1,234 authors who published 658 articles in 69 journals. Malaysia's output shows an incremental rise on a year-on-year basis. In 2009, Malaysia's output was 169 articles; in 2010 it rose to 204 articles; and in 2011 it rose further to 285 articles. This increase also corresponds to Malaysia's impetus in publishing in ISI-ranked journals in recent years. Unlike Turkey, Malaysia received more global citations (total number of citations to papers in WoS) for 2010's published papers compared with 2009. This may be due to the increased number of papers published in 2010. The average citation per paper stood at 5.65, which is very similar to Turkey. In Turkey, the number of country-based self-citations is much higher than in Malaysia. In Malaysia, only 1 in 6 citations came from papers written locally, whereas in Turkey this number is 1 local citation in every 3.82 citations. The bibliometric statistics of both countries are depicted in Table 4.3.1.

In both countries, public universities seem to perform better in research productivity. These institutions in Turkey, namely, Middle East Technical University (METU), Ege University, Istanbul Technical University, Gazi University, and Firat University were among the most productive in Turkey. In the same light, public universities in Malaysia, namely, the University of Malaya (UM), University Science Malaysia (USM), University Kebangsaan Malaysia (UKM), University Technology Malaysia (UTM), and University Putra Malaysia (UPM) garnered more than 65% of the total number of published papers. These five public universities in Malaysia are also designated as RUs, or 'Research Universities', and have received generous research grants from the Malaysian government (Abrizah & Wee, 2011). The research output of top universities in Malaysia contrasts sharply with that of Turkey, where the top five institutions garnered only 30% of the published papers.

Table 4.3.1: Bibliometric Statistics of the Turkey and Malaysia Datasets

	Turkey	**Malaysia**
Number of papers	1658	658
Number of authors	2150	1234
Mean citations per paper	5.82	5.65
Number of journals	79	69
Number of countries collaborated with	44	48
Single-author papers	427	16
Mean number of authors per paper	2.55	3.77
Mean number of papers per author	1.96	2.01
Mean number of citations per author	11.08	9.77

A significant percentage of 5-author (13%) and 6-author (6%) papers are found in the Malaysia dataset. This is not evident in the Turkey dataset.

Lotka (1926) investigated the frequency distribution of author productivity among chemists and physicists and found that the number of authors writing *n* articles is about $1/n^2$ of those writing one paper, and the proportion of all authors that make a one-paper contribution is about 60%. Since publishing his findings, Lotka's measures are now established as Lotka's Law of Scientific productivity (Talukdar, 2011). The author productivity fit using 'Lotka' software (Rousseau & Rousseau, 2000) found that the Turkey and Malaysia datasets fit Lotka's Law with β = 2.2858 and 2.326, respectively.

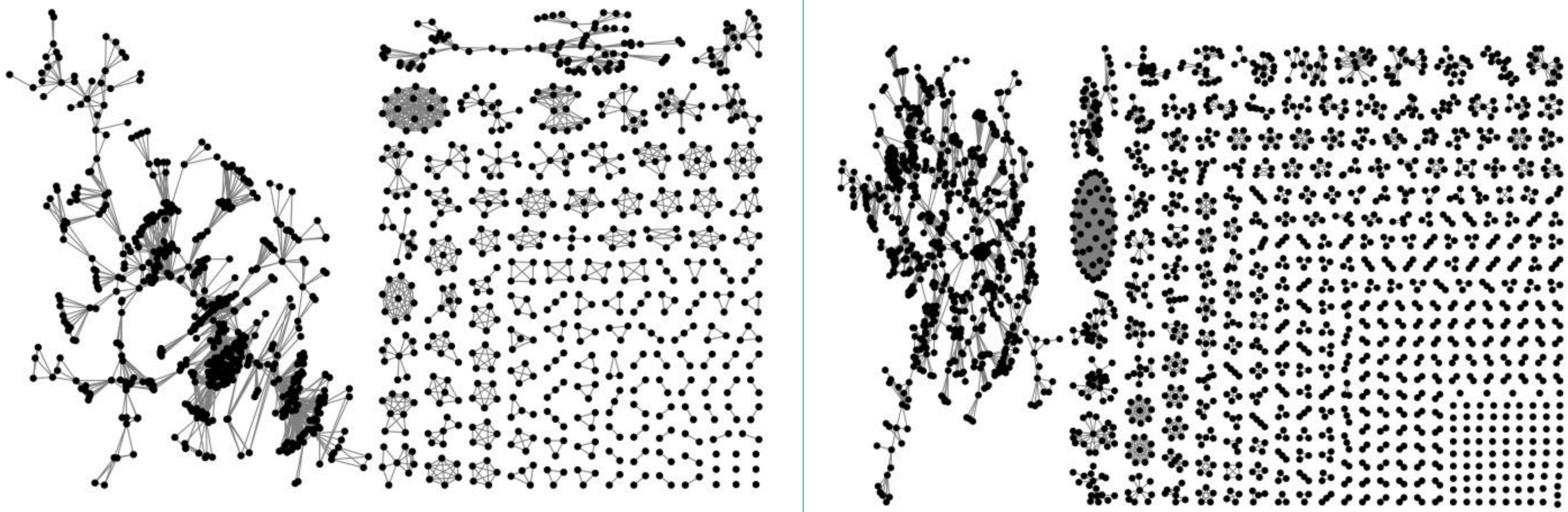
4.3.1 Global properties of the networks

A network may consist of several components of varying sizes. There are almost three times more components in the Turkey network than in the Malaysia network (see Table 4.3.2). Also, the ratio of vertices to edges is greater in the Malaysia network. There are 2.11 edges per vertex in the Turkey network, compared with 2.51 edges per vertex in the Malaysia network. Both of these measures indicate that the Malaysia network is less fragmented, and authors have more diverse connections with other authors in the network.

Table 4.3.2: Topological measures of co-authorship networks

Description	Turkey	Malaysia
Network:		
Vertices	2150	1234
Edges	4545	3099
Number of components	395	131
Isolates	83	9
Size of giant component	31.67	48.86
In the Giant Component:		
Vertices	681	603
Edges	1568	1881
Diameter	22	18
Mean geodesic distance	8.41	6.452
Density	0.0067	0.0103
Clustering coefficient	0.735	0.814
Average Degree	4.605	6

Malaysia has a larger giant component size than Turkey (see Figure 4.3.1) along with higher density than Turkey. This confirms that the former has a relatively larger group of researchers than the latter, who are interconnected in a cohesive network. Cohesiveness is a good sign, however, cohesiveness caused due to repeat relationships may lead to lock-in relations, which may hinder a company from exploiting new opportunities for innovation (D. H. Lee, Seo, Choe, & Kim, 2012). The giant component of the Turkey network occupies 31.67% of the network, whereas the Malaysia network occupies 48.86%.



Malaysia Turkey

Figure 4.3.1: Visualization of all components in the networks of Turkey and Malaysia (includes depiction of solo authors). The giant component is visibly smaller in turkey network than Malaysia network. Harel - Koren Fast multi-scale algorithm is used for the layout of graphs.

On one hand, giant components might represent the core research activity of a research community, where a large portion of connected and influential authors are also present. On the other hand, smaller components may represent areas where more specialized research activities may be taking place (Fatt et al., 2010). Formation of the giant component might also depend on how focused or interdisciplinary the field is. The size of the giant components of both the Turkey and Malaysia datasets were found to be not large enough when compared with other co-authorship networks discussed above. However, this might be due to a shorter time window (three years) that has been used to extract the data. As the network grows further, the likelihood exists of these smaller clusters merging with the giant component. Recall that it just takes an edge to bring two clusters together.

4.3.1.1 Small-world

This section attempts to answer the following sub-question of RQ3:

Whether the giant components of the two networks follow 'small world' model?

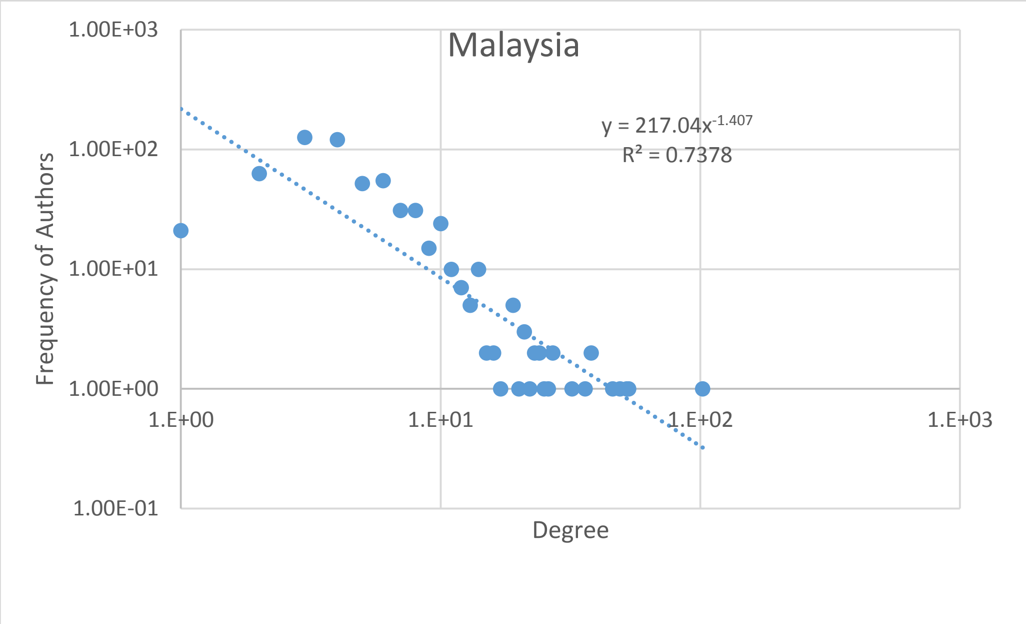
Milgram (1967) conducted an experiment in the 1960s and found that letters passed from person to person reached their destination in a small number of 'hops' or steps. Any two randomly chosen nodes that reach each other via a shorter number of paths has been coined the 'small world effect' of the network. Higher clustering coefficients and short geodesic distances (short path length) are common features of most real-world networks (Watts & Strogatz, 1998). In real-world networks, some nodes in the network have a significantly higher number of connections than the majority of the other nodes in the network. This is another reason why nodes in a small world network happen to be at short distances from one another.

The clustering coefficient of the Malaysia network was found to be higher than the Turkey network (see Table 4.3.2). High clustering coefficient values indicate that both networks possess a strong clustering effect. Any two researchers in the Malaysia network and Turkey network have 81.4% and 73.2% probability of collaborating, respectively, if they have both collaborated with a third researcher. A large percentage of papers with three or more authors per paper could also account for this high clustering coefficient in both datasets.

The longest geodesic distance (diameter) in Turkey's largest component is 22, and the average geodesic distance, also called the 'degree of separation', is 8.41. The Malaysia network, however, exhibits a shorter diameter and average geodesic distance when compared with Turkey, at 18 and 6.452, respectively.

Both Turkey's and Malaysia's networks are small world given that two random nodes can reach each other on average in a small number of steps. These communities demonstrate better connectedness, which allows nodes to achieve mutually beneficial goals (Fatt et al., 2010). Ozel (2012a) demonstrated that small-worldliness structures in local academia are significantly able to explain dispersion of knowledge. As with most previous studies on co-authorship networks, a recent study, taking Slovenian scientific communities as a case, re-confirmed the presence of small-worlds in scholarly networks (Kronegger, Mali, Ferligoj, & Doreian, 2012). Newman (2001c) found the geodesic distance of MEDLINE, SPIRES, NCSTRL, and Los Alamos Preprint Archive to be 4.4, 4, 9.7, and 5.9, respectively. In another study, Newman (2004a) found the average geodesic distances in Biology, Physics, and Mathematics networks to be 4.6, 5.9, and 7.6 respectively. Several other studies found the average geodesic distance to be between 3.02 and 8.84 (Fatt et al., 2010; Yan et al., 2010; Yin et al., 2006). The lower mean geodesic distance of the Malaysia network indicates that information flows more quickly when compared with the Turkey network.

Degree distribution of the two networks shows that a few authors have a large number of connections, whereas the majority of others have between 1 and 3 connections (Figure 4.3.2). A common feature of most real-world networks is that their degree follows a *power law*. A power law is a kind of 80/20 rule. In an author collaborative network, this means some authors will have many connections, with the majority of others having a few or just one. Skewed degree distributions, which has 'hubs' or popular nodes, are a characteristic feature of a scale-free network. In the log-log diagram, the degree distribution shows the fit for Malaysia and Turkey, which resemble scale-free model to a fair degree (see Figure 4.3.2).



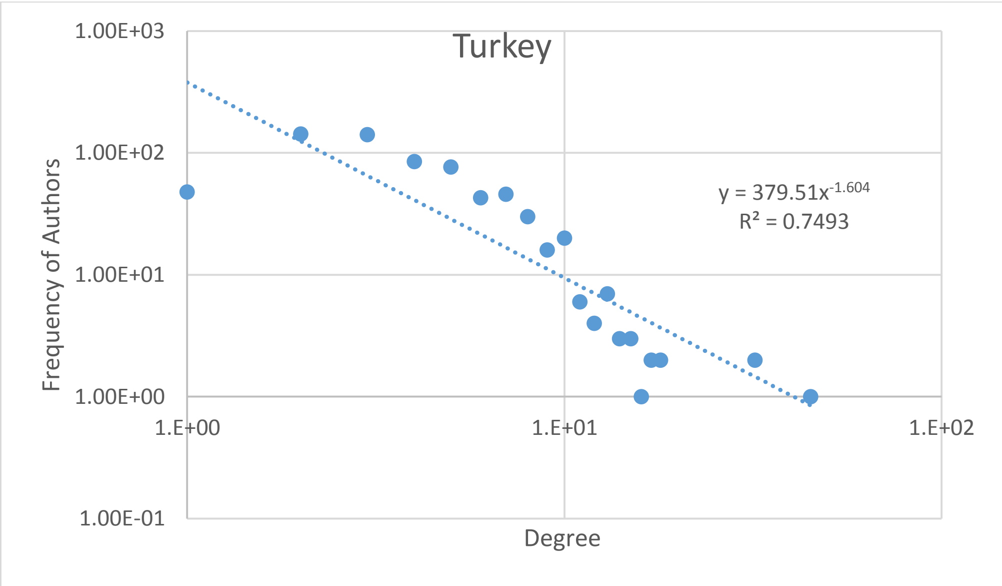


Figure 4.3.2: Chart depicting degree of authors of the Turkey and Malaysia networks. Both the networks demonstrate a skewed degree distribution.

4.3.2 Best connected authors based on centrality measures

This section attempts to answer the following sub-question of RQ3:

Based on Centrality measures who are the key researchers in the networks?

Next, the best-connected authors are determined in Turkey and Malaysia on the basis of their popularity, position, and prestige in their respective networks. Best-connected authors are chosen on the basis of rank on each metric. Popularity is seen through their degree, position through closeness and betweenness centralities, prestige through PageRank metrics, and tie-strength by calculating the strength of ties of individual vertices. Table 4.3.3 depicts the top 10 authors of both countries based on centrality measures.

The Malaysia dataset demonstrates a larger number of authors with a high degree of connections. Sopian, K. (Sopian, Kamaruzzaman) of Malaysia has 102 connections with different authors, whereas the highest number of connections in the Turkey dataset is held by Hepbasli, A., with 45 connections. Sopian, K. works at the University Kebangsaan Malaysia (UKM), a public University in Malaysia. He is a professor and director of the Solar Energy Research Institute and specializes in solar energy and fuel cell technology. Sopian is also the recipient of the 2012 World Renewable Energy Network (WREN) Pioneer Award. WREN is a major UK-based, non-profit organization that recognizes the outstanding contributions of individuals to developing renewable energy (http://ewarga4.ukm.my/ewarga/_pdf/2012/mei/16-87-1.pdf). Hepbasli, A. represents both Ege University in Turkey and King Saud University in Saudi Arabia. Dincer, I. (Dincer Ibrahim) is the second-most connected person in the Turkey network. A Turk, Dincer, I. is a professor at the University of Ontario Institute of Technology. He is also the recipient of the 2004 Canadian Premier's Research Excellence Award (http://www.exergycourse.org/lectrurers/ibrahim-dincer).

Betweenness centrality is another very important local metric of a network. Although degree indicates the popular nodes of a network, betweenness centrality indicates those who are 'power brokers' in the network. Yucesu, Hs. and Lee, K.T. are the authors with the maximum betweenness centrality in the Turkey and Malaysia networks, respectively.

In a co-authorship network, authors with high betweenness centrality are in a favoured position. Authors depend more on these authors to gain access to other authors in the network. In essence, the more authors depend on a particular author (those with high betweenness centrality), the more powerful they become. These authors are important for the network because they function as bridges and can be crucial to the flow of information and resources between clusters. Abbasi, Hossain, and Leydesdorff (2012) takes this argument further by demonstrating that betweenness centrality is a driver for preferential attachment, which means that individuals who are 'bridges' (i.e., PhD. supervisors) would attract more new entrants (i.e., PhD candidates) into the system than those who just possess a higher degree of connections. Another way to look at betweenness centrality is to ask which relationships are most central, rather than which actors are most central (Hanneman & Riddle, 2005).

While degree is based on direct ties, closeness is based on the indirect ties an author has in the entire connected network. The premise of closeness centrality rests on how close an author is to all others in the network. Such authors have access to a larger portion of actors in the network, reaching out to highly connected authors and various dissimilar authors. Yucesu, Hs. of the Turkey network, who ranked highest in betweenness centrality, also ranks highest in closeness centrality. Daud, Wrw. ranks highest in the Malaysia network on this measure. Historically, closeness centrality has been a less prominent measure when compared with degree and betweenness centrality.

PageRank, like Eigenvector centrality and HITS (Fatt et al., 2010), is a prestige metric. It gives higher weight to authors who collaborate with different authors and with authors who are already well-connected. In other words, those with a high PageRank weight are not those who just have connections based on quantity (degree), but also quality (an association with popular authors).

Both Hepbasli, A. and Dincer, I., who have thus far been ranked high in degree and betweenness centralities, also rank high on the prestige metric. In the Turkey network, Aydin, H. ranks second in PageRank and is also featured in the top 10 of both closeness and betweenness centralities. It misses the top 10 in degree ranking, however. In the Malaysia network, Sopian, K. ranks first in PageRank. He, along with Daud, Wrw. and Lee, K.T. are featured in the top 10 of all four centrality measures.

In the Turkey network, no single author is featured in the top 10 of all centrality measures, although several are featured in three of the four measures. Hepbasli, A. ranks top in degree and PageRank. However, he ranks 132nd in closeness centrality. This shows that although he commands both popularity and prestige, he is not particularly close to all of the other authors in the network. Authors with relatively low closeness centrality tend to work in specialized research communities. Yusesu, Hs. ranks top in both closeness and betweenness centralities but ranks 15th in degree centrality. Undoubtedly, he is the author who is not only the most accessible to others in the network but is also the one who holds the most power and thereby the flow of knowledge in the Turkey network.

Table 4.3.3: Top authors based on Centrality Measures and Research performance

Degree		Betweenness		Closeness		PageRank		No. of Works		Citations Count	
Malaysia											
Sopian, K	102	Lee, Kt	82098.135	Daud, Wrw	0.000422	Sopian, K	12.166	Sopian, K	63	Saidur, R	559
Zaharim, A	53	Ahmad, Mm	81523.655	Sopian, K	0.000409	Mahlia, Tmi	6.798	Saidur, R	48	Lee, Kt	375
Daud, Wrw	52	Daud, Wrw	76936.837	Ahmad, Mm	0.000406	Daud, Wrw	6.687	Lee, Kt	46	Daud, Wrw	268
Saidur, R	49	Sopian, K	59506.832	Kamarudin, Sk	0.000392	Saidur, R	6.657	Masjuki, Hh	31	Masjuki, Hh	264
Mahlia, Tmi	46	Abdullah, S	53210.186	Hasran, Ua	0.000386	Lee, Kt	6.260	Zaharim, A	29	Bhatia, S	244
Lee, Kt	38	Mahlia, Tmi	37809.868	Majlis, By	0.000383	Zaharim, A	5.679	Mahlia, Tmi	28	Kamarudin, Sk	220
Alghoul, Ma	38	Ahmad, Al	33500.505	Lee, Kt	0.000381	Masjuki, Hh	4.895	Mohamed, Ar	27	Mohamed, Ar	211
Masjuki, Hh	36	Fernando, Wjn	29816.614	Zaharim, A	0.000380	Mohamed, Ar	4.641	Daud, Wrw	25	Tan, Kt	203
Sulaiman, My	32	Zakaria, R	27097.000	Ibrahim, M	0.000377	Bhatia, S	4.418	Bhatia, S	24	Daud, Wmaw	188
Othman, My	27	Majlis, By	24210.927	Alghoul, Ma	0.000373	Yusup, S	4.039	Alghoul, Ma	23	Mahlia, Tmi	184
Turkey											
Hepbasli, A	45	Yucesu, Hs	84167.620	Yucesu, Hs	0.000265	Hepbasli, A	8.951	Demirbas, A	64	Demirbas, A	750
Yilmaz, M	32	Aydin, H	74823.693	Aydin, H	0.000262	Yilmaz, M	6.293	Hepbasli, A	56	Balat, M	459
Dincer, I	32	Dincer, I	68280.517	Aydin, S	0.000254	Dincer, I	6.225	Balat, M	39	Balat, H	417
Guru, M	18	Yilmaz, M	64415.201	Cinar, C	0.000249	Guru, M	3.749	Dincer, I	38	Demirbas, Mf	290
Yanik, J	18	Sozen, A	59240.814	Yilmaz, M	0.000248	Sari, A	3.390	Kaygusuz, K	27	Hepbasli, A	250
Sari, A	17	Ozdemir, A	55917.018	Can, O	0.000247	Yanik, J	3.122	Sari, A	19	Ozkar, S	219
Soyhan, Hs	17	Hepbasli, A	47755.579	Sahin, F	0.000247	Soyhan, Hs	2.961	Canakci, M	17	Dincer, I	210
Bozkurt, A	16	Aydin, S	45931.066	Sozen, A	0.000246	Kok, Mv	2.839	Oktay, Z	17	Altun, S	194
Sahin, B	15	Sahin, B	42525.747	Bakirci, K	0.000241	Kaygusuz, K	2.735	Kok, Mv	16	Demirbas, Ah	176
Ata, A	15	Kaya, D	37199.222	Behcet, R	0.000241	Yucesu, Hs	2.567	Ilkilic, C	15	Kirtay, E	157

4.3.3 Effect of centrality on research productivity

This section attempts to answer the following sub-question of RQ3:

What is the effect of degree (depicting popularity), closeness and betweenness (both depicting position) and PageRank (depicting prestige) on research performance?

In the prior section, the top 10 most active researchers were determined based on various centrality measures. In this section, Spearman's correlation coefficient is applied to examine how centrality measures are correlated with authors' research performance. Then, linear regression analysis is applied to determine which of these centrality measures have a significant effect on research performance.

As shown in Table 4.3.4, barring only closeness centrality's effect on citation count, all SNA measures have a statistically significant effect (p < 0.01) on research productivity in both networks. I see that even those that have a correlation coefficient value as low of 0.11 are still significant.

Table 4.3.4: Correlation between centrality measures and research performance

MALAYSIA	*Degree*	*Betweenness Centrality*	*Closeness Centrality*	*PageRank*	*Works*	*Times Cited*
Degree	1.00					
Betweenness centrality	0.61	1.00				
Closeness centrality	0.30	0.23	1.00			
PageRank	0.96	0.68	0.20	1.00		
Works	0.89*	0.59*	0.21*	0.92*	1.00	
Times cited	0.57*	0.48*	0.08	0.66*	0.77	1.00

TURKEY	*Degree*	*Betweenness Centrality*	*Closeness Centrality*	*PageRank*	*Works*	*Times Cited*
Degree	1.00					
Betweenness Centrality	0.61	1.00				
Closeness Centrality	0.32	0.38	1.00			
PageRank	0.94	0.65	0.26	1.00		
Works	0.57*	0.45*	0.22*	0.66*	1.00	
Times Cited	0.31*	0.23*	0.11*	0.38*	0.80*	1.00

* p < 0.01, confidence level = 95%

Table 4.3.4 shows that the correlation coefficient of centrality measures with productivity (times cited and number of works) in the Malaysia network is more strongly correlated with productivity than it is in the Turkey network. In fact, eight of the top 10 most-connected authors also are most productive in terms of number of works, and five of the top 10 most-connected authors are most productive in terms of the number of times their works have been cited. In contrast, only three of 10 authors in the Turkey network are included in the top 10 of research productivity (see Table 4.3.3). The correlation results also reveal a distinct fact: there is no guarantee that individuals with higher centrality measures, which indicate their relative position in the network, have produced more publications or have been cited more often. For example, Demirbas, A. ranks relatively lower in centrality ranks, with just 10 connections, and ranks 32nd in degree rank. Similarly, he ranks 48th in betweenness centrality. Nonetheless, Demirbas, A. is the most productive author in the Turkey network both in terms of citations received for his papers and the number of papers published. Similar trends in the Malaysia network are seen as well. For example, Bhatia, S. and Mohamed, Ar. are highly productive authors but are not included in the top 10 rank of the most connected authors.

Hepbasli, A. and Dincer, I. of the Turkey network represent classic cases of authors having high centrality measures that manage to have high productivity ranks (see Table 4.3.3). They also have 13 co-authored papers between them and thus share the citations received for these papers. Similarly, in the Malaysia network, several star authors are found whose position in the network is also positively reflected in their research productivity. Sopian, K. of the Malaysia network is a master weaver who has repeatedly co-authored papers with several authors. Prominent among them are Zaharim, A. (coauthored 26 times), Alghoul, Ma (coauthored 23 times), and Sulaiman, My (coauthored 19 times).

The correlation coefficient of the degree–number of works in the Malaysia network was higher than the Turkey network. In comparison, the degree–times cited showed a lesser correlation (see Table 4.3.4). Direct connections of authors with other authors resulted in both a higher number of papers and a higher number of citations in the Malaysia network compared with the Turkey network. These results are significant because they indicate how differently collaboration impacts productivity in the two networks.

The correlation coefficient between betweenness centrality−number of works and betweenness centrality−times cited is higher for the Malaysia network than the Turkey network (see Table 4.3.4). Several of the authors with a high degree of centrality also have high betweenness centralities in both of the networks. For example, the correlation coefficient between degree and betweenness centrality was found to be 0.61 in the Turkey network, indicating that about 6 of 10 times, authors with a higher degree also had high betweenness centrality. However, a few prominent cases emerged, such as Sozen, A. and Ozdemir, A., who have a low degree but high betweenness centralities. Similar trends were seen in the Malaysian network. In their work, Liu et al. (2005) found betweenness centrality to be the most sophisticated centrality measure, significantly associated with research performance. However, in either of these datasets this is not found—both degree and PageRank centralities outperformed betweenness centrality's association with research performance.

The correlation coefficient results of both networks assert the relative unimportance of closeness centrality. PageRank centrality's correlation with the number of works and times cited are significant and provides the best indicator for correlation among the four centrality measures.

4.3.4 Detection of "Core": K-Core v/s degree-based core representation

This section attempts to describe the following sub-objective of RQ3:

Visualize the 'core' of researchers where most productive researchers could be located.

Our attempt here is to reach to the 'stratum 'or 'core' of researchers, where the maximum number of productive researchers could be located. One of the common ways to get to the core is by examining the K-Core structure of the network (Yin et al., 2006). A K-Core is the largest sub-structure in the graph having at least K interconnections.

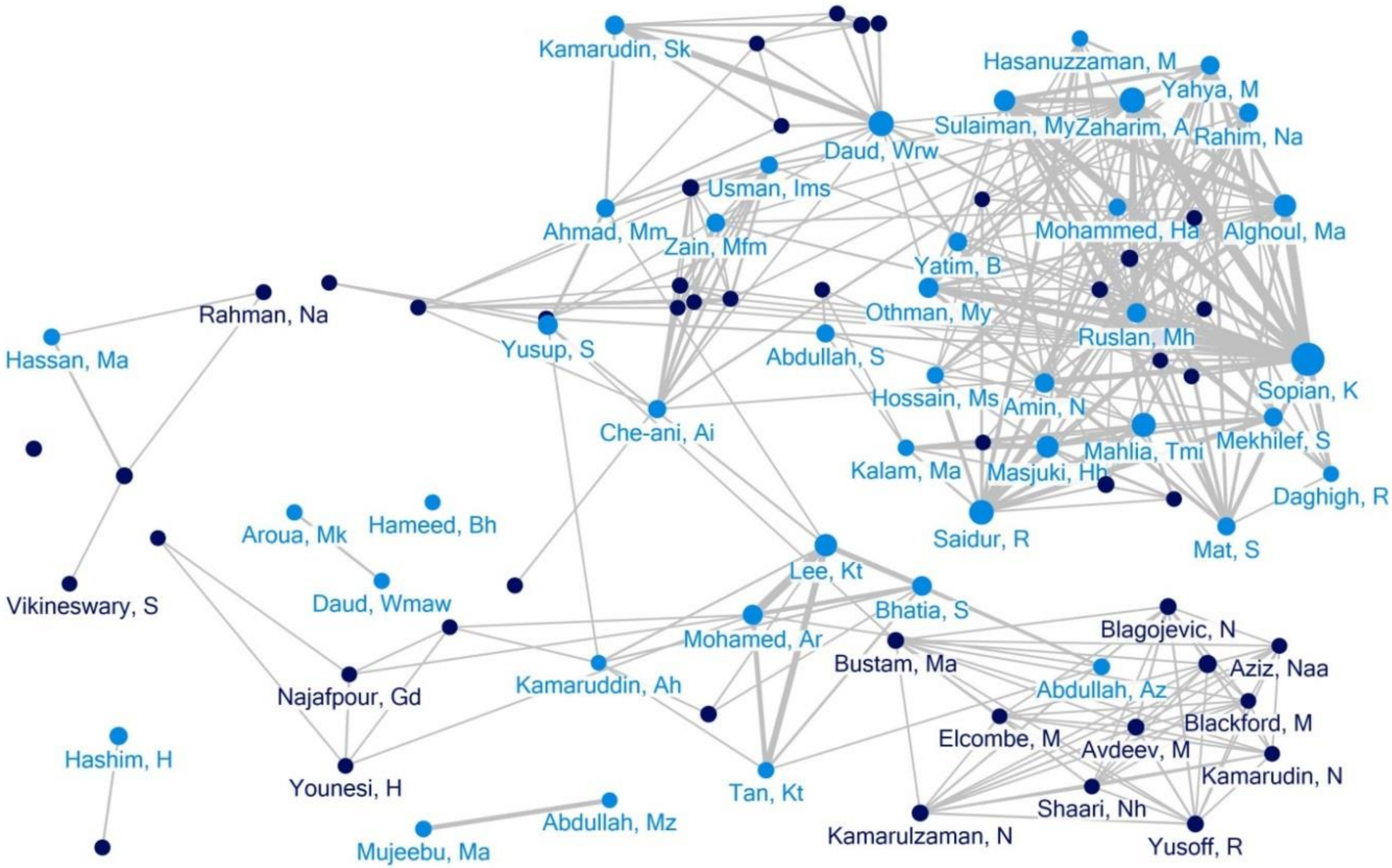
K-Core analysis was carried out for both networks. Here, I was interested in finding a network with a minimum 50 researchers who could represent the maximum number of productive researchers. For this analysis, productivity was restricted to the number of papers each researcher authored. K-Core at 7 (7-Core) gave 75 nodes in the Malaysia network. (K-core at 8 (8-Core) gave 46 authors, which was less than the minimum threshold of 50 researchers set; hence, it was not taken into account.) The K-Core captured 16 researchers among the top 50 most productive researchers. Among the top 10 most productive researchers, it captured four researchers. A similar analysis for the Turkey network, captured just one researcher in the top 50 and none in the top 10. Because these results were not representing the real core, another method was used to evaluate this characteristic. Historically, authors with a large number of connections have more influence over knowledge and resource sharing. With this notion in mind, degree of nodes was applied (called 'Deg-Core') as the threshold to get to the core. Whereas all nodes in the K-Core sub-graph must have at least K interconnections, in Deg-Core, the nodes must have D minimum degree, but it is not necessary that all its connections must also have D minimum degree. A deg-core of degree 10 and above is taken as this number captured our minimum threshold of 50 researchers. The resultant graph captured 41 of the top 50 most productive researchers in the Malaysia network and 18 in the Turkey network (see

Table 4.3.5). Deg-core graphs of the Turkey and Malaysia networks are shown in Figures 4.3.3.1 and 4.3.3.2. Deg-Core, as the representation of the "elite" or core of the network, is far superior to the K-Core representation by the way it captures the most productive authors. In the Malaysia network, because its degree and number of works by author are more correlated than the Turkey network, naturally it produced a much better representation.

Table 4.3.5: Comparison between 'Deg-Core' and K-Core of the two networks

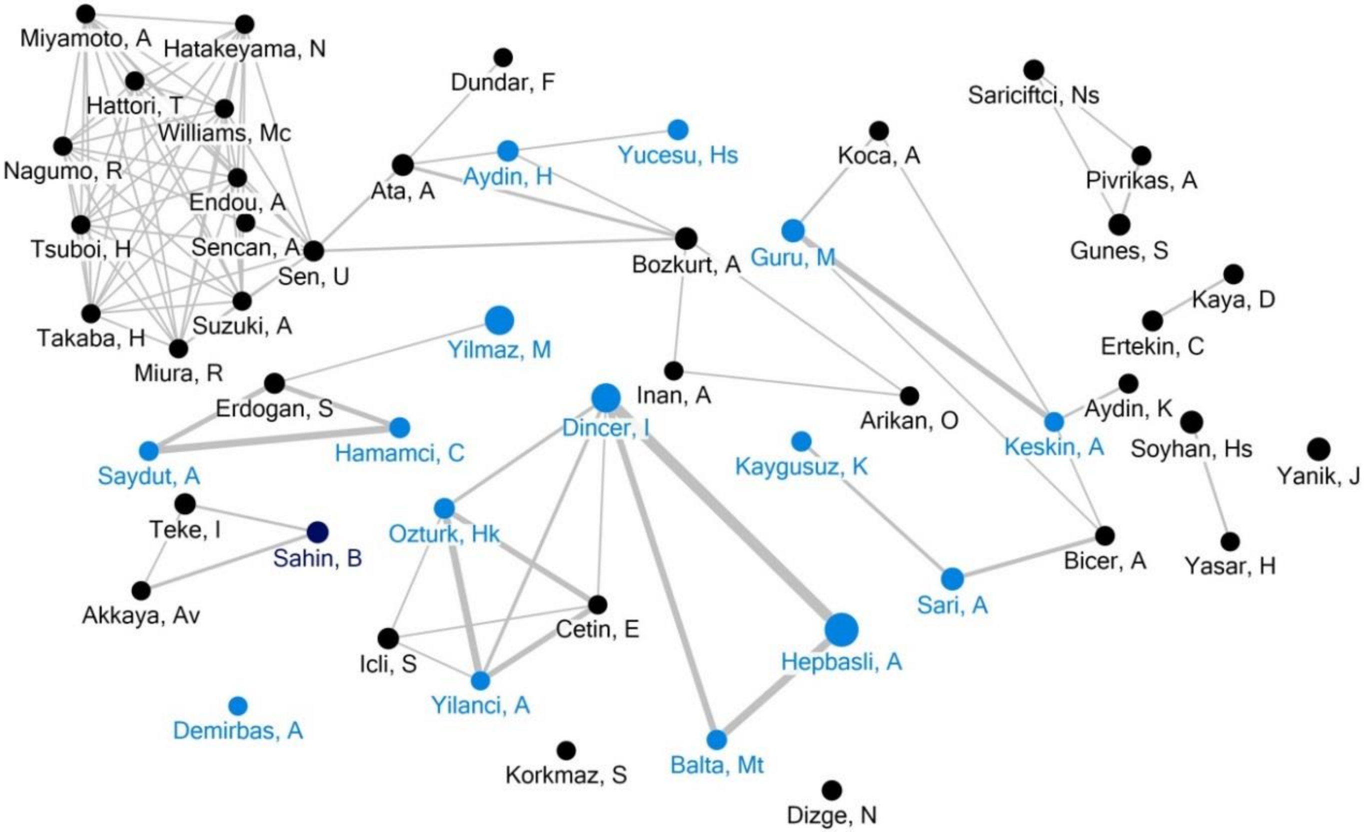
MALAYSIA				TURKEY				
	Total Nodes	Top 50	Top 10		Total Nodes	Top 50		Top 10
Deg-Core	88	41	10	Deg-Core	51	18		5
K-Core	75	16	4	K-Core	52	1		0

A remarkable difference was observed in the pattern of Deg-Core of Turkey and Malaysia networks. Turkey's Deg-Core is quite sparse when compared with Malaysia, even though its total number of authors in the giant component is larger than Malaysia. Though Sopian, K. and Saidur, R., the top performers in the Malaysia network, fall in the same cluster of connections, Lee, KT, another top performer, works almost independently of the other two. In the Turkey network, Demirbas, A. has no connections with other nodes of degree 10 and more. Dincer, I. and Hepbali, A., top performers in the Turkey network, are strongly (thick edge representing strength of connections between them) working together as evident in the network representation.



Malaysia

Figure 4.3.3.1: (Malaysia) Degree-based ‘core’ (Deg-Core) representation. The size of the node is based on degree centrality. Edge thickness is based on the number of co-authored papers. Visualization is carried out using the Frutchterman-Reingold spring algorithm. Some nodes have been slightly moved from their places to avoid overlapping with other nodes. Dark blue color nodes refer to nodes in Malaysia, whereas light blue colour nodes refer to those captured by ‘Deg-core’.



Turkey

Figure 4.3.3.2: (Turkey) Degree-based ‘core’ (Deg-Core) representation. The size of the node is based on degree centrality. Edge thickness is based on the number of co-authored papers. Visualization is carried out using the Frutchterman-Reingold spring algorithm. Some nodes have been slightly moved from their places to avoid overlapping with other nodes. Black color nodes refer to nodes in Turkey, whereas light blue colour nodes refer to those captured by ‘Deg-core’.

4.3.5 Motif-based Communities

This section attempts to describe the following sub-objective of RQ3:

Investigate if researchers in the motif (large cliques) based communities are more productive than the rest of researchers in the giant component

Real-world networks are generally made up of clusters or groups that consist of many edges between the vertices, but between these groups, there are a fewer number of edges. These groups are often termed 'communities' or 'clusters'. Detecting communities, especially in large networks, has been a subject of numerous studies(Girvan & Newman, 2002). Some established community detection algorithms exist, such as the Girvan-Newman (Girvan & Newman, 2002) and Clauset-Newman-Moore (Clauset, Newman, & Moore, 2004) algorithms.

As mentioned, the clustering coefficient is the probability of two nodes connecting if they have a common partner. Here, a way of community detection based on *Motifs* (large cliques) is proposed. A motif in the present case is defined as large clique with a certain threshold of minimum number of nodes. In a clique, all nodes are connected with one another and hence their density is always 1.

To test the efficacy of our community detection method, \the academic performance of nodes within the *Motifs* is examined against the total complete set of nodes in the giant component. The idea of cliques is borrowed from the concept of clustering coefficient, which measures the density of triads in the network. I am motivated to apply this method for academic networks, primarily for three reasons: (1) nodes in the motifs naturally enjoy a better degree of connections, (2) scholars with a higher degree might collaborate repeatedly with their existing partners, thus, increasing the chances of more papers for themselves, and (3) in collaboration networks, cliques occur more often than was expected on the basis of chance (Milo et al., 2002). Motifs in certain systems (i.e., organisms) may be functioning as ‘circuit elements’ and that their frequent occurrence may be an evolutionary result of their usefulness to the systems involved (Milo et al., 2002).

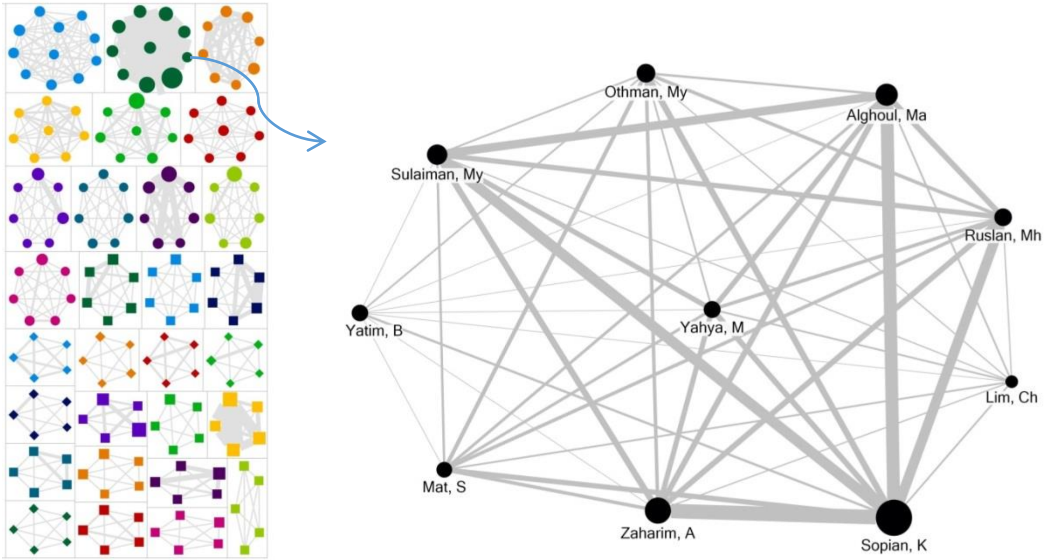
Unlike other forms of community based network detection, detection of motif-based communities ‘identify’ and extract groups of vertices from within the connected network. Here I use NodeXL’s ‘group by motif’ option to segregate cliques in the two networks of Turkey and Malaysia. This NodeXL option is meant to reduce visual complexity and serve a completely different purpose than the one presented here. I consider cliques to be a minimum of five edges and above for our analysis.

Both productive and less productive cliques were found in the networks of Turkey and Malaysia. Productive cliques are those that have authors who have either a good number of citations, number of works, or both. Cliques may be formed by a few authors (in our case, five authors and above) who have written just one paper and never collaborated again in the network. Furthermore, a paper written by this clique may not garner citations. Hence, such a clique is deemed less productive. Productivity is correlated with degree and the phenomenon of preferential attachment induces highly connected authors to attract more researchers to associate with them. These highly connected authors are also most likely captured by one of the motif cliques. Visual representation of motif-based communities of both countries is depicted in Figure 4.3.4. On average, authors in the motif-based communities have performed better in terms of research performance when compared with all the authors in the giant component. In the Malaysia network, this performance is significantly better than Turkey (see Table 4.3.6). Standard deviation (σ_x) of both citations (Malaysia: 41.08; Turkey: 46.62) and number of works (Malaysia: 5.01; Turkey: 4.62) does not show major difference for both countries.

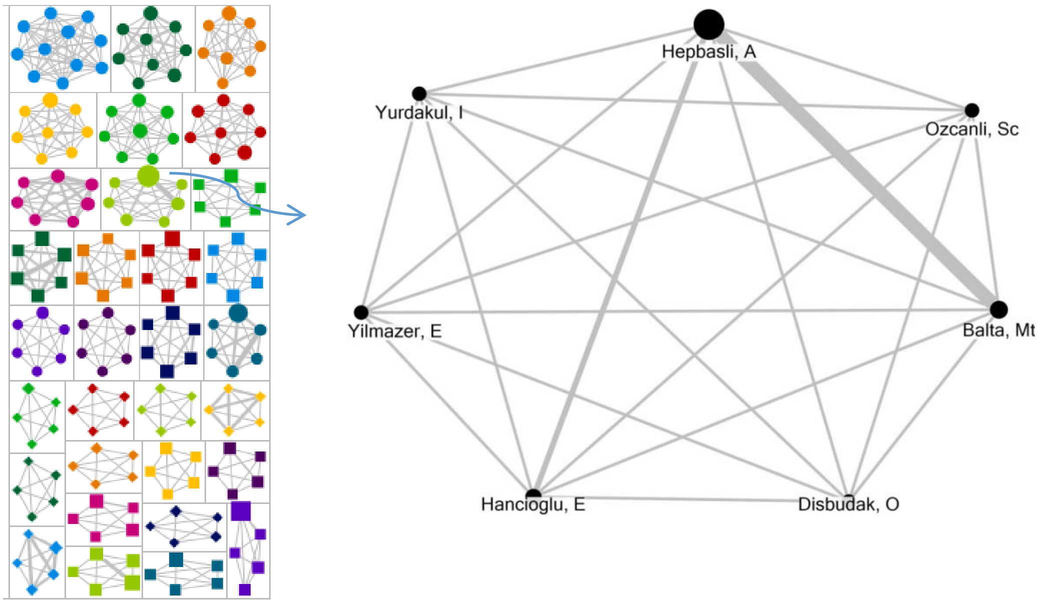
Table 4.3.6: Productivity in motif-based communities in comparison with giant component

Country	**Motif Communities Description**	**Average No. of Works**		**Average Citations count**	
		Giant Component	Motif-based communities	Giant Component	Motif-based communities
Malaysia	29 Clique-Motifs 181/603 nodes (30.01% of the total nodes)	2.68	4.94	15.10	29.66
Turkey	31 Clique-Motifs 190/681 nodes (27.90% of the total nodes)	2.81	3.68	17.06	20.24

However, Turkey has both a lower clustering coefficient and density than the Malaysia network, which makes the former network sparser than the latter. Most of the best connected authors find their way in the clique communities.



a) Malaysia



b) Turkey

Figure 4.3.4: Two of the active Motif based communities in Malaysia and Turkey.

The correlation between degree and number of works is significantly higher in the Malaysia network than the Turkey network. I surmise this may have contributed to Turkey-specific communities to be less correlated with research productivity. In Malaysia, motif-communities are twice more productive than the authors in the giant component (see Table 4.3.6).

4.3.6 Research focus areas (RFA) and prominent researchers

This section attempts to describe the following sub-objective of RQ3:

Visualize prominent Research focus areas (RFAs) in the field of energy fuels and their association with prominent authors working in these RFAs.

Among several ways in which knowledge of a field could be represented, co-word network analysis is one of the most common methods. In co-word network analysis, prominent keywords (or frequently used words) are extracted and two keywords form a connection if they have appeared in the same paper. Here a 2-mode method is presented, which not only maps prominent knowledge areas in the field of energy fuels but also maps the most active researchers in those areas. In a 1-mode network, the vertices refer to same set of entities (i.e., author-author), whereas in a 2-mode network they refer to different set of entities (i.e. institution-author) (Borgatti, 2009). 2-mode networks effectively depict 'macro-micro' social structures. Visualization of 2-mode data shows how individuals are 'nested' in larger structures (Hanneman & Riddle, 2005). This type of author-RFA is similar to other affiliation networks such as a club affiliations or social gatherings (Faust, 1997). Here, our attempt is to present this information through a clutter-free graphical representation, which also conveys maximum meaning.

'Generic keywords' are common words mentioned by the authors in the keyword list that support the main research focus area ('non-generic' keyword) of the paper. For example, in Figure 4.3.5, one paper mentions the following three keywords – Biomass, Sustainable process and Energy business. Here 'Sustainable process' and 'Energy Business' are supporting the main research area, 'Biomass'. In the same light, generic keywords, for example, 'sustainable', 'fuel' and 'energy' were excluded as we are interested in identifying focus areas within energy fuels. Non-generic key words are taken based on the number of occurrences in the ‘original keyword’ field.

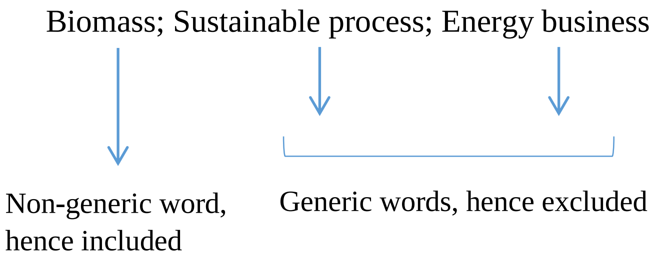


Figure 4.3.5: Example of inclusion and exclusion of words taking keywords of a paper as an example.

These words are represented in original keywords with several variations, and those variations have been included while calculating the total number of occurrences. To differentiate it with academic field or sub-fields, These words are named as Research Focus areas (RFA). Once the words representing a focus area of both datasets were extracted, prominent authors were chosen based on the number of times they had used these keywords in their papers. Table 4.3.7 gives details of the top focus areas, top word variations and prominent authors in those focus areas of both Turkey and Malaysia. Seven of the nine areas—Biodiesel, Solar, Biomass, Hydrogen, fuel-cell, waste and thermal—are common in both Malaysia and Turkey.

Table 4.3.7: Research Focus Areas (RFAs) and prominent researchers of the two countries

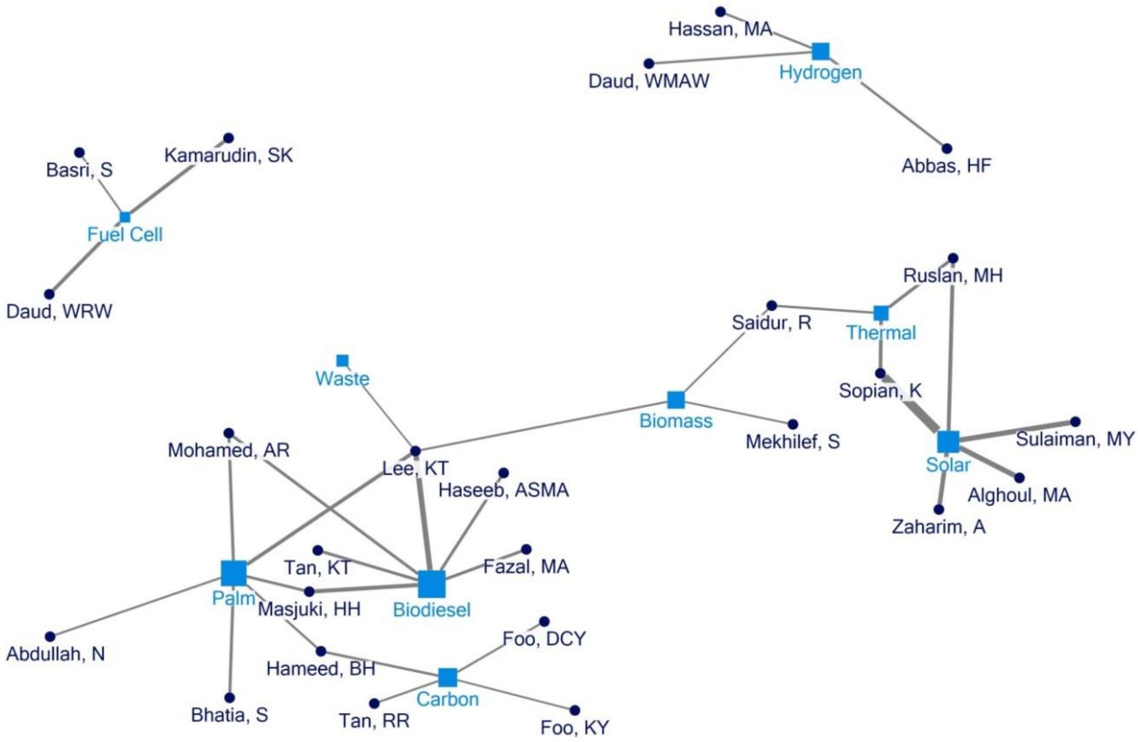
Field	Some prominent key word variations	Occurrences	Prominent Researchers
MALAYSIA			
Biodiesel	Biodiesel,Palm biodiesel, Biodiesel engine, Biodiesel feedstocks,Biodiesel refining	82	Lee, KT (20), Masjuki, HH (14), Tan, KT (9) , Fazal, MA (9), Mohamed, AR (9), Haseeb, ASMA (9)
Palm	Palm Oil, Palm oil mill effluent, Oil palm, Sludge palm oil, Oil palm fruit press fiber (FPF)	72	Lee, KT (12), Mohamed, AR (9), Bhatia, S (9), Masjuki, HH (8), Hameed, BH (6), Abdullah, N (5)
Solar	Solar,solar energy,double-pass solar collector,solar fraction,V-groove solar collector, solar photovoltaic	55	Sopian, K (37), Sulaiman, MY (19), Alghoul, MA. (19), Zaharim, A (16), Ruslan, MH (13)
Carbon	Activated carbon, Carbon, Carbon dioxide, Carbon dioxide hydrate, Carbon sequestration	42	Hameed, BH (7), Foo, DCY (5), Tan, RR (5), Foo, KY (4)
Biomass	Biomass, Biomass concentration, Lignocellulosic biomass,Biomass conversion technology, Palm oil biomass	37	Lee, KT (5),Saidur, R (4),Mekhilef, S (4)
Hydrogen	Biohydrogen, Hydrogen production, Hydrogen, Hydrogen production, Hydrogen purification	37	Abbas, HF (7), Hassan, MA (6), Daud, WMAW (6)
Thermal	Thermal, Photovoltaic thermal (PVT), Thermal resistance, multifunctional solar thermal collector, Hydrothermal	29	Sopian, K (12) , Ruslan, MH (10), Saidur, R (6)
Waste	Waste cooking oil, Oil palm wastes, Municipal solid waste (MSW), agricultural waste	21	Lee, KT (3)
Fuel Cell	Fuel cell, Direct methanol fuel cell, Solid oxide fuel cell, Direct borohydride fuel cell	18	Kamarudin, SK (12), Daud, WRW (12), Basri, S (4)

Table 4.3.7 (continued): Research Focus Areas (RFAs) and prominent researchers of the two countries

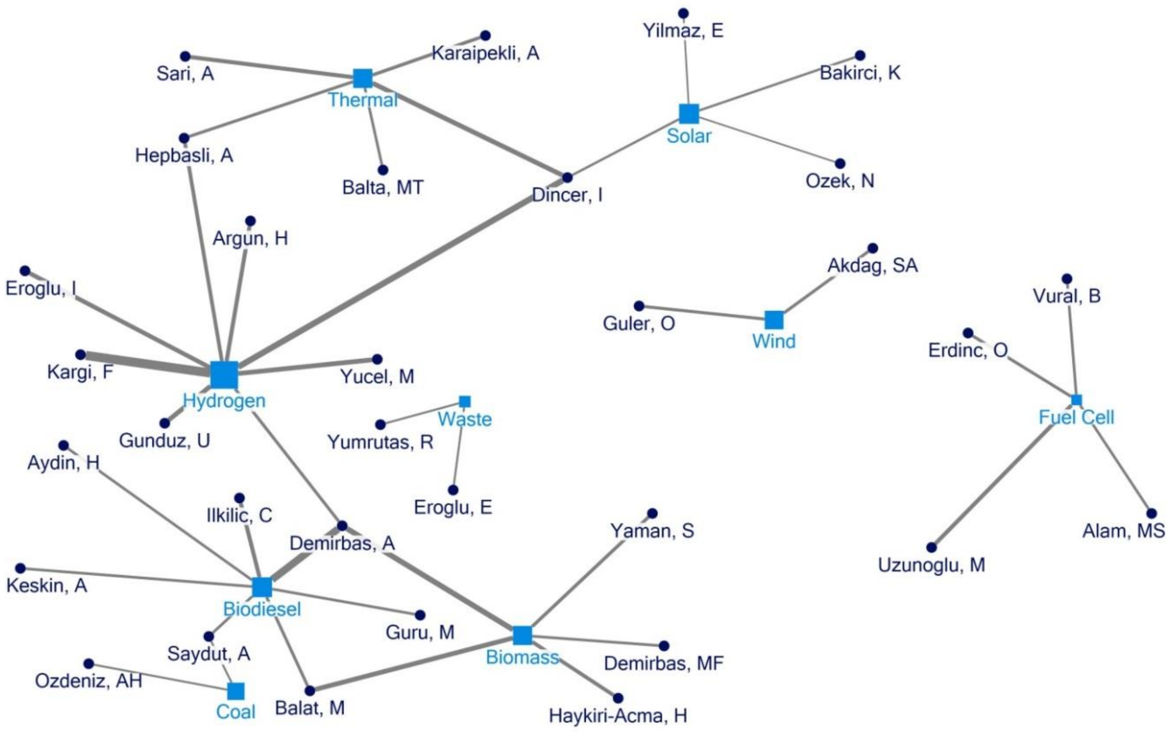
Field	Some prominent key word variations	Occurrences	Prominent Researchers
TURKEY			
Hydrogen	Hydrogen, Bio-hydrogen, Hydrogen storage, Hydrogen production, hydrogen energy	185	Kargi, F (25), Dincer, I (16), Gunduz, U (12), Yucel, M,(12), Eroglu, I(11), Argun, H (10), Hepbasli, A (9), Demirbas, A (7)
Solar	Solar energy, solar radiation, Organic solar cells	113	Bakirci, K (5), Dincer, I (5), Ozek, N (3),Yilmaz, E (3)
Biodiesel	biodiesel economy, Biodiesel production, biodiesel policy	112	Demirbas, A (20), Ilkilic, C (10), Balat, M (7), Keskin, A (6), Aydin, H (6), Saydut, A (6), Guru, M (6)
Biomass	Biomass energy,Lignocellulosic biomass	106	Demirbas, A (14), Balat, M (12), Haykiri-Acma, H (9), Yaman, S (8), Demirbas, MF (6)
Thermal	Geothermal energy, Thermal analysis, Thermal energy storage, Thermal efficiency	106	Dincer, I(12), Sari, A(10), Karaipekli, A(8), Hepbasli, A(7), Balta, MT(6)
Wind	Wind energy, wind turbine, wind power	103	Akdag, SA(7), Guler, O(7)
Coal	Coal oxidation, Coal tar pitch, Turkish coals	93	Saydut, A (4), Ozdeniz, AH (4)
Waste	Waste oil, Olive mill wastewater, Wastewater, Waste engine oil	60	Eroglu, E (4), Yumrutas, R (4)
Fuel cell	PEM fuel cell,Solid oxide fuel cell,Direct borohydride fuel cell	56	Uzunoglu, M (10), Erdinc, O (7), Alam, MS (6), Vural, B (6)

Next, a 2-mode network representation to identify prominent researchers in each of the RFAs in Turkey and Malaysia is carried out. By providing a 2-mode representation, I believe that our network provides a more diverse cognitive structure than is available through 1-mode knowledge domain visualizations (KDVs).

The standard representation of cognitive structure (Mane & Börner, 2004), which mostly represents connections between keywords (might also represent frequent words, research topics or fields, etc.), does not provide information on the prominent authors who are working in these research topics; prominent authors are an important part of cognitive structure, which is missed in 1-mode presentation through KDVs. In a study, Hou et al. (2008) , presented the cognitive structure of the *Scientometrics* journal by first drawing a word co-occurrence network and then manually partitioning the network based on the research sub-field. Hou et al. (2008) finally textually described the prominent authors working in those sub-fields. In contrast, our representation provides a multi-dimensional bird's eye view of RFA (prominent research areas), prominent authors working in these RFA and the strength of this association (see Figure 4.3.6). These graphs are drawn considering how our eyes and brains process visual information (Kosslyn, 2006)



a) Malaysia



b) Turkey

Figure 4.3.6: 2-mode network diagram representing the cognitive structure of Malaysia and Turkey

In the networks of Turkey and Malaysia, it is the prominent authors in the network that connect the various focus areas. Few researchers have carried out their research in multiple focus areas. Lee, Kt of Malaysia and Dincer, I. and Demirbas, A. of Turkey are among the researchers who have carried out their research in multiple focus areas.

The overall impetus of research in both countries is in the field of renewable and sustainable energy. Palm is an important plantation in Malaysia, and palm oil is a burgeoning industry in this country. Use of palm oil for biofuel and for biomass has been studied aggressively by Malaysian researchers. Wind energy, on the other hand, has seen tremendous research interest in Turkey. Turkey has wind potential to generate 83,000 MW; however, the installed wind capacity was 3.33% of this wind potential (Bilgili & Simsek, 2012). In areas affected by ocean thermal energy and wave and tidal energy, few activities have been conducted in OIC countries (Sopian et al., 2011). The same pertains to Turkey and Malaysia. Missing in the top 9 RFAs is ‘nuclear’, an energy source with is controversial due to potential environmental hazards but has tremendous potential. Neither country has a nuclear power generation plant, but has government agencies in place to review the nuclear option. In Turkey, however, an application has been submitted to construct the first nuclear plant at Akkuyu (http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/Turkey/#.UUvcWxxgenA).

4.4 Chapter conclusion

I have presented the results and analysis of the study. An attempt was made to answer the research questions, with their respective sub-objectives and sub questions. The results brought out new aspects of research collaborations in the context of Malaysia. The network approach located central authors in the research community, determined the cohesiveness of various collaboration networks, and provided new propositions for analysis of research collaboration networks, among others. The key findings emerging from each of the research questions are given in the next chapter.

CHAPTER 5: CONCLUSIONS

The key findings of each of the three case studies are first delineated. Limitations of the study and its contribution to the literature are presented. Lastly, I discuss avenues for future research.

5.1 Key findings

Common statistics and topological properties of all seven networks of case studies representing the three research questions are delineated in Table 5.1.

All of the networks studied here follow a *small-world* topology. In most networks, the distance between any two members is small. I see the same phenomenon here – the average geodesic distance or degree of separation of the network is between 1.2 and 8.41. A high clustering coefficient is another characteristic of small world networks; in all networks; here the clustering coefficient is high. (see Table 5.1.).

Table 5.1: Summary of bibliometric stats topological properties of the networks in the 3 case studies.

Description	**Case Study 1 (RQ1)**	**Case Study 2 (RQ2)**				**Case Study 3 (RQ3)**	
	BM*	**CHEM**	**EEE**	**MECH**	**CIVIL**	**Malaysia+**	**Turkey+**
BIBLIOMETRIC STATS							
No. of Papers	209	1247	1560	466	402	658	1658
Average papers per author	1.17	2.16	2.22	1.76	1.51	2.01	1.96
Average authors per paper	2.76	3.44	3.17	3.05	3.21	3.77	2.55
NETWORK METRICS							
No. of Nodes (number of distinct authors)	285	1985	2210	809	855	1234	2150
No. of Edges	277	4710	4759	1502	1604	3099	4545
Isolates	-	14	24	10	12	9	83
Number of components	92	163	215	132	173	131	395

Description	Case Study 1 (RQ1)	Case Study 2 (RQ2)				Case Study 3 (RQ3)	
	BM*	**CHEM**	**EEE**	**MECH**	**CIVIL**	**Malaysia+**	**Turkey+**
Average Geodesic Distance	1.2	5.52	6.39	3.69	2.67	6.452	8.41
Maximum Geodesic Distance (Diameter)	5	14	17	13	9	18	22
Average Clustering Coefficient	0.586	0.791	0.739	0.756	0.755	0.814	0.735
Density (Disregarding weights)	0.0071	0.0024	0.0019	0.0046	0.0044	0.0103	0.0067
Nodes in the Largest component	17	1269	1338	107	57	603	681
% Size of Largest component.	5.96	63.93	60.30	13.27	6.66	48.86	31.67
Degree	2	4.74	4.28	3.71	3.75	6	4.61

(table continued from the earlier page)

* The network metrics exclude the two hyper authored articles and only include multi-authored papers.

+ Network metrics pertaining to geodesic distance, clustering coefficient, density and degree are computed on the giant component

In case studies 1 and 3, representing RQ1 and RQ3 respectively, it was checked whether the research productivity of authors followed Lotka’s Law. Lotka’s law postulates that some authors produce many more papers than most others in a community with the number of authors writing *n* articles (or contributions) is $1/n^{\beta}$ of those writing one article. The case study representing RQ1 failed to follow Lotka’s law; in both networks the case study presenting RQ3 did follow Lotka’s Law.

In the case study 1 that represents RQ1, by applying social network analysis, a multi-dimensional view of research collaboration in Malaysia in the field of business and management are acquired. The disambiguation of author's names is a difficult issue to resolve. Most studies either avoid disambiguation or do not explain how they accomplished it. I disambiguated authors' names using a hand-cleaning method. A large percentage of records had to be cleaned; failing to do so would have yielded significantly different results. There was a surge in paper production after the year 2007. This surge corresponds to increased emphasis on developing "first-class" human resource under Malaysia's 9th and 10th Malaysia Plans (9MP and 10MP). Academic research is an important agenda under these plans. Universities, especially those in the public sector, have been trying to increase their research output. MOHE, through the Malaysia Research Assessment Instrument (MyRA), recognizes papers indexed in the Thomson Reuters' Web of Science (WoS) to empirically gauge quality research production by academicians and universities. Specific to this case study author productivity did not follow Lotka's law. Nonetheless, some authors in the data-set had published a significantly higher number of papers than others.

Collaboration through co-authorship may not have led to the increase in paper production. Regression analysis was carried out to examine if association in multi-authored papers accounted for the increase in paper production. From results it was not evident if collaboration led to an increase in research productivity. Collaborative papers were cited twice as often as individually authored papers, and internationally co-authored papers are cited three times as often as locally-authored papers. Although the analysis could not determine whether or not collaboration led to increase in production, it was amply clear that collaborated papers were cited twice as often as solo papers. Internationally co-authored papers were cited three times more frequently than locally co-authored papers. Malaysian authors have collaborated more with authors of developed nations such as the US, the UK, Australia, Japan, and Canada than with authors from non-developed countries. The last decade has seen significantly more collaborative activity than the previous two decades. The average number of authors per paper has almost doubled during the past three decades. While the average number of authors per paper was 1.66

from 1980 to 1990, it rose to 3 from 2001 to 2010. The dynamics of networks formed by co-authorship also demonstrate a faster formation of networks during the last decade compared to the previous two decades.

The co-authorship network is a small world. High clustering coefficient and smaller geodesic distance between any two random nodes in a network are characteristics of a small-world network. The short geodesic distance between the nodes is likely due to hubs or popular nodes in the network. Hubs are a feature of yet another property of networks – the scale free of the network. The network has the maximum geodesic distance (diameter) of 5, average geodesic distance of just 1.2, and a high clustering coefficient of 0.586. This low average geodesic distance is likely due to high fragmentation and the absence of a giant component of any meaningful size. The degree distribution shows the fit of the exponential model in the log-log diagram at $R^2 = 0.87$, which is quite good and resembles a scale-free network model to a good extent.

Hyper-authored articles highjack centrality and global scores in their favor. The largest components of co-authorship networks were formed by two hyper-authored articles. Particularly in a small network such as this one, the authors of these articles skew centrality and global scores in their favor, adding a strong bias to the result. Hence, for computations related to co-authorship networks, the authors of these two articles were excluded.

At individual, institutional and international levels, better connected entities are also better research performers. Top authors, institutions and countries that have collaborated with Malaysia were ranked based on their popularity (degree), position (betweenness), and prestige (PageRank) and found that entities that were better connected also had better research performance. There is significant effect of degree, tie strength, and efficiency on research performance. I tested the effect of centrality measures, structural holes measures (efficiency and constraint) and tie strength on two performance measures: the number of works and the number of citations. The results demonstrated a significant effect of degree, tie strength, and efficiency on research performance.

The assortativity coefficient indicated affinity of like-connected authors with like-others. With the overall assortativity coefficient at 0.46, the network displayed a positive (yet not too strong) association of well-connected authors, connecting with well-connected others. From 1980-1990, the degree assortativity was 0.158, which grew to 0.392 during 1990 – 2000 and then to 0.424 from 2001 - 2010. This growth correlates with the increasing number of authors in the network.

Geographical proximity still mattered in intra-national collaboration. Geographical proximity has played an important role in research collaborations. Technological advances have closed the distance gap between researchers. A regression analysis conducted to examine the effect of distance on frequency in intra-national research collaborations found a significant effect of distance on the frequency of collaborations.

Malaysia-affiliated authors are in "driver's seat." Author order is an important element of co-authorship. More than two-thirds of the papers have a Malaysian as a first author. This finding is important because harvesting the data from the SSCI database only had Malaysia as one (or more) of the addresses of authors in the business and management field.

There is comparatively little national-level inter-institutional collaboration. Malaysian institutions have collaborated more intra-institutionally or with their foreign partner institutions than with other Malaysian institutions. Intra-institutional collaboration may be the result of geographical proximity. Collaboration with international counterparts can occur because authors may obtain better opportunities to share resources and expertise. Also, there is a fair degree of collaboration among the five designated Research

Universities in Malaysia. Among the total of links that the five research universities (RUs) have extended outside their institutions, about 23% have been within these research universities. This reflects a fair degree of collaboration among the research universities. Inter-collaborations among the RUs are a healthy trend. Furthermore, the top five slots in terms of the number of unique authors and articles produced are also occupied by the RUs. This may be due to additional government funding that is reserved for research to these institutions. Although Malaysia is part of ASEAN, which has an important agenda of educational cooperation, little research collaboration has occurred between Malaysia and ASEAN member states. Thailand and Singapore are the only ASEAN countries with which Malaysia has collaborated. Large ASEAN countries such as the Philippines and Indonesia have not collaborated with Malaysia.

Based on the results, I suggested an effective co-authorship strategy for researchers. Collaboration could be a strategy in and of itself, because collaborative papers are cited more frequently. Having an author who is affiliated with the foreign university, however, could prove to be an even better strategy. These papers were cited several times more frequently than those written with local co-authors. Furthermore, the influence of SNA measures on research productivity suggests that having many connections through co-authorship, co-authoring repeatedly with the same author, and aligning with only one additional author within a group of authors who already know one another, could be a multifaceted strategy that would likely improve the research productivity of authors.

In the second case study that represents research question 2, I empirically investigated one of the prominent topological properties, the giant component, in the collaborative networks of four prominent engineering disciplines in Malaysia. The premise was to analyze if other topological properties and (or) the pace of paper production had any impact in the formation of giant components. That study found that CIVIL had relatively more authors in the network, yet it has produced fewer papers. EEE had the maximum number of papers, followed by CHEM, MECH and CIVIL. The ratio of number of papers with the number of distinct authors is in the range of 1.59 to 1.73 for EEE, CHEM and MECH, but a good 2.12 for CIVIL, which means that although CIVIL had relatively more authors in the network, they have produced fewer papers. CHEM and EEE networks already possess well-formed giant components, whereas MECH and CIVIL networks had not yet formed one. Giant components of well-formed size have been formed in CHEM (63.3%) and EEE (60.30%) disciplines. In MECH and CIVIL, the largest components are 13.27% and 6.66% respectively, too small to be well-formed giant components.

Networks demonstrate small-world properties. All four networks demonstrated small-world properties, with networks possessing larger giant components having longer distance of separation between the nodes. The degree of separation between any two random authors in the largest component had an average distance of about 6, confirming their "small world" character. Degree and clustering coefficient are both positively correlated with the size of giant component. Although both degree of collaboration and clustering coefficient showed positive correlation with the size of giant component, the former showed a much stronger correlation than the latter.

The average degree of separation positively correlates with the size of giant component. When the network is small, the average degree of separation between any two random nodes is small due to high fragmentation and the smaller giant component. As the network grows the fragmentation reduces and the giant component also starts to form. The formation of giant component, which has large number of nodes inter-connected in a single component, may also lead to an increase in the geodesic distance of the overall network.

There is a negative correlation between density of a network and the size of giant component. Networks of CIVIL and MECH are denser than the other two networks, yet their giant components are smaller. One possible explanation for this is that as the network grows the number of possible connections increases proportionately, thus, making the network sparser. There is a positive correlation between the average degree and the size of the giant component.

Multitude of factors may be responsible in the faster formation of a giant component. Using temporal data, that study found that until the mid-1990s, all four disciplines had similar paper production. However, after this period, CHEM and EEE added papers faster than MECH and CIVIL. Corresponding to this activity, CHEM and EEE show well-formed giant components. Nonetheless, it is also pointed out that just the presence of large number of nodes cannot be a sole criterion for the formation of giant component. Rather a multitude of factors (e.g. addition of nodes and these nodes working in related sub-disciplines), may be instrumental in the faster formation of the giant component.

In the third case study, representing Research question 3, a network approach was taken to understand the collaborative patterns of authors of Turkey and Malaysia, two prominent OIC nations, in the field of energy fuels. The study found that Malaysia has shown an incremental increase in paper production during the time window. While Turkey's production of papers has been consistent since 2010, Malaysia has shown an incremental increase. Malaysia's increase in paper production corresponds with impetus in research publications under its 9th and 10th Malaysia Plans. In both countries, public universities are among the five most productive institutions in terms of paper publication. However, Malaysia's top five universities garnered more than twice the percentage of total papers than Turkey. Turkey received a larger number of local citations than Malaysia, indicating a higher intra-country citation pattern. In Malaysia, only 1 in 6 citations came from papers written locally; in Turkey this number is 1 local citation in every 3.82 citations. Malaysia has more than four times higher percentage of five and more authors per paper than Turkey, indicating more team work (team collaborations) in Malaysia than Turkey. Research performance of both Turkey and Malaysia conformed to Lotka's Law of research productivity. Turkey and Malaysia datasets fit Lotka's Law with β = 2.2858 and 2.326, respectively.

Malaysia has a larger giant component with higher density than Turkey. Being representative of core research activity in a research community, giant components usually capture prominent researchers. Malaysia has a larger giant component size than Turkey along with higher density than Turkey. This indicates that the former has a relatively larger group of researchers than the latter, who are interconnected in a cohesive network.

Both the networks demonstrated "small world" properties. The longest geodesic distance (diameter) in Turkey's largest component is 22, and the average geodesic distance, or "degree of separation" is 8.41. The Malaysia network, however, exhibits a shorter diameter and average geodesic distance than does Turkey, at 18 and 6.452, respectively. The lower mean geodesic distance of the Malaysia network indicates that information flows more quickly than it does in the Turkey network. The clustering coefficient of the Malaysia network was found to be higher than the Turkey network. High clustering coefficient values indicate that both networks possess a strong clustering effect. Any two researchers in the Malaysia network and Turkey network have 81.4% and 73.2% probability of collaborating, respectively, if both have collaborated with a third researcher. The degree distribution shows the fit of the exponential model at R^2 = 0.63 for Turkey and R^2 = 0.46 for Malaysia, which resemble scale-free model to a fair degree.

Centrality measures had a statistically significant effect on research performance. PageRank and degree, in that order, were best correlated with research performance. The correlation between centrality measures and research performance was stronger in Malaysia network. The results indicate that influential authors are well positioned in the network. The correlation results also reveal that there is no guarantee that individuals with higher centrality measures, indicative of their position in the network, have published more papers or have been cited more often.

In contrast to K-Core, by using degree of an author (‘Deg-Core’), I could more effectively reach the core of productive authors. The K-Core captured 16 researchers among the top 50 most productive researchers in the Malaysia network. Among the top 10 most productive researchers, it captured four. A similar analysis for the Turkey network, captured just one researcher in the top 50 and none in the top 10. In contrast, ‘Deg-core’ captured 41 of the top 50 most productive researchers in the Malaysia network and 18 in the Turkey network. It captured all 10 top performers in the Malaysia and as many as five among the top 10 in the Turkey network. A remarkable difference was observed in the pattern of Deg-Core of Turkey and Malaysia networks. Turkey’s Deg-Core is quite sparse in comparison with Malaysia's, even though the total number of authors in the giant component is larger than Malaysia's.

Motif-based communities could contain productive authors. Unlike other forms of community-based network detection, detection of motif-based communities identify and extract groups of vertices from within the connected network. On average, authors in the motif-based communities have performed better in terms of research performance when compared with all authors in the giant component. In the Malaysia network, this performance is significantly better than in Turkey.

2-mode network visualization depicts cognitive structure that displays both topics and authors. Important research focus areas (RFAs) were extracted from original keywords and linked with the authors more often using these words in their keyword list. By applying 2-mode network representation, RFAs and their association with prominent authors were visualized. Although few of these authors are dedicated to a focus area, most of the others have shown an interest in multiple focus areas. By providing a 2-mode representation, I believe that this network provides a more diverse cognitive structure than is available through 1-mode knowledge domain visualizations (KDVs).

5.1.1. Summary of key findings

All the seven reseach collaboration networks studied through the three case studies are small worlds – they possess high clustering coefficient and short geodesic distances. Geographical proximity matters in intra-national collaboration. This is true even after the proliferation of communications technology and internet in particular.

Internationally collaborated papers are cited more than locally co-authered papers. Popularity and position and prestige of nodes in the network have positive correlation with research performance. Structural holes values of 'efficiency' positively correlates with research performance and 'constraint' negatively. Tie-strength, degree and efficiency have significant effect on Research performance

Density is negatively correlated with size of giant component and the bigger the size of giant component, the more the geodesic distance. Factors other than just the number of nodes or edges being added into the network may be responsible in the faster formation of a giant component in collaboration networks.

In contrast to K-Core, by using degree of an author ('Deg-Core'), one could more effectively reach to the core of productive authors and motif-based communities could contain productive authors. 2-mode network visualization depicts cognitive structure that displays both research focus areas (RFA) and authors.

5.2 Limitations of the study

The study has been carried out in the ambit of certain limitations. Most of these limitations are common to the studies of research collaborations.

*Study limited to articles in Web of Science***.** One of the limitations of this study is its scope. I have taken into consideration only those publications that are indexed by ISI – WoS databases. However, researchers publish in several journals, many of which may not yet be part of WoS. A network would be more complete if there was a possibility of gathering all possible research articles published to date from all the researchers. As of date and for all practical reasons there is no single window or database that could index *all* the publications of researchers. Nonetheless, WoS represents peer-review journals. Although only selected articles of researchers are represented in WoS, the subject categorization provided by WoS, was useful in carving out the boundary.

Co-authorship is only a partial indicator of research collaboration. I use co-authorship to represent research collaboration. Studies have shown that such a proxy for research collaboration is only a partial indicator, as collaboration happens even when researchers have not co-authored a paper. However, using co-authorship to represent research collaboration is the most tangible and verifiable indicator of research collaboration. Representation of research collaboration using co-authorship must be seen in this light.

*WoS records update is a dynamic process***.** WoS authorities continually update the records for errors, either through self-checks or when reported by authors of the paper or by other researchers. Such updates are a dynamic process. However, our dataset was extracted from WoS SSCI certain specific dates (e.g. 4th Jan 2011, for case study 1), and only the entries in records available on this day have been considered in our study.

*Author name disambiguation***.** The disambiguation of author names is a difficult and unresolved issue in bibliometrics (Garfield, 1969; Tang & Walsh, 2010). In bibliometrics records, due to similarity of author names, two or more authors may be represented as one. Additionally, variations in author name can give the impression of one author being two or more. There have been several proposed solutions to this issue but they all suffer from drawbacks (*for a review* - (Smalheiser & Torvik, 2009). Tang and Walsh (2010) state that some studies simply avoid micro-level analysis, others indicate a method without elaborating on how author names issue is dealt with and still others show results and analysis, but keep the authorship identification in the black box. Manual cleaning seems to be a partial solution, however, even manual disambiguation is a surprisingly difficult process, even on a small scale, and is completely impractical for common names (Smalheiser & Torvik, 2009). Moreover, hand cleaning relies on institutional affiliation and full names, which is always a challenge. Even while using a standardized bibliometric database such as WoS, this is a perplexing issue. Before 2007, WoS did not have a "full author name" field; identification was based on an author's last name and initials. In addition, while identifying authors with their institutional affiliations in WoS, one can never be certain if they exactly match, except for the correspondence address (Tang & Walsh, 2010). For case study 1, the record size was small so I carried out hand cleaning. For case studies 2 and 3, although manual checks have been made for author name disambiguation, I have retained the data quality of WoS. WoS has "[met] the high standards of an objective evaluation process that eliminates clutter and excess and delivers data that is accurate, meaningful and timely. "Regarding author identification: "eliminating the problems of similar author names or several authors with the same name." Thomson Scientific, the publishers/aggregators of WoS has made its own internal disambiguation efforts on a massive scale (Smalheiser & Torvik, 2009). Quality of WoS database ensures that I are using a clean database. However, it still does not solve the problem of name variations or other issues related to the dynamic nature of WoS records.

5.3 Adding to the body of knowledge

The present study adds to the body of knowledge of research collaboration networks. The first case study, while providing a network view of research collaboration in a prominent discipline of a country that is preparing to become a developed nation, re-examines some of the longstanding questions in research collaborations, including the impact of centrality and social capital on research productivity and the importance of geographical proximity on frequency of collaboration. It then suggests a co-authorship strategy for researchers.

The second case study adds to the body of knowledge of social network analysis by examining one of the important topological characteristics: the giant component. That research collaboration accrues quantifiable benefits is largely understood. Giant component in a co-authorship network may represent core research activity within the academic community. While in some research collaboration networks, giant components form quickly, in others they may remain small and less well formed. By using a country-based context, I obtained further insights about whether other topological properties and the pace of paper production have any relationship with the size of giant components in research collaboration networks.

The third case study adds to the body of knowledge of social network analysis in four ways. First, it reasserts the significance of centrality and prestige measures on research performance. Second, it contrasts K-Core with degree of a node (Deg-Core) as a method to reach the core of productive authors. Third, it suggests another method of detecting communities: through motifs. Unlike other forms of communities, where the networks are partitioned based on the method chosen, our method extracts communities from the network based on the higher-threshold cliques. Finally, I applied a method to extract prominent research focus areas (RFAs) from author keywords and then link them with the prominent authors frequently mentioning these RFAs in their keyword list. The graph is depicted by a 2-mode network representation. Such a representation is both information-rich and clutter-free, which could be applied in future studies as a way of representing the cognitive structure of a discipline. The study contributes to the body of knowledge of energy fuels by providing an updated view on research collaboration in this field in two prominent OIC nations.

5.4 Future studies

Future avenues of research in this field could entail examining journals that are not indexed in the WoS, with research that could investigate the dynamics of network formation. Such a study would reveal nodes that have become inactive and those that have taken center stage at certain times. New research could also compare Malaysian researchers with their counterparts in other countries or in other disciplines. Authors' assortative mixing patterns based on other discrete parameters such as ethnicity, gender, age, or professional position could shed light on the role of the author's social-academic profile that unites or segregates researchers.

All the three case studies examine only one form of interaction: co-authorship in papers. Future studies could explore another important form of interaction – acquaintances among researchers. Although co-authors of a research paper are expected to know each other, it is also likely that researchers will be acquainted with other researchers, yet may not have ever co-authored a paper with them. A study along these lines could examine, for example, the extent to which acquaintance networks and co-authorship networks overlap.

Future researchers could also examine the temporal evolution of research collaborations and topic 'bursts' by studying a dataset with a larger time window. Suggestion on Deg-Core and clique-based communities must be tested with datasets representing other countries and disciplines.

Hopefully, these results would serve as input for asking deeper questions on the goal oriented social-behavioural aspect of researchers when strategizing networking among peers.

REFERENCES

Abbasi, A., Altmann, J., & Hossain, L. (2011). Identifying the effects of co-authorship networks on the performance of scholars: A correlation and regression analysis of performance measures and social network analysis measures. *Journal of Informetrics, 5*(4), 594-607.

Abbasi, A., Chung, K. S. K., & Hossain, L. (2011). Egocentric analysis of co-authorship network structure, position and performance. *Information Processing & Management*, *48*(4), 671-679.

Abbasi, A., Hossain, L., & Leydesdorff, L. (2012). Betweenness centrality as a driver of preferential attachment in the evolution of research collaboration networks. *Journal of Informetrics, 6*(3), 403-412. Abbasi, A., Hossain, L., Uddin, S., & Rasmussen, K. (2011). Evolutionary dynamics of scientific collaboration networks: multi-levels and cross-time analysis. *Scientometrics, 89*(2), 687-710.

Abbott, A. (2002). Dispute over first authorship lands researchers in dock. *Nature, 419*(6902), 4-4.

Abramo, G., D'Angelo, C. A., & Cicero, T. (2012). What is the appropriate length of the publication period over which to assess research performance? *Scientometrics, 93*(3), 1005-1017.

Abramo, G., D'Angelo, C. A., & Di Costa, F. (2011). Research productivity: Are higher academic ranks more productive than lower ones? *Scientometrics, 88*(3), 915-928.

Abrizah, A., & Wee, M. C. (2011). Malaysia's Computer Science research productivity based on publications in the Web of Science, 2000-2010. *Malaysian Journal of Library & Information Science, 16*(1), 109-124.

Adamic, L. A. (2000). Zipf, Power-laws, and Pareto - a ranking tutorial. *http://www.hpl.hp.com/research/idl/papers/ranking/ranking.htm*(5th Feb 2011).

Albert, R., & Barabasi, A. L. (2002). Statistical mechanics of complex networks. *Reviews of Modern Physics, 74*(1), 47-97.

Albert, R., Jeong, H., & Barabasi, A. L. (1999). Internet - Diameter of the World-Wide Web. *Nature, 401*(6749), 130-131.

Alcaide, G. G., Calatayud, V. A., Zurian, J. C. V., & Benavent, R. A. (2009). Participation of Women and Co-Authorship Networks in Spanish Sociology Journals. *Revista Espanola De Investigaciones Sociologicas*(126), 153-166.

Aldrich, H., & Zimmer, C. (1986). Entrepreneurship through social networks. *The art and science of entrepreneurship, 22,* 3-23.

Aleixandre-Benavent, R., Aleixandre-Tudo, J. L., Alcaide, G. G., Ferrer-Sapena, A., Aleixandre, J. L., & du Toit, W. (2012). Bibliometric analysis of publications by South African viticulture and oenology research centres. *South African Journal of Science, 108*(5-6), 74-84.

Amabile, T. M., Patterson, C., Mueller, J., Wojcik, T., Kramer, S. J., Odomirok, P. W., & Marsh, M. (2001). Academic-practitioner collaboration in management research: A case of cross-profession collaboration. *Academy of Management Journal, 44*(2), 418-431.

Andreas, S., Dangzhi, Z., & Tania, B. (2009). *Author name disambiguation for collaboration network analysis and visualization.* Paper presented at the Proceedings of The American Society for Information Science and Technology 2009 Annual Meeting, Vancouver, British Columbia, Canada, *46*(1), 1-20

Ardanuy, J. (2012). Scientific collaboration in Library and Information Science viewed through the Web of Knowledge: the Spanish case. *Scientometrics, 90*(3), 877-890.

Barabasi, A. L., & Albert, R. (1999). Emergence of scaling in random networks. *Science, 286*(5439), 509-512.

Barabasi, A. L., & Bonabeau, E. (2003). Scale-free networks. *Scientific American, 288*(5), 60-69.

Barabasi, A. L., Jeong, H., Neda, Z., Ravasz, E., Schubert, A., & Vicsek, T. (2002). Evolution of the social network of scientific collaborations. *Physica a-Statistical Mechanics and Its Applications, 311*(3-4), 590-614.

Barrat, A., Cattuto, C., Szomszor, M., Van den Broeck, W., & Alani, H. (2010). Social Dynamics in Conferences: Analyses of Data from the Live Social Semantics Application. In P. F. PatelSchneider, Y. Pan, P. Hitzler, P. Mika, L. Zhang, J. Z. Pan, I. Horrocks & B. Glimm (Eds.), *Semantic Web-Iswc 2010, Pt Ii* (Vol. 6497, pp. 17-33). Berlin: Springer-Verlag Berlin.

Batagelj, V., & Mrvar, A. (1998). Pajek-program for large network analysis. *Connections, 21*(2), 47-57.

Beaver, D. B. (2001). Reflections on scientific collaboration, (and its study): past, present, and future. *Scientometrics, 52*(3), 365-377.

Beaver, D. B., & Rosen, R. (1978). Studies in scientific collaboration. *Scientometrics, 1*(1), 65-84.

Beaver, D. B., & Rosen, R. (1979). Studies in scientific collaboration Part III. Professionalization and the natural history of modern scientific co-authorship. *Scientometrics, 1*(3), 231-245.

Bhandari, M., Einhorn, T. A., Swiontkowski, M. F., & Heckman, J. D. (2003). Who did what?:(Mis) perceptions about authors' contributions to scientific articles based on order of authorship. *The Journal of Bone and Joint Surgery, 85*(8), 1605.

Bilgili, M., & Simsek, E. (2012). Wind Energy Potential and Turbine Installations in Turkey. *Energy Sources, Part B: Economics, Planning, and Policy, 7*(2), 140-151.

Birnholtz, J. P. (2006). What does it mean to be an author? The intersection of credit, contribution, and collaboration in science. *Journal of the American Society for Information Science and Technology, 57*(13), 1758-1770.

Blakeslee, J. E., & Keller, T. E. (2012). Building the youth mentoring knowledge base: publishing trends and coauthorship networks. *Journal of Community Psychology, 40*(7), 845-859.

Borgatti, S. P. (2009). 2-mode concepts in social network analysis. *Encyclopedia of Complexity and System Science*.

Borgatti, S. P., Everett, M. G., & Freeman, L. C. (2002). Ucinet for Windows: Software for social network analysis.

Borgatti, S. P., & Foster, P. C. (2003). The network paradigm in organizational research: A review and typology. *Journal of Management*, *29*(6), 991-1013.

Borgatti, S. P., Mehra, A., Brass, D. J., & Labianca, G. (2009). Network Analysis in the Social Sciences. *Science, 323*(5916), 892-895.

Boyack, K. W., Klavans, R., & Börner, K. (2005). Mapping the backbone of science. *Scientometrics, 64*(3), 351-374.

Bradford, S. C. (1985). Sources of information on specific subjects. *Journal of Information Science, 10*(4), 173-180.

Breiger, R. L. (2004). The analysis of social networks. *Handbook of data analysis*, 505-526.

Bukvova, H. (2010). Studying research collaboration: a literature review. Sprouts: Working Papers on Information Systems, 10(3). http://sprouts.aisnet.org/10-3

Burt, R. S. (1997). The contingent value of social capital. *Administrative Science Quarterly, 42*(2), 339-365.

Cerroño, A. L. C., & Keynan, A. (1996). Scientific cooperation, state conflict: the roles of scientists in mitigating international discord. *Proceedings of the American Philosophical Society*. Annals of the New York Academy of Sciences, 866

Chinchilla-Rodriguez, Z., Ferligoj, A., Miguel, S., Kronegger, L., & de Moya-Anegon, F. (2012). Blockmodeling of co-authorship networks in library and information science in Argentina: a case study. *Scientometrics*, *93*(3), 699-717.

Christakis, N. A., & Fowler, J. H. (2007). The spread of obesity in a large social network over 32 years. *New England Journal of Medicine*, *357*(4), 370-379.

Clauset, A., Newman, M. E. J., & Moore, C. (2004). Finding community structure in very large networks. *Physical Review E, 70*(6), 066111.

Coleman, J. S. (1988). Social capital in the creation of human capital. *American Journal of Sociology*, 95-120.

Crane, D. (1972). *Invisible colleges: Diffusion of knowledge in scientific communities* (p.34) Chicago: University of Chicago Press.

Cronin, B. (2001). Hyperauthorship: A postmodern perversion or evidence of a structural shift in scholarly communication practices? *Journal of the American Society for Information Science and Technology, 52*(7), 558-569.

Cronin, B. (2004). Bowling alone together: Academic writing as distributed cognition. *Journal of the American Society for Information Science and Technology, 55*(6), 557-560.

Cronin, B., Shaw, D., & La Barre, K. (2003). A cast of thousands: Coauthorship and subauthorship collaboration in the 20th century as manifested in the scholarly journal literature of psychology and philosophy. *Journal of the American Society for Information Science and Technology*, *54*(9), 855-871.

Cummings, J. N., & Kiesler, S. (2007). Coordination costs and project outcomes in multi-university collaborations. *Research Policy, 36*(10), 1620-1634. de Souza, C. G., Barbastefano, R. G., & de Lima, L. S. (2012). Chemistry collaboration networks in Brazil: a coauthorship study in quimica nova articles. *Quimica Nova*, *35*(4), 671-676.

Demirkan, I., & Demirkan, S. (2012). Network Characteristics and Patenting in Biotechnology, 1990-2006. *Journal of Management*, *38*(6), 1892-1927.

Ding, Y. (2011). Scientific collaboration and endorsement: Network analysis of coauthorship and citation networks. *Journal of Informetrics, 5*(1), 187-203.

Dong, B. S., Xu, G. Q., Luo, X., Cai, Y., & Gao, W. (2012). A bibliometric analysis of solar power research from 1991 to 2010. *Scientometrics, 93*(3), 1101-1117.

Drenth, J. P. H. (1998). Multiple authorship. *JAMA: The Journal of the American Medical Association*, *280*(3), 219-221.

Dresselhaus, M., & Thomas, I. (2001). Alternative energy technologies. *Nature, 414*(6861), 332-337.

Durbach, I. N., Naidoo, D., & Mouton, J. (2008). Co-authorship networks in South African chemistry and mathematics. *South African Journal of Science, 104*(11-12), 487-492.

Eblen, M., Fabsitz, R. R., Olson, J. L., Pearson, K., Pool, L. R., Puggal, M., . . . Wagner, R. M. (2012). Social network analysis comparing researcher collaborations in two cardiovascular cohort studies. *Research Evaluation*, *21*(5), 392-405.

Erdős, P., & Rényi, A. (1959). On Random Graphs. I. *Publicationes Mathematicae*, ***6***, 290–297.

Erdős, P., & Rényi, A. (1960). The Evolution of Random Graphs. *Magyar Tud. Akad. Mat. Kutató Int. Közl.*, *5*, 17–61.

Etzkowitz, H. (2008). The triple helix: Industry, university, and government in innovation. *Social Science Information*, 42(3), 293-337

Etzkowitz, H., & Dzisah, J. (2008). Rethinking development: circulation in the triple helix. *Technology Analysis & Strategic Management, 20*(6), 653-666.

Etzkowitz, H., & Klofsten, M. (2005). The innovating region: toward a theory of knowledge-based regional development. *R&D Management, 35*(3), 243-255.

Fakhree, M. A. A., & Jouyban, A. (2011). Scientometric analysis of the major Iranian medical universities. *Scientometrics, 87*(1), 205-220.

Fatt, C. K., Abu Ujum, E., & Ratnavelu, K. (2010). The structure of collaboration in the Journal of Finance. *Scientometrics, 85*(3), 849-860.

Faust, K. (1997). Centrality in affiliation networks. *Social Networks, 19*(2), 157-191.

Fine, M. A., & Kurdek, L. A. (1993). Reflections on determining authorship credit and authorship order on faculty student collaborations. *American Psychologist, 48*(11), 1141-1147.

Fischbach, K., Putzke, J., & Schoder, D. (2011). Co-authorship networks in electronic markets research. *Electronic Markets, 21*(1), 19-40.

Fishbaugh, M. S. (1997). *Models of collaboration*. Boston: Allyn and Bacon.

Flanagin, A., Carey, L. A., Fontanarosa, P. B., Phillips, S. G., Pace, B. P., Lundberg, G. D., & Rennie, D. (1998). Prevalence of articles with honorary authors and ghost authors in peer-reviewed medical journals. *JAMA-Journal of the American Medical Association, 280*(3), 222-224.

Frame, J. D., & Carpenter, M. P. (1979). International research collaboration. *Social studies of Science, 9*(4), 481-497.

Fruchterman, T. M. J., Reingold, E. M. (1991).. Graph drawing by force-directed placement. *Software: Practice and experience*, 21(11), 1129-1164.

Garfield, E. (1969). British quest for uniqueness versus American egocentrism. *Nature, 223*, 763.

Garfield, E. (1980). Is citation analysis a legitimate evaluation tool - reply. *Scientometrics, 2*(1), 92-94.

Garg, K. C., & Padhi, P. (2001). A study of collaboration in laser science and technology. *Scientometrics, 51*(2), 415-427.

Girvan, M., & Newman, M. E. J. (2002). Community structure in social and biological networks. *Proceedings of the National Academy of Sciences of the United States of America, 99*(12), 7821-7826.

Glänzel, W., & Schubert, A. (2001). Double effort= double impact? A critical view at international co-authorship in chemistry. *Scientometrics, 50*(2), 199-214.

Glänzel, W., & Schubert, A. (2005). Analysing scientific networks through co-authorship. *Handbook of quantitative science and technology research,* 257-276.

Glänzel, W., Schubert, A., & Czerwon, H. J. (1999). A bibliometric analysis of international scientific cooperation of the European Union (1985–1995). *Scientometrics, 45*(2), 185-202.

Glänzel, W., & Thijs, B. (2011). Using 'core documents' for the representation of clusters and topics. *Scientometrics, 88*(1), 297-309.

Goffman, W. (1964). Generalization of epidemic theory. An application to the transmission of ideas: DTIC Document. Western Reserve Univ, Cleveland, Ohio

Gonzalez-Alcaide, G., Aleixandre-Benavent, R., & de Grande-Orive, J. I. (2010). A Study of the Bibliometry and Areas of the Research Groups of Archivos de Bronconeumologia (2003-2007). *Archivos De Bronconeumologia, 46*(2), 78-84.

Gonzalez-Alcaide, G., Park, J., Huamani, C., Gascon, J., & Ramos, J. M. (2012). Scientific authorships and collaboration network analysis on chagas disease: papers indexed in pubmed (1940-2009). *Revista Do Instituto De Medicina Tropical De Sao Paulo, 54*(4), 219-228.

Gossart, C., & Ozman, M. (2009). Co-authorship networks in social sciences: The case of Turkey. *Scientometrics, 78*(2), 323-345.

Graeml, A. R., Macada, M. A., & Rossoni, L. (2010). Intellectuals in social networks and information administration: Scientometric analysis of the period 1997-2006. *Informacao & Sociedade-Estudos, 20*(1), 95-110.

Granovetter, M.S. (1973). The Strength of Weak Ties. *The American Journal of Sociology, 78*(6), 1360-1380.

Grossman, J. W. (2002). The evolution of the mathematical research collaboration graph. *Congressus Numerantium*, 201-212.

Hagstrom, W. O. (1965). *The Scientific Community*. New York: Basic Books.

Hanneman, R. A., & Riddle, M. (2005). Introduction to social network methods: University of California Riverside. http://faculty.ucr.edu/~hanneman/nettext/

Harirchi, G., Melin, G., & Etemad, S. (2007). An exploratory study of the feature of Iranian co-authorships in biology, chemistry and physics. *Scientometrics, 72*(1), 11-24.

Hart, R. L. (2000). Co-authorship in the academic library literature: A survey of attitudes and behaviors. *Journal of Academic Librarianship, 26*(5), 339-345.

Hart, R. L. (2007). Collaboration and article quality in the literature of academic librarianship. *Journal of Academic Librarianship, 33*(2), 190-195.

Hassan, E. (2005). The evolution of the knowledge structure of fuel cells. *Scientometrics, 62*(2), 223-238.

Hassan, S. U., & Haddawy, P. (2013). Measuring international knowledge flows and scholarly impact of scientific research. *Scientometrics, 94*(1), 163-179.

Havemann, F., Heinz, M., & Kretschmer, H. (2006). Collaboration and distances between German immunological institutes–a trend analysis. *Journal of Biomedical Discovery and Collaboration, 1*(1), 6.

Haythornthwaite, C. (1996). Social network analysis: An approach and technique for the study of information exchange. *Library & Information Science Research, 18*(4), 323-342.

Heffner, A. G. (1981). Funded research, multiple authorship, and subauthorship collaboration in four disciplines. *Scientometrics*, *3*(1), 5-12.

Heidler, R. (2011). Cognitive and Social Structure of the Elite Collaboration Network of Astrophysics: A Case Study on Shifting Network Structures. *Minerva, 49*(4), 461-488.

Heimeriks, G., Horlesberger, M., & Van den Besselaar, P. (2003). Mapping communication and collaboration in heterogeneous research networks. *Scientometrics*, *58*(2), 391-413.

Heinze, T., & Kuhlmann, S. (2008). Across institutional boundaries? Research collaboration in German public sector nanoscience. *Research Policy, 37*(5), 888-899.

Hennemann, S. (2010). Hierarchies in the science and technology system of China - System reforms and their consequences for knowledge flows. *Geographische Zeitschrift, 98*(3), 155-174.

Hood, W. W., & Wilson, C. S. (2001). The literature of bibliometrics, scientometrics, and informetrics. *Scientometrics, 52*(2), 291-314.

Hou, H., Kretschmer, H., & Liu, Z. (2008). The structure of scientific collaboration networks in Scientometrics. *Scientometrics*, *75*(2), 189-202.

Hu, C., & Racherla, P. (2008). Visual representation of knowledge networks: A social network analysis of hospitality research domain. *International Journal of Hospitality Management, 27*(2), 302-312.

Huang, M. H., Dong, H. R., & Chen, D. Z. (2013). The unbalanced performance and regional differences in scientific and technological collaboration in the field of solar cells. *Scientometrics, 94*(1), 423-438.

Hwang, S. S., Song, H. H., Baik, J. H., Jung, S. L., Park, S. H., Choi, K. H., & Park, Y. H. (2003). Researcher Contributions and Fulfillment of ICMJE Authorship Criteria: Analysis of Author Contribution Lists in Research Articles with Multiple Authors Published in Radiology1. *Radiology, 226*(1), 16-23.

Jang, S.-L., Chen, L.-J., Chen, J. H., & Chiu, Y.-C. (2013). Innovation and production in the global solar photovoltaic industry. *Scientometrics, 94*(3), 1021-1036.

Jassawalla, A. R., & Sashittal, H. C. (1998). An Examination of Collaboration in High-Technology New Product Development Processes. *Journal of Product Innovation Management, 15*(3), 237-254.

Kadushin, C. (2011). *Understanding social networks: Theories, concepts, and findings*. New York: Oxford University Press.

Kang, I. S., Na, S. H., Lee, S., Jung, H., Kim, P., Sung, W. K., & Lee, J. H. (2009). On co-authorship for author disambiguation. *Information Processing & Management, 45*(1), 84-97.

Katz, J. S. (1994). Geographical proximity and scientific collaboration. *Scientometrics, 31*(1), 31-43.

Katz, J. S., & Martin, B. R. (1997). What is research collaboration? *Research Policy, 26*(1), 1-18.

Kliegl, R., & Bates, D. (2011). International collaboration in psychology is on the rise. *Scientometrics, 87*(1), 149-158.

Knoke, D., & Kuklinski, J. H. (1982). Network analysis. *Sage University paper Series on Quantitative Applications in the Social Sciences, nr. 07-028*.

Knudson, D. (2012). Twenty-year trends of authorship and sampling in applied biomechanics research. *Perceptual and Motor Skills, 114*(1), 16-20.

Koren, Y., & Harel, D. (2004). *Axis-by-axis stress minimization*. In Graph Drawing (pp. 450-459). Springer Berlin Heidelberg.

Kosslyn, S. M. (2006). *Graph design for the eye and mind*. New York: Oxford University Press, USA.

Krackhardt, D. (1992). The strength of strong ties: The importance of philos in organizations. *Networks and organizations: Structure, form, and action, 216*, 239.

Kretschmer, H. (2004). Author productivity and geodesic distance in bibliographic co-authorship networks, and visibility on the Web. *Scientometrics, 60*(3), 409-420.

Krichel, T., & Bakkalbasi, N. (2006). A social network analysis of research collaboration in the economics community. *Journal of Information Management and Scientometrics*, 3, 1-12.

Kromer, P., Snasel, V., Platos, J., Kudelka, M., Horak, Z. (2012). An ACO Inspired Weighting Approach for the Spectral Partitioning of Co-authorship Networks. *In Evolutionary Computation (CEC), 2012 IEEE Congress on* (pp. 1-7). IEEE.

Kronegger, L., Mali, F., Ferligoj, A., & Doreian, P. (2012). Collaboration structures in Slovenian scientific communities. *Scientometrics, 90*(2), 631-647.

Krumov, L., Fretter, C., Muller-Hannemann, M., Weihe, K., & Hutt, M. T. (2011). Motifs in co-authorship networks and their relation to the impact of scientific publications. *European Physical Journal B, 84*(4), 535-540.

Kuhn, T. S. (1996). *The structure of scientific revolutions* (Vol. 2). Chicago:University of Chicago press.

Kuzhabekova, A. (2011). *Impact of Co-authorship Strategies on Research Productivity: A Social-network Analysis of Publications in Russian Cardiology*. University of Minnesota.

Lambiotte, R., & Panzarasa, P. (2009). Communities, knowledge creation, and information diffusion. *Journal of Informetrics, 3*(3), 180-190.

Landry, R., Traore, N., & Godin, B. (1996). An econometric analysis of the effect of collaboration on academic research productivity. *Higher Education, 32*(3), 283-301.

Larsen, K. (2009). Co-authorship Networks in Development of Solar Cell Technology: International and Regional Knowledge Interaction. In A. E. Andersson, P. C. Cheshire & R. R. Stough (Eds.), *New Directions in Regional Economic Development* (pp. 347-372). New York: Springer.

Laudel, G. (2002). What do we measure by co-authorships? *Research Evaluation, 11*(1), 3-15.

Lee, D. H., Seo, I. W., Choe, H. C., & Kim, H. D. (2012). Collaboration network patterns and research performance: the case of Korean public research institutions. *Scientometrics, 91*(3), 925-942.

Lee, S., & Bozeman, B. (2005). The impact of research collaboration on scientific productivity. *Social studies of Science, 35*(5), 673-702.

Lemarchand, G. A. (2012). The long-term dynamics of co-authorship scientific networks: Iberoamerican countries (1973-2010). *Research Policy, 41*(2), 291-305.

Leung, K. (2007). The glory and tyranny of citation impact: An East Asian perspective. *The Academy of Management Journal ARCHIVE, 50*(3), 510-513.

Lewison, G., & Markusova, V. (2010). The evaluation of Russian cancer research. *Research Evaluation, 19*(2), 129-144.

Leydesdorff, L. (2001). *The Challenge of Scientometrics: The development, measurement, and self-organization of scientific communications*: Universal-Publishers/upublish.com.

Leydesdorff, L., & Rafols, I. (2009). A global map of science based on the ISI subject categories. *Journal of the American Society for Information Science and Technology, 60*(2), 348-362.

Leydesdorff, L., & Wagner, C. S. (2008). International collaboration in science and the formation of a core group. *Journal of Informetrics, 2*(4), 317-325.

Linton, C. F. (1977). A Set of Measures of Centrality Based on Betweenness. *Sociometry, 40*(1), 35-41.

Liu, X. M., Bollen, J., Nelson, M. L., & Van de Sompel, H. (2005). Co-authorship networks in the digital library research community. *Information Processing & Management, 41*(6), 1462-1480.

Lotka, A. J. (1926). The frequency distribution of scientific productivity. *Journal of Washington Academy Sciences*, 16, 317-323

Luukkonen, T., Persson, O., & Sivertsen, G. (1992). Understanding patterns of international scientific collaboration. *Science, Technology & Human Values, 17*(1), 101-126.

Mane, K. K., & Börner, K. (2004). Mapping topics and topic bursts in PNAS. *Proceedings of the National Academy of Sciences of the United States of America, 101*(Suppl 1), 5287.

Marusic, A., Bosnjak, L., & Jeroncic, A. (2011). A Systematic Review of Research on the Meaning, Ethics and Practices of Authorship across Scholarly Disciplines. *Plos One, 6*(9).

McKendry, P. (2002). Energy production from biomass (part 1): overview of biomass. *Bioresource technology, 83*(1), 37-46.

McPherson, M., Smith-Lovin, L., & Cook, J. M. (2001). Birds of a feather: Homophily in social networks. *Annual Review of Sociology*, 415-444.

Melin, G. (2000). Pragmatism and self-organization: research collaboration on the individual level. *Research Policy, 29*(1), 31-40.

Melin, G., & Persson, O. (1996). Studying research collaboration using co-authorships. *Scientometrics, 36*(3), 363-377.

Milgram, S. (1967). The Small World Problem. *Psychology Today, 1*, 61-67.

Milo, R., Shen-Orr, S., Itzkovitz, S., Kashtan, N., Chklovskii, D., & Alon, U. (2002). Network motifs: simple building blocks of complex networks. *Science Signaling, 298*(5594), 824.

Milojević, S., Sugimoto, C. R., Yan, E., & Ding, Y. (2011). The cognitive structure of library and information science: Analysis of article title words. *Journal of the American Society for Information Science and Technology, 62*(10), 1933-1953.

Miro, O., de la Iglesia, M. A. V., Pallas, R. M. C., Burillo-Putze, G., Julian, A., & Sanchez, F. J. M. (2012). Productivity of Spanish emergency physicians in the 5-year periods from 2005 to 2009 and 2000-2004. *Emergencias, 24*(3), 164-174.

Moody, J. (2004). The structure of a social science collaboration network: Disciplinary cohesion from 1963 to 1999. *American Sociological Review, 69*(2), 213-238.

Morel, C. M., Serruya, S. J., Penna, G. O., & Guimaraes, R. (2009). Co-authorship Network Analysis: A Powerful Tool for Strategic Planning of Research, Development and Capacity Building Programs on Neglected Diseases. *Plos Neglected Tropical Diseases, 3*(8).

Moreno, J. L. (1953). *Who shall survive?* . New York: Beacon House.

Morrison, P. S., Dobbie, G., & McDonald, F. J. (2003). Research collaboration among university scientists. *Higher Education Research & Development, 22*(3), 275-296.

Mowatt, G., Shirran, L., Grimshaw, J. J. M., Rennie, D., Flanagin, A., Yank, V., . . . Bero, L. A. (2002). Prevalence of honorary and ghost authorship in Cochrane reviews. *JAMA-Journal of the American Medical Association, 287*(21), 2769-2771.

Nalimov, V., & Mulchenko, B. (1969). Scientometrics. *Moscow: Nauka*.

Narin, F. (1991). Globalization of research, scholarly information, and patents–ten year trends. *The Serials Librarian, 21*(2-3), 33-44.

Narin, F., Stevens, K., & Whitlow, E. S. (1991). Scientific co-operation in Europe and the citation of multinationally authored papers. *Scientometrics, 21*(3), 313-323.

Newman, M. E. J. (2001a). Scientific collaboration networks. I. Network construction and fundamental results. *Physical Review E, 64*(1).

Newman, M. E. J. (2001b). Scientific collaboration networks. II. Shortest paths, weighted networks, and centrality. *Physical Review E, 64*(1).

Newman, M. E. J. (2001c). The structure of scientific collaboration networks. *Proceedings of the National Academy of Sciences of the United States of America, 98*(2), 404-409.

Newman, M. E. J. (2002). Assortative mixing in networks. *Physical Review Letters, 89*(20), 208701

Newman, M. E. J. (2003). The structure and function of complex networks. *SIAM Review, 45*(2), 167-256.

Newman, M. E. J. (2004a). Coauthorship networks and patterns of scientific collaboration. *Proceedings of the National Academy of Sciences of the United States of America, 101*, 5200-5205.

Newman, M. E. J. (2004b). Who is the best connected scientist? A study of scientific coauthorship networks. *Complex networks*, 337-370.

Newman, M. E. J. (2007). The mathematics of networks. *The new palgrave encyclopedia of economics*,2, 1-12.

Nikzad, M., Jamali, H. R., & Hariri, N. (2011). Patterns of Iranian co-authorship networks in social sciences: A comparative study. *Library & Information Science Research, 33*(4), 313-319.

Olmeda-Gomez, C., Perianes-Rodriguez, A., Ovalle-Perandones, M. A., & Moya-Anegon, F. (2008). Comparative analysis of university-government-enterprise co-authorship networks in three scientific domains in the region of Madrid. *Information Research-an International Electronic Journal, 13*(3). http://informationr.net/ir/13-3/paper352.html.

Otte, E., & Rousseau, R. (2002). Social network analysis: a powerful strategy, also for the information sciences. *Journal of Information Science, 28*(6), 441-453.

Ovalle-Perandones, M. A., Perianes-Rodriguez, A., & Olmeda-Gomez, C. (2009). *Hubs and Authorities in a Spanish Co-authorship Network*. Los Alamitos: IEEE Computer Soc., 514-518.

Ozel, B. (2012a). Collaboration structure and knowledge diffusion in Turkish management academia. *Scientometrics, 93*(1), 183-206. Ozel, B. (2012b). Individual cognitive structures and collaboration patterns in academia. *Scientometrics, 91*(2), 539-555.

Page, L., Brin, S., Motwani, R., & Winograd, T. (1999). The PageRank citation ranking: Bringing order to the web. Technical report, Stanford Digital Library Technologies Project.

Pao, M. L. (1982). Collaboration in computational musicology. *Journal of the American Society for Information Science, 33*(1), 38-43.

Pepe, A. (2008). Socio-epistemic analysis of scientific knowledge production in little science research. *tripleC, 6(2)*, 134-145.

Pepe, A., & Rodriguez, M. A. (2010). Collaboration in sensor network research: an in-depth longitudinal analysis of assortative mixing patterns. *Scientometrics, 84*(3), 687-701.

Perc, M. (2010). Growth and structure of Slovenia’s scientific collaboration network. *Journal of Informetrics, 4*(4), 475-482.

Perianes-Rodriguez, A., Olmeda-Gomez, C., & Moya-Anegon, F. (2010). Detecting, identifying and visualizing research groups in co-authorship networks. *Scientometrics, 82*(2), 307-319. Persson, O., Melin, G., Danell, R., & Kaloudis, A. (1997). Research collaboration at Nordic universities. *Scientometrics, 39*(2), 209-223.

Ponds, R., Van Oort, F., & Frenken, K. (2007). The geographical and institutional proximity of research collaboration*. *Papers in Regional Science, 86*(3), 423-443.

Poole, A. D., Bain, R. L., Cavallo, A., Larson, E. D., Macedo, I. C., Barnett, A. M., . . . Zweibel, K. (1992). *Renewable energy: sources for fuels and electricity*. Washington D.C.: Island Press.

Presser, S. (1980). Collaboration and the quality of research. *Social studies of Science, 10*(1), 95-101.

Price, D. S. (1963). Big science, little science. *Columbia University, New York*.

Price, D. S. (1965). Networks of Scientific Papers. *Science, 149*(3683), 510-515. Price, D. S. (1976). A general theory of bibliometric and other cumulative advantage processes. *Journal of the American Society for Information Science, 27*(5), 292-306.

Price, D. S., & Beaver, D. B. (1966). Collaboration in an invisible college. *American Psychologist, 21*(11), 1011.

Price, D. S., & Weber, L. (1961). Science since Babylon. *Physics Today, 14*, 46.

Pritchard, A. (1969). Statistical bibliography or bibliometrics. *Journal of documentation, 25*, 348.

Putnam, R. D. (2001). *Bowling alone*. New York:Simon & Schuster.

Quatman, C., & Chelladurai, P. (2008). The Social Construction of Knowledge in the Field of Sport Management: A Social Network Perspective. *Journal of Sport Management, 22*(6), 651-676.

Racherla, P., & Hu, C. (2010). A Social network Prespective of Tourism Research Collaborations. *Annals of Tourism Research, 37*(4), 1012-1034Radcliffe-Brown, A. R. (1940). On social structure. *The Journal of the Royal Anthropological Institute of Great Britain and Ireland, 70*(1), 1-12.

Reijers, H. A., Song, M., Romero, H., Dayal, U., Eder, J., & Koehler, J. (2009). A Collaboration and Productiveness Analysis of the BPM Community. In U. Dayal,

J. Eder, J. Koehler & H. A. Reijers (Eds.), *Business Process Management, Proceedings* (Vol. 5701, pp. 1-14). Berlin: Springer-Verlag Berlin.

Riesenberg, D., & Lundberg, G. D. (1990). The order of authorship: who's on first? *JAMA: the journal of the American Medical Association, 264*(14), 1857-1857.

Rousseau, B., & Rousseau, R. (2000). LOTKA: A program to fit a power law distribution to observed frequency data. *Cybermetrics: International Journal of Scientometrics, Informetrics and Bibliometrics*(4), 4.

Sakata, I., Sasaki, H., & Inoue, T. (2011). *Structure of international research collaboration in wind and solar energy*. Paper presented at the Industrial Engineering and Engineering Management (IEEM), 2011 IEEE International Conference,1053-1057

Sanz-Casado, E., Garcia-Zorita, J. C., Serrano-López, A. E., Larsen, B., & Ingwersen, P. Renewable energy research 1995–2009: a case study of wind power research in EU, Spain, Germany and Denmark. *Scientometrics*, 1-28.

Sci^{2,} T. (2009). Science of Science (Sci^{2}) tool: Indiana University and SciTech Strategies,http://sci.slis.indiana.edu.

Serenko, A., Bontis, N., & Grant, J. (2009). A scientometric analysis of the proceedings of the McMaster World Congress on the Management of Intellectual Capital and Innovation for the 1996-2008 period. *Journal of Intellectual Capital, 10*(1), 8-21.

Series, O. O. (2012). Current Stance of Energy Resources and Potential in OIC Member Countries. http:// eocaqig.oicvet.org/files/article/459.pdf.

SESRIC, T. (2010). Research and Scientific Development in OIC Countries. http://www.sesrtcic.org/files/article/394.pdf

Shrum, W., Genuth, J., & Chompalov, I. (2007). *Structures of scientific collaboration*. Cambridge:The MIT Press.

Smalheiser, N. R., & Torvik, V. I. (2009). Author name disambiguation. *Annual review of information science and technology, 43*(1), 1-43.

Smith, M. A., Shneiderman, B., Milic-Frayling, N., Mendes Rodrigues, E., Barash, V., Dunne, C., . . . Gleave, E. (2009). *Analyzing (social media) networks with NodeXL*. Paper presented at the Proceedings of the Fourth International Conference on Communities and Technologies. ACM, 255-264

Sonnenwald, D. H. (2003). *Expectations for a scientific collaboratory: a case study*. Proceedings of the 2003 international ACM SIGGROUP conference on Supporting group work. ACM, 68-74.

Sonnenwald, D. H. (2008). Scientific collaboration. *Annual Review of Information Science and Technology, 41*(1), 643-681.

Sooryamoorthy, R. (2011). Collaboration in south african engineering research. *South African Journal of Industrial Engineering, 22*(2), 18-26.

Sopian, K., Ali, B., & Asim, N. (2011). Strategies for renewable energy applications in the organization of Islamic conference (OIC) countries. *Renewable and Sustainable Energy Reviews, 15*(9), 4706-4725.

Subramanyam, K. (1983). Bibliometric studies of research collaboration: A review. *Journal of Information Science, 6*(1), 33-38.

Talukdar, D. (2011). Patterns of Research Productivity in the Business Ethics Literature: Insights from Analyses of Bibliometric Distributions. *Journal of Business Ethics, 98*(1), 137-151.

Tang, L., & Walsh, J. P. (2010). Bibliometric fingerprints: name disambiguation based on approximate structure equivalence of cognitive maps. *Scientometrics, 84*(3), 763-784.

Teodorescu, D., & Andrei, T. (2011). The growth of international collaboration in East European scholarly communities: a bibliometric analysis of journal articles published between 1989 and 2009. *Scientometrics, 89*(2), 711-722. Thomas, S. M. (1992). The Evaluation of Plant Biomass Research - A Case-study of the problems inherent in bibliometric indicators. *Scientometrics*, *23*(1), 149-167.

Torrisi, B. (2013). Academic productivity correlated with well-being at work. *Scientometrics*, *94(2)*, 801-815.

Tsay, M. Y. (2008). A bibliometric analysis of hydrogen energy literature, 1965-2005. *Scientometrics, 75*(3), 421-438.

Uddin, S., Hossain, L., Abbasi, A., & Rasmussen, K. (2012). Trend and efficiency analysis of co-authorship network. *Scientometrics, 90*(2), 687-699.

Uddin, S., Hossain, L., & Rasmussen, K. (2013). Network Effects on Scientific Collaborations. *Plos One, 8*(2).

Velden, T., Haque, A., & Lagoze, C. (2010). A new approach to analyzing patterns of collaboration in co-authorship networks: mesoscopic analysis and interpretation. *Scientometrics, 85*(1), 219-242.

Vidican, G., Woon, W. L., & Madnick, S. (2009). Measuring Innovation Using Bibliometric Techniques: The Case of Solar Photovoltaic Industry. Working paper CISL #2009-05, Sloan School of Management, MIT.

Vinluan, L. R. (2012). Research productivity in education and psychology in the Philippines and comparison with ASEAN countries. *Scientometrics, 91*(1), 277-294.

Wagner, C. S. (2005). Six case studies of international collaboration in science. *Scientometrics*, *62*(1), 3-26. Wagner, C. S., Brahmakulam, I., Jackson, B., Wong, A., & Yoda, T. (2001). Science and Technology Collaboration: Building Capability in Developing Countries: DTIC Document.

Wasserman, S., & Faust, K. (1994). *Social Network Analysis, Methods and Applications* (First edition ed.).Cambridge: Cambridge University Press.

Watts, D. J., & Strogatz, S. H. (1998). Collective dynamics of 'small-world' networks. *Nature, 393*(6684), 440-442.

Wislar, J. S., Flanagin, A., Fontanarosa, P. B., & DeAngelis, C. D. (2011). Honorary and ghost authorship in high impact biomedical journals: a cross sectional survey. *British Medical Journal, 343*.

Wray, K. B. (2006). Scientific authorship in the age of collaborative research. *Studies in History and Philosophy of Science, 37*(3), 505-514.

Yan, E. J., & Ding, Y. (2009). Applying Centrality Measures to Impact Analysis: A Coauthorship Network Analysis. *Journal of the American Society for Information Science and Technology, 60*(10), 2107-2118.

Yan, E. J., Ding, Y., & Zhu, Q. H. (2010). Mapping library and information science in China: a coauthorship network analysis. *Scientometrics, 83*(1), 115-131.

Ye, Q., Li, T., & Law, R. (2013). A co-authorship network analysis of tourism and hospitality research collaboration. *Journal of Hospitality & Tourism Research, 37*(1), 51-76.

Yin, L. C., Kretschmer, H., Hanneman, R. A., & Liu, Z. Y. (2006). Connection and stratification in research collaboration: An analysis of the COLLNET network. *Information Processing & Management, 42*(6), 1599-1613.

Zaki, S. A., Taqi, S. A., Sami, L. B., & Nilofer, A. R. (2012). Ethical guidelines on authorship. *Indian Journal of Dental Research, 23*(2), 292.

Zheng, J., Zhao, Z. Y., Zhang, X., Chen, D. Z., Huang, M. H., Lei, X. P., . . . Zhao, Y. H. (2012). International scientific and technological collaboration of China from 2004 to 2008: a perspective from paper and patent analysis. *Scientometrics, 91*(1), 65-80.

Zipf, G. K. (1949). Human behavior and the principle of least effort:An Introduction to Human Ecology. Cambridge, Massachusetts: Addison Wesley.

Zuckerman, H. (1967). Nobel laureates in science: Patterns of productivity, collaboration, and authorship. *American Sociological Review*, 391-403.

Zuckerman, H. (1968). Patterns of name ordering among authors of scientific papers: A study of social symbolism and its ambiguity. *American Journal of Sociology*, 276-291.

APPENDIX

Annexure A: Common terms

Scientometrics: The study of the literature of science and technology. It includes all quantitative aspects of the science of science, communications in science and science policy (Hood & Wilson, 2001).

Collaboration: The coming together of diverse interests and people to achieve a common purpose in terms of interactions, information sharing and co-ordination of activities (Melin & Persson, 1996).

Research collaboration: A special form of collaboration, undertaken for the purpose of scientific research (Bukvova, 2010).

Social Networks: A special class of networks where a set of people are connected through some kind of relationship.

Social Capital: Value contained in the social relationships.

Social Network Analysis: A set of established algorithms used for the analysis and visualization of social networks.

Co-authorship Networks: A social network formed when two or more researchers co-author a paper. Authors form nodes; the paper they write is the relationship or edge between them.

Structure of a Network: The organization of the network based on its topological properties.

Topological Properties of a network: The global and local properties of a network. Global properties include degree distribution, density, diameter, average geodesic distance, clustering coefficient. Local properties include centrality measures, such as degree, closeness centrality, betweenness centrality and Pagerank (these terms are defined in Chapter 3)

Giant Component: The largest component in a network. In a co-authorship network it represents a core activity.

Small-World Networks: Networks with a smaller mean distance.

Scale-Free Networks: Networks that have "hubs" or few nodes with many connections and others having one or only a few connections

Assortative mixing: Where individuals associate with similar others.

Preferential attachment: Similar to assortative mixing, it is the tendency of less-connected individuals (or nodes) to connect to better-connected individuals (or nodes).

Geographical proximity: Physical nearness between two nodes.

Note:

"Scholarly networks", "research collaboration networks", "co-authorship networks" are interchangeable terms used in the study.

Annexure B: Institutional Collaboration – Centrality measures and organzational category (RQ1)

Vertex	Degree	Betweenness Centrality	Closeness Centrality	PageRank	Clustering Coefficient	Works	Citations	Organizational Category	Country
UPM	20	1303.121	0.007	5.339	0.065	41	153	Public	Malaysia
UTM	16	795.602	0.006	4.093	0.099	21	75	Public	Malaysia
USM	13	457.66	0.004	3.41	0.109	21	108	Public	Malaysia
UM	13	699.752	0.006	3.351	0.127	40	121	Public	Malaysia
UKM	14	875.931	0.006	3.347	0.136	44	111	Public	Malaysia
Monash	7	25	0.091	2.293	0.19	4	1	Private	Malaysia
UUM	9	337.212	0.005	2.178	0.143	17	9	Public	Malaysia
UNiM	7	333	0.004	2.142	0.1	10	41	Private	Malaysia
UiTM	8	149.333	0.005	2.001	0.267	9	0	Public	Malaysia
Monash Univ	5	14	0.077	1.61	0.4	2	8	Foreign University	Australia
Kianan Univ	2	1	0.5	1.459	0	2	0	Foreign University	Taiwan
Univ S Australia	6	201	0.004	1.428	0.5	3	0	Foreign University	Australia
IIUM	5	108.34	0.005	1.372	0.4	3	8	Public	Malaysia
MMU	5	175.224	0.005	1.366	0.5	3	4	Private	Malaysia
Catholic Univ Leuven	3	0	1	1.298	0	4	48	Foreign University	Belgium
UTAR	5	82	0.004	1.255	0	7	0	Private	Malaysia
Univ Nottingham	5	384	0.004	1.158	0.333	5	12	Foreign University	UK
Ft Hays State Univ	4	36.507	0.004	1.126	0.333	3	31	Foreign University	USA
Qatar Univ	4	46.667	0.005	1.115	0.5	2	12	Foreign University	Qatar
UNIMAS	3	136	0.003	1.057	0.333	2	0	Public	Malaysia
UMS	3	0	1	1	0	4	18	Public	Malaysia
Univ Aberdeen	3	0	1	1	0	2	0	Foreign University	UK

Vertex	Degree	Betweenness Centrality	Closeness Centrality	PageRank	Clustering Coefficient	Works	Citations	Organizational Category	Country
Sunway	1	0	1	1	0	1	0	Private	Malaysia
Taylor	1	0	1	1	0	1	0	Private	Malaysia
OWW Consulting	1	0	1	1	0	4	2	Company	Malaysia
Zinkin Ettinger Consulting Sdn Bhd	1	0	1	1	0	2	2	Company	Malaysia
Ritsumeikan Asia Pacific Univ	1	0	1	1	0	1	0	Foreign University	Japan
MUST	1	0	1	1	0	1	0	Private	Malaysia
Univ Salford	1	0	1	1	0	2	2	Foreign University	UK
UTeM	1	0	1	1	0	1	2	Public	Malaysia
Minist Nat Resources & Environm	1	0	1	1	0	1	0	Government	Malaysia
Univ Strathclyde	1	0	1	1	0	1	0	Foreign University	UK
Inst Putra	1	0	1	1	0	1	3	Private College	Malaysia
Louisiana State Univ	1	0	1	1	0	1	3	Foreign University	USA
Cranfield Univ	1	0	1	1	0	1	8	Foreign University	UK
Pricewaterhouse Coopers	1	0	1	1	0	1	8	Company	Malaysia
Minist Sci Technol & Environm	1	0	1	1	0	1	14	Government	Malaysia
Univ Tokyo	1	0	1	1	0	1	14	Foreign University	Japan
City Univ Hong Kong	1	0	1	1	0	2	36	Foreign University	Peoples R China
Asia Pacific Ctr Org Dev	1	0	1	1	0	1	36	Institute	Malaysia
Univ London Queen Mary Coll	1	0	1	1	0	1	4	Foreign University	UK

Vertex	Degree	Betweenness Centrality	Closeness Centrality	PageRank	Clustering Coefficient	Works	Citations	Organizational Category	Country
STAR	1	0	1	1	0	2	4	Company	Malaysia
SCH ACCOUNTANCY	1	0	1	1	0	1	0	Company	Malaysia
Indian Inst Technol	1	0	1	1	0	1	0	Foreign Institute	India
MSU	2	0	0	1	0	3	3	Private	Malaysia
Swinburne Univ Technol	3	0	0.067	0.98	1	1	0	Foreign University	Australia
Univ Leeds	3	0	0.067	0.98	1	1	0	Foreign University	UK
Univ Bath	2	69	0.003	0.909	0	2	7	Foreign University	UK
Stanford Univ	3	6.5	0.005	0.9	0.667	4	75	Foreign University	USA
Nanyang Technol Univ	3	7	0.004	0.889	0.333	3	8	Foreign University	Singapore
Univ Western Ontario	4	0	0.004	0.882	1	2	20	Foreign University	Canada
Old Dominion Univ	4	0	0.003	0.88	1	3	26	Foreign University	USA
Temple Univ	3	0	0.004	0.879	1	1	0	Foreign University	Japan
Zurich Univ Appl Sci	3	0	0.004	0.879	1	1	0	Foreign University	Switzerland
USIM	3	0	0.005	0.868	1	1	1	Public	Malaysia
INCEIF	3	0	0.005	0.868	1	1	0	Private	Malaysia
BUCME	3	0	0.004	0.856	1	2	1	Private	Malaysia
Minist Hlth	3	0	0.004	0.854	1	1	0	Government	Malaysia
Natl Heart Inst	3	0	0.004	0.854	1	1	0	Institute	Malaysia
Aston Univ	3	52.15	0.005	0.846	0.667	2	1	Foreign University	UK
Cardiff Univ	2	69	0.005	0.808	0	2	0	Foreign University	UK

Vertex	Degree	Betweenness Centrality	Closeness Centrality	PageRank	Clustering Coefficient	Works	Citations	Organizational Category	Country
Univ Lancaster	2	69	0.005	0.808	0	2	52	Foreign University	UK
Univ Manchester	2	69	0.004	0.806	0	2	3	Foreign University	UK
SAS Malaysia	2	0	0.003	0.789	1	1	24	Company	Malaysia
Open Univ	2	0	0.003	0.789	1	1	24	Foreign University	Peoples R China
Dept Educ	2	0	0.003	0.782	1	1	0	Government	Malaysia
Murdoch Univ	2	0	0.003	0.782	1	1	0	Foreign University	Australia
Da Yeh Univ	1	0	0.333	0.77	0	1	0	Foreign University	Taiwan
SUNY Buffalo	1	0	0.333	0.77	0	1	0	Foreign University	USA
NIDA	2	0	0.056	0.745	1	1	0	Foreign Institute	Thailand
Claremont Grad Univ	2	0	0.056	0.745	1	1	0	Foreign University	USA
Wolverhampton Univ	3	0	0.053	0.745	0	2	0	Foreign University	UK
MALAYSIAN IND DEV AUTHOR	2	0	0.05	0.737	1	1	8	Government	Malaysia
Brunel Univ	2	0	0.05	0.737	1	1	8	Foreign University	UK
RUBBER RES INST MALAYSIA	1	0	1	0.702	0	2	24	Institute	Malaysia
Univ Tennessee	2	0	0.003	0.681	1	1	0	Foreign University	USA
Univ Arkansas	2	0	0.003	0.681	1	1	0	Foreign University	USA
UMIST	2	0	0.003	0.681	1	1	2	Foreign University	UK
Univ Liverpool	2	0	0.003	0.681	1	1	2	Foreign University	UK

Vertex	Degree	Betweenness Centrality	Closeness Centrality	PageRank	Clustering Coefficient	Works	Citations	Organizational Category	Country
UTHM	2	0	0.004	0.664	1	1	0	Public	Malaysia
Thammasat Univ	2	0	0.004	0.664	1	1	0	Foreign University	Thailand
Univ Osaka Prefecture	3	0	0.004	0.664	0	2	38	Foreign University	Japan
Univ Loughborough	3	0	0.004	0.663	0	3	10	Foreign University	UK
Univ Illinois	2	0	0.005	0.644	1	1	1	Foreign University	USA
Univ Kentucky	2	0	0.004	0.641	1	1	31	Foreign University	USA
St Cloud State Univ	2	0	0.004	0.641	1	1	31	Foreign University	USA
Minerals & Geosci Dept	2	0	0.005	0.626	1	1	0	Government	Malaysia
Univ Alicante	2	0	0.005	0.621	1	1	0	Foreign University	Spain
Univ Pittsburgh	2	0	0.004	0.619	1	1	10	Foreign University	USA
Murray State Univ	2	0	0.004	0.618	1	1	0	Foreign University	USA
Putra Int Coll	2	0	0.004	0.614	1	1	1	Company	Malaysia
Thames Valley Univ	1	0	0.002	0.537	0	2	4	Foreign University	UK
OUM	1	0	0.003	0.494	0	1	0	Private	Malaysia
UNISZA	1	0	0.003	0.494	0	1	2	Public	Malaysia
Govt Malaysia	1	0	0.003	0.493	0	1	2	Government	Malaysia
St Francis Xavier Univ	1	0	0.003	0.453	0	1	0	Foreign University	Canada
Curtin Univ Technol	1	0	0.053	0.428	0	1	1	Foreign University	Australia
INTI-IU	1	0	0.003	0.417	0	1	0	Private	Malaysia

Vertex	Degree	Betweenness Centrality	Closeness Centrality	PageRank	Clustering Coefficient	Works	Citations	Organizational Category	Country
Lembaga Akreditasi Negara	1	0	0.003	0.393	0	1	0	Government	Malaysia
Ipoh Branch Off	1	0	0.003	0.393	0	1	0	Government	Malaysia
Natl Inst Bank Management	1	0	0.003	0.392	0	1	7	Foreign Institute	India
Univ London Kings Coll	1	0	0.003	0.392	0	1	6	Foreign University	UK
Univ Bradford	1	0	0.005	0.389	0	1	0	Foreign University	UK
Univ Kelaniya	1	0	0.005	0.389	0	1	1	Foreign University	Sri Lanka
Al alBayt Univ	1	0	0.005	0.389	0	1	1	Foreign University	Jordan
UNITAR	1	0	0.005	0.389	0	1	0	Private	Malaysia
Govt Orissa	1	0	0.004	0.387	0	1	0	Foreign Govt.	India
Q Tech Advances	1	0	0.004	0.387	0	1	4	Company	Malaysia
Sonoma State Univ	1	0	0.004	0.382	0	1	0	Foreign University	USA
Univ Birmingham	1	0	0.004	0.382	0	1	11	Foreign University	UK
UMP	1	0	0.004	0.381	0	1	0	Public	Malaysia

Annexure C: Institutional Collaboration – Strength of ties between Institutions (RQ1)

Vertex 1	Vertex 2	Edge Weight
UPM	UPM	18
UPM	Univ Bradford	2
UUM	UMP	2
UUM	UUM	9
Univ Illinois	UPM	1
Univ Illinois	Stanford Univ	1
UPM	Stanford Univ	1
Temple Univ	Zurich Univ Appl Sci	1
Temple Univ	Univ S Australia	1
Temple Univ	UM	1
Zurich Univ Appl Sci	Univ S Australia	1
Zurich Univ Appl Sci	UM	1
Univ S Australia	UM	1
UKM	UKM	31
Murray State Univ	Qatar Univ	1
Murray State Univ	UUM	1
Qatar Univ	UUM	1
USM	USM	10
UiTM	UiTM	3
IIUM	USIM	1
IIUM	UPM	3
IIUM	INCEIF	1
USIM	UPM	1
USIM	INCEIF	1
UPM	INCEIF	1
UM	UM	13
UTM	Sonoma State Univ	2
UTM	UTM	7
Sunway	Taylor	1
USM	Univ Tennessee	1
USM	Univ Arkansas	1
Univ Tennessee	Univ Arkansas	1
UTAR	UTM	1
UM	Govt Orissa	2
UTAR	UTAR	3
UTAR	INTI-IU	3
UKM	Aston Univ	1
UKM	Univ Nottingham	1
Aston Univ	Univ Nottingham	1
MSU	MSU	3
UNIMAS	Univ S Australia	2
Univ S Australia	Univ S Australia	1
UMS	Univ Aberdeen	2

Vertex 1	Vertex 2	Edge Weight
Univ Aberdeen	Univ Aberdeen	1
Cardiff Univ	OUM	1
UUM	UTM	4
Minerals & Geosci Dept	UPM	1
Minerals & Geosci Dept	UM	1
UPM	UM	1
UTHM	UTM	2
UTHM	Thammasat Univ	1
UTM	Thammasat Univ	2
OWW Consulting	Zinkin Ettinger Consulting Sdn Bhd	2
Ritsumeikan Asia Pacific Univ	MUST	1
MMU	Putra Int Coll	1
MMU	UTM	2
Putra Int Coll	UTM	1
Da Yeh Univ	Kianan Univ	1
Kianan Univ	SUNY Buffalo	2
Univ Kelaniya	UPM	1
UNIMAS	Dept Educ	1
UNIMAS	Murdoch Univ	1
Dept Educ	Murdoch Univ	1
UTM	UPM	3
UTM	Univ Alicante	1
UPM	Univ Alicante	1
Univ Salford	UTeM	1
UNiM	Univ Bath	1
UPM	Al alBayt Univ	1
Minist Nat Resources & Environm	Univ Strathclyde	1
Inst Putra	Louisiana State Univ	1
Univ Manchester	UM	1
UNITAR	UPM	1
UiTM	Lembaga Akreditasi Negara	2
UiTM	Ipoh Branch Off	2
UPM	Cardiff Univ	1
Wolverhampton Univ	Monash	2
Wolverhampton Univ	Wolverhampton Univ	1
Swinburne Univ Technol	Monash Univ	1
Swinburne Univ Technol	Monash	1
Swinburne Univ Technol	Univ Leeds	1
Monash Univ	Monash	1
Monash Univ	Univ Leeds	1
Monash	Univ Leeds	1
UPM	UKM	3
NIDA	Monash	1
NIDA	Claremont Grad Univ	1
Monash	Claremont Grad Univ	1

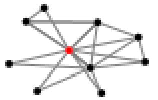
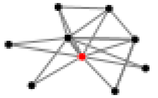
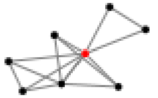
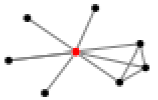
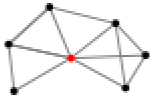
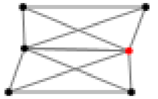
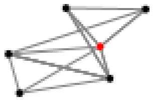
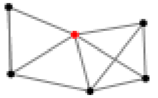
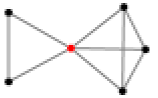
Vertex 1	Vertex 2	Edge Weight
UNiM	UNiM	3
MMU	USM	1
MMU	BUCME	1
USM	BUCME	1
USM	UTM	1
BUCME	UTM	1
UKM	Univ Western Ontario	2
UKM	Univ Pittsburgh	1
Univ Western Ontario	Univ Pittsburgh	2
Univ Western Ontario	Univ Western Ontario	1
UKM	UUM	4
UTAR	Nanyang Technol Univ	1
Monash	Curtin Univ Technol	1
UNiM	SAS Malaysia	1
UNiM	Open Univ	1
SAS Malaysia	Open Univ	1
Univ Loughborough	UUM	3
Univ Nottingham	Univ Nottingham	2
Univ Nottingham	UNiM	4
Qatar Univ	UPM	2
Qatar Univ	UTM	1
UMS	UMS	3
UUM	Aston Univ	1
UNISZA	Univ Lancaster	1
Thames Valley Univ	Univ Bath	1
Ft Hays State Univ	USM	3
Ft Hays State Univ	Old Dominion Univ	3
USM	Old Dominion Univ	4
Old Dominion Univ	Old Dominion Univ	1
MMU	UPM	1
Cranfield Univ	Pricewaterhouse Coopers	1
UMIST	USM	1
UMIST	Univ Liverpool	1
USM	Univ Liverpool	1
IIUM	Ft Hays State Univ	1
IIUM	Nanyang Technol Univ	1
Ft Hays State Univ	Nanyang Technol Univ	1
Univ Loughborough	Univ Loughborough	1
UM	Q Tech Advances	1
St Francis Xavier Univ	UNiM	1
UTM	Univ Birmingham	1
Minist Hlth	UiTM	1
Minist Hlth	Natl Heart Inst	1
Minist Hlth	UKM	1
UiTM	Natl Heart Inst	1

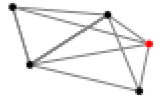
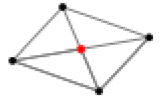
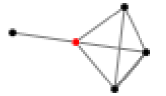
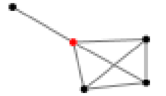
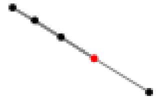
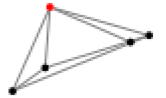
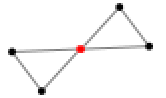
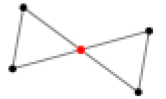
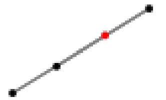
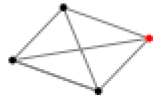
Vertex 1	Vertex 2	Edge Weight
UiTM	UKM	4
Natl Heart Inst	UKM	1
UKM	UM	5
UiTM	UM	1
Minist Sci Technol & Environm	Univ Tokyo	1
UPM	Univ Lancaster	1
City Univ Hong Kong	Asia Pacific Ctr Org Dev	1
Govt Malaysia	Univ Manchester	1
UTM	Univ Osaka Prefecture	4
Univ Osaka Prefecture	Univ Osaka Prefecture	1
Univ London Queen Mary Coll	STAR	1
MALAYSIAN IND DEV AUTHOR	Brunel Univ	1
MALAYSIAN IND DEV AUTHOR	Monash Univ	1
Brunel Univ	Monash Univ	1
Natl Inst Bank Management	USM	1
SCH ACCOUNTANCY	Indian Inst Technol	1
Univ London Kings Coll	USM	1
RUBBER RES INST MALAYSIA	Catholic Univ Leuven	4
Catholic Univ Leuven	Catholic Univ Leuven	2
UM	Stanford Univ	3
Univ Kentucky	UKM	1
Univ Kentucky	St Cloud State Univ	1
UKM	St Cloud State Univ	1

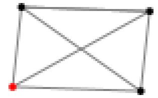
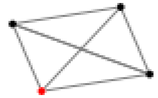
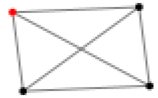
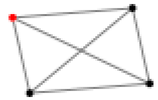
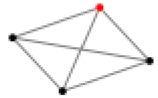
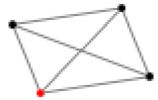
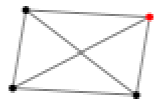
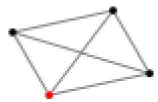
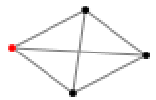
Annexure D: International collaboration – strength of ties between countries (RQ1)

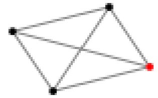
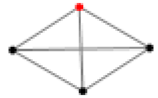
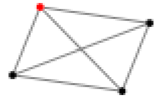
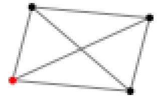
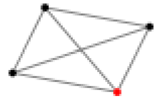
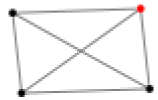
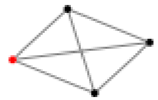
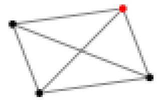
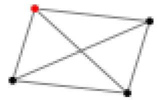
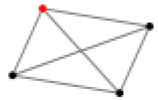
Vertex 1	Vertex 2	Edge Weight
Malaysia	Malaysia	172
Malaysia	UK	33
USA	Malaysia	23
Australia	Malaysia	9
UK	UK	8
USA	USA	7
Japan	Malaysia	7
Qatar	Malaysia	4
Malaysia	India	4
Malaysia	Thailand	4
Malaysia	Belgium	4
Australia	UK	3
Malaysia	Canada	3
Malaysia	Peoples R China	3
Australia	Australia	2
Taiwan	USA	2
Malaysia	Spain	2
Canada	USA	2
Malaysia	Singapore	2
Belgium	Belgium	2
Japan	Switzerland	1
Japan	Australia	1
Switzerland	Australia	1
Switzerland	Malaysia	1
USA	Qatar	1
Taiwan	Taiwan	1
Sri Lanka	Malaysia	1
Malaysia	Jordan	1
Thailand	USA	1
Canada	Canada	1
USA	Singapore	1
Japan	Japan	1

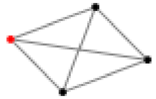
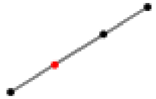
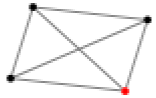
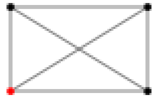
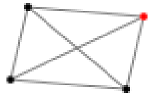
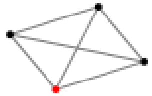
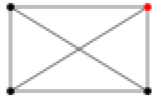
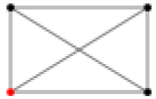
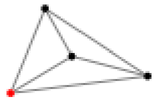
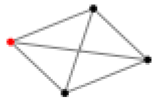
Annexure E: Individual collaboration – centrality, structural holes, tie strength and sub-graph (ego) of each node (RQ1)

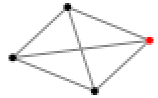
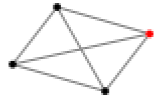
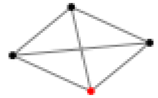
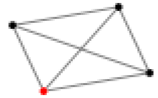
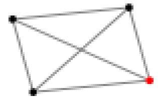
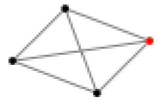
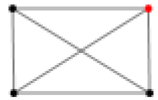
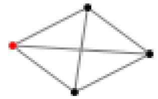
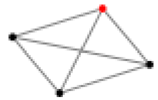
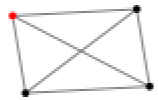
Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Abdullah, M	9	41.000	1.987	UKM	7	11	14	1.555556	0.724	0.398	
Husain, N	8	31.083	1.786	UKM	5	5	11	1.375	0.645	0.509	
Ahmed, ZU	7	12.000	1.911	Ft Hays State Univ	3	31	8	1.142857	0.714	0.418	
Yusof, SM	7	18.000	2.735	UTM	5	17	8	1.142857	0.893	0.24	
Krishnan, SK	6	15.500	1.337	UKM	3	7	7	1.166667	0.69	0.487	
Johnson, JP	5	2.000	1.349	Old Dominion Univ	2	23	6	1.2	0.533	0.617	
Agus, A	5	2.250	1.105	UKM	6	21	8	1.6	0.688	0.596	
Chinna, K	5	11.917	1.142	UiTM	2	0	5	1	0.62	0.584	
Zain, M	5	6.000	1.604	Qatar Univ	2	12	5	1	0.68	0.513	

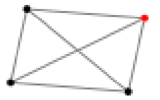
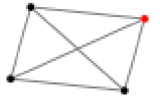
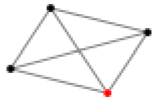
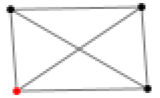
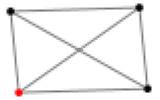
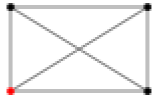
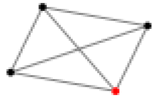
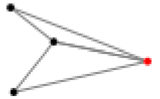
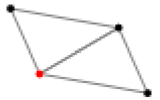
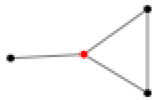
Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Sagir, RM	4	1.667	0.919	UKM	2	9	4	1	0.578	0.854	
Kadir, SLSA	4	0.583	0.909	UM	3	7	6	1.5	0.542	0.739	
Idris, F	4	48.000	0.959	UKM	2	3	4	1	0.719	0.674	
Musa, G	4	3.000	1.420	UM	2	1	4	1	0.625	0.583	
Abu Bakar, N	4	3.000	1.420	UTM	2	1	4	1	0.625	0.583	
Ali, KAM	4	39.000	1.111	UKM	2	1	4	1	0.625	0.583	
Ang, CL	4	4.000	1.596	UUM	2	3	4	1	0.75	0.563	
Sambasivan, M	4	4.000	1.596	UPM	2	0	4	1	0.75	0.563	
Mohamad, O	3	0.000	0.853	USM	1	20	3	1	0.444	0.997	
Tan, B	3	0.000	0.853	USM	1	20	3	1	0.444	0.997	

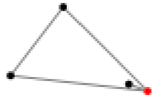
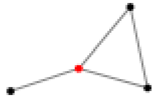
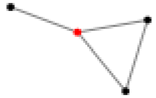
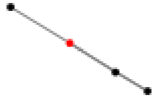
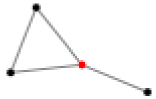
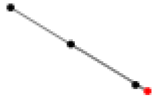
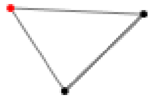
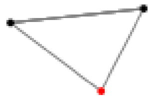
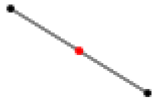
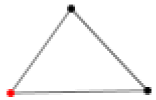
Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Mohamed, O	3	0.000	0.853	Old Dominion Univ	1	3	3	1	0.444	0.997	
Meng, LY	3	0.000	0.853	USM	1	3	3	1	0.444	0.997	
Zakuan, NM	3	0.000	1.112	UTHM	1	0	3	1	0.333	0.926	
Laosirihongthong, T	3	0.000	1.112	Thammasat Univ	1	0	3	1	0.333	0.926	
Shaharoun, AM	3	0.000	1.112	UTM	1	0	3	1	0.333	0.926	
Safa, MS	3	0.000	1.043	BUCME	2	1	3	1	0.333	0.926	
Boon, OK	3	0.000	1.043	MMU	1	1	3	1	0.333	0.926	
Arumugam, V	3	0.000	1.043	USM	1	1	3	1	0.333	0.926	
Dinnie, K	3	0.000	1.043	Temple Univ	1	0	3	1	0.333	0.926	
Melewar, TC	3	0.000	1.043	Zurich Univ Appl Sci	1	0	3	1	0.333	0.926	

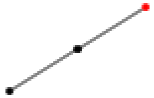
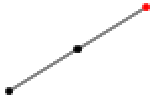
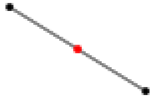
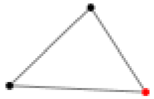
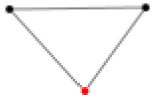
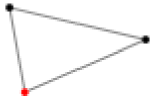
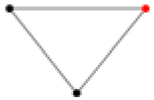
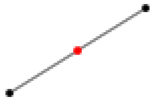
Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Seidenfuss, KU	3	0.000	1.043	Univ S Australia	1	0	3	1	0.333	0.926	
Ooi, KB	3	0.000	1.000	UTAR	2	0	3	1	0.333	0.926	
Tan, BI	3	0.000	1.000	UTAR	2	0	3	1	0.333	0.926	
Deris, SB	3	0.000	1.000	UTM	1	19	3	1	0.333	0.926	
Omatu, S	3	0.000	1.000	Univ Osaka Prefecture	1	19	3	1	0.333	0.926	
Ohta, H	3	0.000	1.000	Univ Osaka Prefecture	1	19	3	1	0.333	0.926	
Samat, PABD	3	0.000	1.000	UTM	1	19	3	1	0.333	0.926	
Ainuddin, RA	3	0.000	1.000	UKM	1	10	3	1	0.333	0.926	
Beamish, PW	3	0.000	1.000	Univ Western Ontario	1	10	3	1	0.333	0.926	
Hulland, JS	3	0.000	1.000	Univ Pittsburgh	1	10	3	1	0.333	0.926	

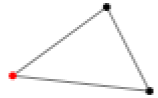
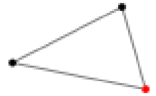
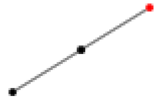
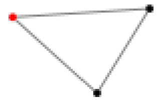
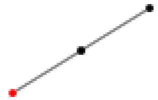
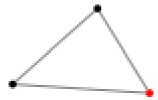
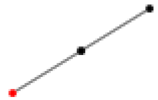
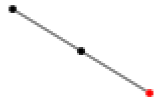
Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Rouse, MJ	3	0.000	1.000	Univ Western Ontario	1	10	3	1	0.333	0.926	
Ahmad, N	3	0.000	1.000	USIM	1	1	3	1	0.333	0.926	
Mohamed , ZM	3	0.000	1.000	UKM	1	0	3	1	0.333	0.926	
Aman, A	3	0.000	1.000	UKM	1	0	3	1	0.333	0.926	
Hamzah, N	3	0.000	1.000	UKM	1	0	3	1	0.333	0.926	
Auzair, SM	3	0.000	1.000	UKM	1	0	3	1	0.333	0.926	
Duasa, J	3	0.000	1.000	IIUM	1	0	3	1	0.333	0.926	
Ibrahim, MH	3	0.000	1.000	UPM	1	0	3	1	0.333	0.926	
Zainal, MP	3	0.000	1.000	INCEIF	1	0	3	1	0.333	0.926	
Lee, VH	3	0.000	1.000	UTAR	1	0	3	1	0.333	0.926	

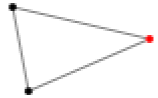
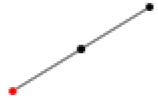
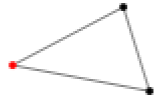
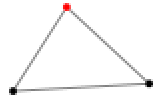
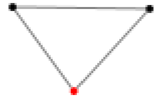
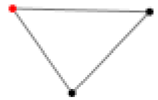
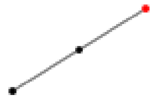
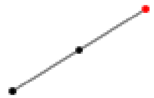
Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Chong, AYL	3	0.000	1.000	INTI-IU	1	0	3	1	0.333	0.926	
Katuk, N	3	0.000	1.000	UUM	1	0	3	1	0.333	0.926	
Ku-Mahamud, KR	3	0.000	1.000	UUM	1	0	3	1	0.333	0.926	
Norwawi, N	3	0.000	1.000	UUM	1	0	3	1	0.333	0.926	
Deris, S	3	0.000	1.000	UTM	1	0	3	1	0.333	0.926	
Jack, R	3	0.000	1.000	Swinburne Univ Technol	1	0	3	1	0.333	0.926	
As-Saber, S	3	0.000	1.000	Monash Univ	1	0	3	1	0.333	0.926	
Edwards, R	3	0.000	1.000	Monash	1	0	3	1	0.333	0.926	
Buckley, P	3	0.000	1.000	Univ Leeds	1	0	3	1	0.333	0.926	
Rose, RC	3	0.000	0.975	UPM	1	12	3	1	0.333	0.926	

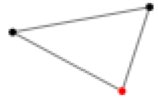
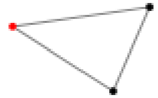
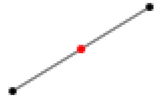
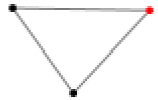
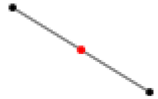
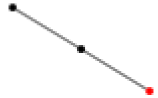
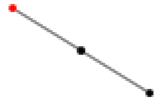
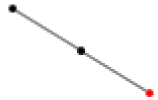
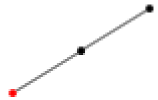
Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Abdullah, I	3	0.000	0.975	UPM	1	12	3	1	0.333	0.926	
Masrom, M	3	0.000	0.975	UTM	1	12	3	1	0.333	0.926	
Jemain, AA	3	0.000	0.891	UKM	1	0	3	1	0.333	0.926	
Yusoff, RZ	3	0.000	0.891	UUM	1	0	3	1	0.333	0.926	
Abas, Z	3	0.000	0.891	UUM	1	0	3	1	0.333	0.926	
Abu Bakar, A	3	0.000	0.744	Minist Hlth	1	0	3	1	0.333	0.926	
Awang, Y	3	0.000	0.744	Natl Heart Inst	1	0	3	1	0.333	0.926	
Tambi, AMBA	3	0.500	1.181	UiTM	2	0	4	1.333333	0.583	0.844	
Ghazali, MC	3	0.500	1.181	UiTM	2	0	4	1.333333	0.583	0.844	
Rasiah, R	3	2.000	1.467	UM	3	5	3	1	0.778	0.611	

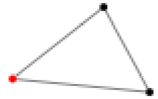
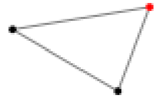
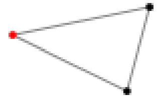
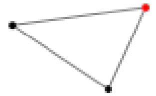
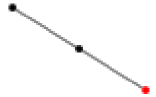
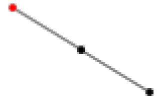
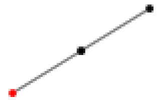
Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Devlin, JF	3	2.000	1.467	UNiM	3	4	3	1	0.778	0.611	
Wong, CY	3	2.000	1.467	UM	3	1	3	1	0.778	0.611	
Ali, H	3	2.000	1.467	UUM	2	1	3	1	0.778	0.611	
Othman, R	3	3.000	1.452	UPM	2	5	3	1	0.778	0.611	
Arshad, R	3	3.000	1.452	UKM	2	3	3	1	0.778	0.611	
TAN, LP	3	5.000	1.788	UM	3	5	3	1	1	0.333	
Al-Nasser, AD	2	0.000	0.527	UKM	1	2	2	1	0.5	1.62	
Kuman, S	2	0.000	0.527	UKM	1	1	2	1	0.5	1.62	
Endut, WJW	2	0.000	0.527	UiTM	1	0	2	1	0.5	1.62	
Yahya, NB	2	0.000	0.819	Lembaga Akreditasi Negara	1	0	2	1	0.5	1.389	

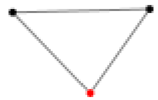
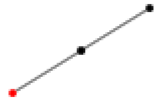
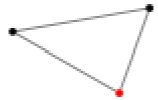
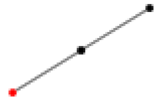
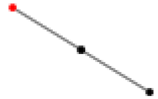
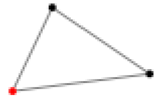
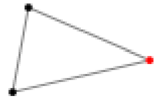
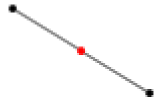
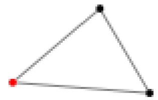
Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Rahim, NABA	2	0.000	0.819	Ipoh Branch Off	1	0	2	1	0.5	1.389	
NAMBIAR, JM	2	0.000	1.000	RUBBER RES INST MALAYSIA	2	24	4	2	0.5	1.125	
GELDERS, LF	2	0.000	1.000	Catholic Univ Leuven	2	24	4	2	0.5	1.125	
VANWASSENHOVE, LN	2	0.000	1.000	Catholic Univ Leuven	2	24	4	2	0.5	1.125	
Uli, J	2	0.000	1.000	UPM	2	0	2	1	0.5	1.125	
Mastor, NH	2	0.000	1.000	UTM	2	0	2	1	0.5	1.125	
Cheah, JET	2	0.000	1.000	UNiM	2	0	2	1	0.5	1.125	
GUILTINAN, JP	2	0.000	1.000	Univ Kentucky	1	31	2	1	0.5	1.125	
REJAB, IB	2	0.000	1.000	UKM	1	31	2	1	0.5	1.125	
RODGERS, WC	2	0.000	1.000	St Cloud State Univ	1	31	2	1	0.5	1.125	

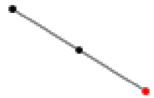
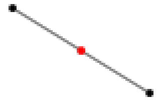
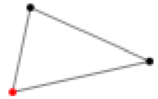
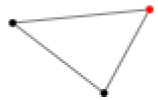
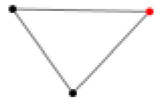
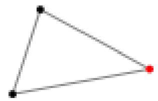
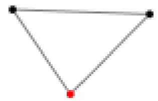
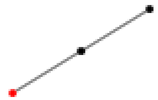
Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Ramasamy, B	2	0.000	1.000	UNiM	1	24	2	1	0.5	1.125	
Goh, KW	2	0.000	1.000	SAS Malaysia	1	24	2	1	0.5	1.125	
Yeung, MCH	2	0.000	1.000	Open Univ	1	24	2	1	0.5	1.125	
Chong, CW	2	0.000	1.000	UPM	1	10	2	1	0.5	1.125	
Ahmad, MI	2	0.000	1.000	UPM	1	10	2	1	0.5	1.125	
Abdullah, MY	2	0.000	1.000	UPM	1	10	2	1	0.5	1.125	
Jegathesan, J	2	0.000	1.000	MALAYSIAN IND DEV AUTHOR	1	8	2	1	0.5	1.125	
Gunasekaran, A	2	0.000	1.000	Brunel Univ	1	8	2	1	0.5	1.125	
Muthaly, S	2	0.000	1.000	Monash Univ	1	8	2	1	0.5	1.125	
Vasant, P	2	0.000	1.000	UMS	1	6	2	1	0.5	1.125	

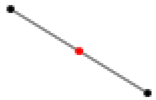
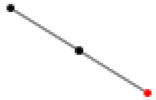
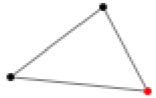
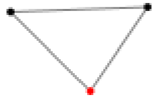
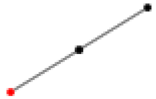
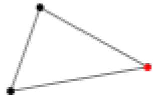
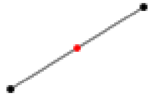
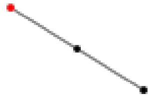
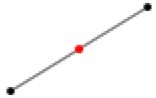
Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Nagarajan, R	2	0.000	1.000	UMS	1	6	2	1	0.5	1.125	
Yaacob, S	2	0.000	1.000	UMS	1	6	2	1	0.5	1.125	
Sobhani, FA	2	0.000	1.000	USM	1	4	2	1	0.5	1.125	
Amran, A	2	0.000	1.000	USM	1	4	2	1	0.5	1.125	
Zainuddin, Y	2	0.000	1.000	USM	1	4	2	1	0.5	1.125	
Chan, WL	2	0.000	1.000	UNiM	1	4	2	1	0.5	1.125	
Chieng, CLL	2	0.000	1.000	UNiM	1	4	2	1	0.5	1.125	
Kuk, G	2	0.000	1.000	Univ Nottingham	1	2	2	1	0.5	1.125	
Fokeer, S	2	0.000	1.000	Univ Nottingham	1	2	2	1	0.5	1.125	
Hung, WT	2	0.000	1.000	UNiM	1	2	2	1	0.5	1.125	

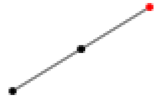
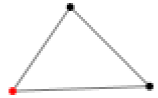
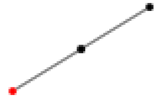
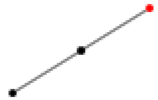
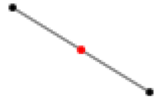
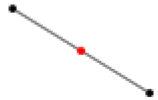
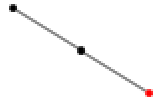
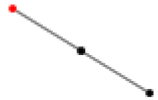
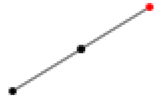
Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Zain, ZM	2	0.000	1.000	UMIST	1	2	2	1	0.5	1.125	
Dale, BG	2	0.000	1.000	USM	1	2	2	1	0.5	1.125	
Kehoe, DF	2	0.000	1.000	Univ Liverpool	1	2	2	1	0.5	1.125	
Shumate, M	2	0.000	1.000	Univ Illinois	1	1	2	1	0.5	1.125	
Ibrahim, R	2	0.000	1.000	UPM	1	1	2	1	0.5	1.125	
Levitt, R	2	0.000	1.000	Stanford Univ	1	1	2	1	0.5	1.125	
Kumar, M	2	0.000	1.000	MSU	1	1	2	1	0.5	1.125	
Kee, FT	2	0.000	1.000	MSU	1	1	2	1	0.5	1.125	
Manshor, AT	2	0.000	1.000	MSU	1	1	2	1	0.5	1.125	
Wei, CC	2	0.000	1.000	MMU	1	1	2	1	0.5	1.125	

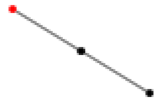
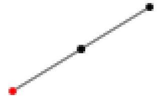
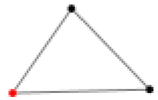
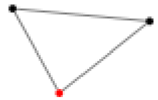
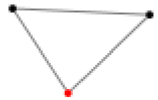
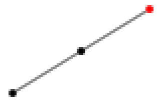
Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Choy, CS	2	0.000	1.000	Putra Int Coll	1	1	2	1	0.5	1.125	
Yew, WK	2	0.000	1.000	UTM	1	1	2	1	0.5	1.125	
Raman, Mu	2	0.000	1.000	Monash	1	0	2	1	0.5	1.125	
Ali, NA	2	0.000	1.000	UPM	1	0	2	1	0.5	1.125	
Mahat, F	2	0.000	1.000	UPM	1	0	2	1	0.5	1.125	
Zairi, M	2	0.000	1.000	Univ Bradford	1	0	2	1	0.5	1.125	
Nor, KM	2	0.000	1.000	UTM	1	0	2	1	0.5	1.125	
Sutanonpaiboon, J	2	0.000	1.000	Sonoma State Univ	1	0	2	1	0.5	1.125	
Al-Eraqi, AS	2	0.000	1.000	USM	1	0	2	1	0.5	1.125	
Khader, AT	2	0.000	1.000	USM	1	0	2	1	0.5	1.125	

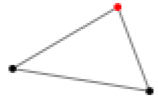
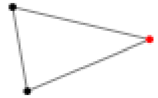
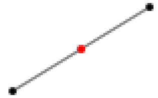
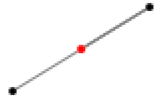
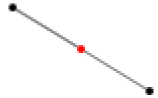
Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Mustafa, A	2	0.000	1.000	USM	1	0	2	1	0.5	1.125	
Tan, AKG	2	0.000	1.000	USM	1	0	2	1	0.5	1.125	
Yen, ST	2	0.000	1.000	Univ Tennessee	1	0	2	1	0.5	1.125	
Nayga, RM	2	0.000	1.000	Univ Arkansas	1	0	2	1	0.5	1.125	
Krauss, SE	2	0.000	1.000	UPM	1	0	2	1	0.5	1.125	
Hamid, JA	2	0.000	1.000	UPM	1	0	2	1	0.5	1.125	
Ismail, IA	2	0.000	1.000	UPM	1	0	2	1	0.5	1.125	
Abdul-Majid, M	2	0.000	1.000	UKM	1	0	2	1	0.5	1.125	
Saal, DS	2	0.000	1.000	Aston Univ	1	0	2	1	0.5	1.125	
Battisti, G	2	0.000	1.000	Univ Nottingham	1	0	2	1	0.5	1.125	

Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Hassan, Z	2	0.000	1.000	UNIMAS	1	0	2	1	0.5	1.125	
Dollard, MF	2	0.000	1.000	Univ S Australia	1	0	2	1	0.5	1.125	
Winefield, AH	2	0.000	1.000	Univ S Australia	1	0	2	1	0.5	1.125	
Malek, MDA	2	0.000	1.000	UMS	1	0	2	1	0.5	1.125	
Mearns, K	2	0.000	1.000	Univ Aberdeen	1	0	2	1	0.5	1.125	
Flin, R	2	0.000	1.000	Univ Aberdeen	1	0	2	1	0.5	1.125	
Zulhaidi, H	2	0.000	1.000	UPM	1	0	2	1	0.5	1.125	
Zahidi, IM	2	0.000	1.000	UPM	1	0	2	1	0.5	1.125	
Abu Bakar, S	2	0.000	1.000	UPM	1	0	2	1	0.5	1.125	
Abd Manap, M	2	0.000	1.000	Minerals & Geosci Dept	1	0	2	1	0.5	1.125	

Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Ramli, MF	2	0.000	1.000	UPM	1	0	2	1	0.5	1.125	
Redzwan, G	2	0.000	1.000	UM	1	0	2	1	0.5	1.125	
Ismail, A	2	0.000	1.000	UNIMAS	1	0	2	1	0.5	1.125	
Ibrahim, DKA	2	0.000	1.000	Dept Educ	1	0	2	1	0.5	1.125	
Girardi, A	2	0.000	1.000	Murdoch Univ	1	0	2	1	0.5	1.125	
Bin Abdullah, MM	2	0.000	1.000	UTM	1	0	2	1	0.5	1.125	
Tari, JJ	2	0.000	1.000	Univ Alicante	1	0	2	1	0.5	1.125	
Machold, S	2	0.000	1.000	Wolverha mpton Univ	1	0	2	1	0.5	1.125	
Ahmed, PK	2	0.000	1.000	Monash	1	0	2	1	0.5	1.125	
Farquhar, SS	2	0.000	1.000	Wolverha mpton Univ	1	0	2	1	0.5	1.125	

Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Charoen, D	2	0.000	1.000	NIDA	1	0	2	1	0.5	1.125	
Olfman, L	2	0.000	1.000	Claremont Grad Univ	1	0	2	1	0.5	1.125	
Gwynne, AL	2	0.000	0.984	Univ Nottingha m	1	4	2	1	0.5	1.125	
Ennew, CT	2	0.000	0.984	Univ Nottingha m	1	4	2	1	0.5	1.125	
Thirucelv am, K	2	0.000	0.984	UM	1	0	2	1	0.5	1.125	
Ratnavelu , K	2	0.000	0.984	UM	1	0	2	1	0.5	1.125	
Kaur, K	2	0.000	0.984	UM	1	0	2	1	0.5	1.125	
Kumar, A	2	0.000	0.984	Govt Orissa	1	0	2	1	0.5	1.125	
Abdullah, NAC	2	0.000	0.984	UUM	1	0	2	1	0.5	1.125	
Subrama niam, C	2	0.000	0.984	UUM	1	0	2	1	0.5	1.125	

Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Abdul-Ghani, R	2	0.000	0.973	UKM	1	3	2	1	0.5	1.125	
Davies, M	2	0.000	0.851	Univ Loughborough	1	3	2	1	0.5	1.125	
Finlay, PN	2	0.000	0.851	Univ Loughborough	1	3	2	1	0.5	1.125	
Cheng, JK	2	0.000	0.851	UUM	1	0	2	1	0.5	1.125	
Tahar, RM	2	0.000	0.851	UMP	1	0	2	1	0.5	1.125	
Md-Sidin, S	2	0.000	0.851	UPM	1	0	2	1	0.5	1.125	
Ismail, I	2	0.000	0.851	IIUM	1	0	2	1	0.5	1.125	
Abdul, M	2	0.000	0.851	UPM	1	0	2	1	0.5	1.125	
Yusop, Y	2	0.000	0.851	UPM	1	0	2	1	0.5	1.125	
Asree, S	2	0.000	0.735	Murray State Univ	1	0	2	1	0.5	1.125	

Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Razalli, MR	2	0.000	0.735	UUM	1	0	2	1	0.5	1.125	
Mukhtar, SM	2	0.000	0.664	Nanyang Technol Univ	2	8	2	1	0.5	1.125	
Saeed, M	2	0.000	0.664	IIUM	1	8	2	1	0.5	1.125	
FONG, CO	2	3.000	1.227	UM	6	78	4	2	1	0.625	
Larbani, M	2	1.000	1.459	Kianan Univ	2	0	3	1.5	1	0.556	
Sufian, F	1	0.000	1.000	UPM	4	4	1	1	1	1	
Williams, G	1	0.000	1.000	OWW Consultin g	4	2	2	2	1	1	
Wong, ESK	1	0.000	1.000	UM	4	0	1	1	1	1	
Martinso ns, MG	1	0.000	1.000	City Univ Hong Kong	2	36	1	1	1	1	
Zailani, S	1	0.000	1.000	USM	2	18	1	1	1	1	

Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Habibullah, MS	1	0.000	1.000	UPM	2	4	1	1	1	1	
Nasirin, S	1	0.000	1.000	Thames Valley Univ	2	4	1	1	1	1	
Muthu, G	1	0.000	1.000	STAR	2	4	1	1	1	1	
Zinkin, J	1	0.000	1.000	Zinkin Ettinger Consulting Sdn Bhd	2	2	2	2	1	1	
Wang, W	1	0.000	1.000	Univ Salford	2	2	1	1	1	1	
Yahya, S	1	0.000	1.000	UPM	1	50	1	1	1	1	
Kingsman, B	1	0.000	1.000	Univ Lancaster	1	50	1	1	1	1	
Chong, PKC	1	0.000	1.000	Asia Pacific Ctr Org Dev	1	36	1	1	1	1	
Rajagopal, P	1	0.000	1.000	USM	1	17	1	1	1	1	
ZABID, ARM	1	0.000	1.000	UPM	1	16	1	1	1	1	

Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
ALSAGOFF, SK	1	0.000	1.000	UPM	1	16	1	1	1	1	
Letchumanan, R	1	0.000	1.000	Minist Sci Technol & Environm	1	14	1	1	1	1	
Kodama, F	1	0.000	1.000	Univ Tokyo	1	14	1	1	1	1	
Moin, NH	1	0.000	1.000	UM	1	10	1	1	1	1	
Salhi, S	1	0.000	1.000	UM	1	10	1	1	1	1	
Sudarsanam, S	1	0.000	1.000	Cranfield Univ	1	8	1	1	1	1	
Lai, J	1	0.000	1.000	Pricewaterhouse Coopers	1	8	1	1	1	1	
Gupta, JL	1	0.000	1.000	Natl Inst Bank Managem ent	1	7	1	1	1	1	
Sulaiman, M	1	0.000	1.000	USM	1	7	1	1	1	1	
ABDULLAH, SRS	1	0.000	1.000	Univ London Kings Coll	1	6	1	1	1	1	

Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
KEENOY, T	1	0.000	1.000	USM	1	6	1	1	1	1	
Boocock, G	1	0.000	1.000	Univ Loughborough	1	4	1	1	1	1	
Shariff, MNM	1	0.000	1.000	UUM	1	4	1	1	1	1	
Birks, DF	1	0.000	1.000	Univ Bath	1	4	1	1	1	1	
Buick, I	1	0.000	1.000	Univ London Queen Mary Coll	1	4	1	1	1	1	
Thornborrow, T	1	0.000	1.000	UNiM	1	3	1	1	1	1	
Brown, AD	1	0.000	1.000	Univ Bath	1	3	1	1	1	1	
Chong, SC	1	0.000	1.000	Inst Putra	1	3	1	1	1	1	
Lin, BS	1	0.000	1.000	Louisiana State Univ	1	3	1	1	1	1	
Hussin, B	1	0.000	1.000	UTeM	1	2	1	1	1	1	

Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Muda, MS	1	0.000	1.000	UNISZA	1	2	1	1	1	1	
Hendry, L	1	0.000	1.000	Univ Lancaster	1	2	1	1	1	1	
Kassim, NM	1	0.000	1.000	MMU	1	2	1	1	1	1	
Bojei, J	1	0.000	1.000	UPM	1	2	1	1	1	1	
bin Idris, AR	1	0.000	1.000	Govt Malaysia	1	2	1	1	1	1	
Eldridge, D	1	0.000	1.000	Univ Manchester	1	2	1	1	1	1	
Alam, SS	1	0.000	1.000	UKM	1	1	1	1	1	1	
Yasin, NM	1	0.000	1.000	UKM	1	1	1	1	1	1	
Wickramasinghe, CN	1	0.000	1.000	Univ Kelaniya	1	1	1	1	1	1	
Tabassi, AA	1	0.000	1.000	USM	1	1	1	1	1	1	

Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Abu Bakar, AH	1	0.000	1.000	USM	1	1	1	1	1	1	
Baharumshah, AZ	1	0.000	1.000	UPM	1	1	1	1	1	1	
Almasaied, SW	1	0.000	1.000	Al alBayt Univ	1	1	1	1	1	1	
Da Silva, RV	1	0.000	1.000	Univ Manchester	1	1	1	1	1	1	
Alwi, SFS	1	0.000	1.000	UM	1	1	1	1	1	1	
Reddy, YS	1	0.000	1.000	Monash	1	1	1	1	1	1	
Rath, S	1	0.000	1.000	Curtin Univ Technol	1	1	1	1	1	1	
Othman, Ra	1	0.000	1.000	UiTM	1	0	1	1	1	1	
Ahmad, Na	1	0.000	1.000	UPM	1	0	1	1	1	1	
Ameer, R	1	0.000	1.000	UiTM	1	0	1	1	1	1	

Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Nga, JKH	1	0.000	1.000	Sunway	1	0	1	1	1	1	
Shamuganathan, G	1	0.000	1.000	Taylor	1	0	1	1	1	1	
Loke, YJ	1	0.000	1.000	USM	1	0	1	1	1	1	
Foo, CS	1	0.000	1.000	USM	1	0	1	1	1	1	
Chong, HY	1	0.000	1.000	UTAR	1	0	1	1	1	1	
Zin, RM	1	0.000	1.000	UTM	1	0	1	1	1	1	
Devi, S	1	0.000	1.000	UM	1	0	1	1	1	1	
Mokhtar, SSM	1	0.000	1.000	UUM	1	0	1	1	1	1	
Yusof, RZ	1	0.000	1.000	UUM	1	0	1	1	1	1	
Gould-Williams, J	1	0.000	1.000	Cardiff Univ	1	0	1	1	1	1	

Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Mohamed , RB	1	0.000	1.000	OUM	1	0	1	1	1	1	
Aini, MS	1	0.000	1.000	UPM	1	0	1	1	1	1	
Fakhru'l-Razi, A	1	0.000	1.000	UPM	1	0	1	1	1	1	
Asgari, B	1	0.000	1.000	Ritsumeikan Asia Pacific Univ	1	0	1	1	1	1	
Yen, LW	1	0.000	1.000	MUST	1	0	1	1	1	1	
Abdullah, S	1	0.000	1.000	UM	1	0	1	1	1	1	
Muhammad, A	1	0.000	1.000	UM	1	0	1	1	1	1	
Thiruchelvam, K	1	0.000	1.000	UM	1	0	1	1	1	1	
Ahmad, KZ	1	0.000	1.000	UM	1	0	1	1	1	1	
Malairaja , C	1	0.000	1.000	Minist Nat Resources & Environm	1	0	1	1	1	1	

Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Zawdie, G	1	0.000	1.000	Univ Strathclyde	1	0	1	1	1	1	
Rashid, Z	1	0.000	1.000	UNITAR	1	0	1	1	1	1	
Ibrahim, S	1	0.000	1.000	UPM	1	0	1	1	1	1	
Abdullah, Z	1	0.000	1.000	UPM	1	0	1	1	1	1	
Threadgold, T	1	0.000	1.000	Cardiff Univ	1	0	1	1	1	1	
Leong, P	1	0.000	1.000	UTAR	1	0	1	1	1	1	
Sriramesh, K	1	0.000	1.000	Nanyang Technol Univ	1	0	1	1	1	1	
KOLAY, MK	1	0.000	1.000	SCH ACCOUNTANCY	1	0	1	1	1	1	
SAHU, KC	1	0.000	1.000	Indian Inst Technol	1	0	1	1	1	1	
Chen, YW	1	0.000	0.770	Da Yeh Univ	1	0	1	1	1	1	

Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Chang, YP	1	0.000	0.770	SUNY Buffalo	1	0	2	2	1	1	
SRINIVASAN, V	1	0.000	0.672	Stanford Univ	3	74	3	3	1	1	
Gilbert, LTS	1	0.000	0.657	Q Tech Advances	1	4	1	1	1	1	
Tan, JKC	1	0.000	0.657	UM	1	0	1	1	1	1	
Krishnan, G	1	0.000	0.566	UM	1	1	1	1	1	1	
Goh, KL	1	0.000	0.566	UM	1	1	1	1	1	1	
Davies, DR	1	0.000	0.566	Aston Univ	1	1	1	1	1	1	
Sherman, A	1	0.000	0.566	St Francis Xavier Univ	1	0	1	1	1	1	
Ghani, RA	1	0.000	0.561	UKM	1	2	1	1	1	1	
Sparrow, P	1	0.000	0.561	UKM	1	0	1	1	1	1	

Vertex	Degree	Betweenness Centrality	PageRank	Institution	No. of works	Citations	Total Tie	Vertex Tie strength	Efficiency	Constraint	Subgraph
Aspinwall, EM	1	0.000	0.482	Univ Birmingham	1	11	1	1	1	1	
Eng, QE	1	0.000	0.482	UTM	1	5	2	2	1	1	
Zadry, HR	1	0.000	0.482	UTM	1	1	1	1	1	1	
Bin Ahmad, MF	1	0.000	0.482	UTM	1	0	1	1	1	1	
Zamani-Farahani, H	1	0.000	0.452	UM	1	1	1	1	1	1	
Yahaya, SY	1	0.000	0.452	UUM	1	1	1	1	1	1	

Annexure F: Tie Strength between authors (RQ1)

Vertex 1	Vertex 2	Edge Weight
Ali, NA	Mahat, F	1
Ali, NA	Zairi, M	1
Mahat, F	Zairi, M	1
Cheng, JK	Tahar, RM	1
Cheng, JK	Ang, CL	1
Tahar, RM	Ang, CL	1
Shumate, M	Ibrahim, R	1
Shumate, M	Levitt, R	1
Ibrahim, R	Levitt, R	1
Dinnie, K	Melewar, TC	1
Dinnie, K	Seidenfuss, KU	1
Dinnie, K	Musa, G	1
Melewar, TC	Seidenfuss, KU	1
Melewar, TC	Musa, G	1
Seidenfuss, KU	Musa, G	1
Arshad, R	Sparrow, P	1
Asree, S	Zain, M	1
Asree, S	Razalli, MR	1
Zain, M	Razalli, MR	1
Sobhani, FA	Amran, A	1
Sobhani, FA	Zainuddin, Y	1
Amran, A	Zainuddin, Y	1
Othman, Ra	Ameer, R	1
Mohamed, ZM	Aman, A	1
Mohamed, ZM	Hamzah, N	1
Mohamed, ZM	Auzair, SM	1
Aman, A	Hamzah, N	1
Aman, A	Auzair, SM	1
Hamzah, N	Auzair, SM	1
Duasa, J	Ahmad, N	1
Duasa, J	Ibrahim, MH	1
Duasa, J	Zainal, MP	1
Ahmad, N	Ibrahim, MH	1
Ahmad, N	Zainal, MP	1
Ibrahim, MH	Zainal, MP	1
Wong, CY	Thirucelvam, K	1
Wong, CY	Ratnavelu, K	1
Thirucelvam, K	Ratnavelu, K	1
Nor, KM	Sutanonpaiboon, J	1
Nor, KM	Mastor, NH	1
Sutanonpaiboon, J	Mastor, NH	1
Nga, JKH	Shamuganathan, G	1

Vertex 1	Vertex 2	Edge Weight
Alam, SS	Yasin, NM	1
Al-Eraqi, AS	Khader, AT	1
Al-Eraqi, AS	Mustafa, A	1
Khader, AT	Mustafa, A	1
Loke, YJ	Foo, CS	1
Tan, AKG	Yen, ST	1
Tan, AKG	Nayga, RM	1
Yen, ST	Nayga, RM	1
Chong, HY	Zin, RM	1
Rasiah, R	Kaur, K	1
Rasiah, R	Kumar, A	1
Kaur, K	Kumar, A	1
Lee, VH	Ooi, KB	1
Lee, VH	Tan, BI	1
Lee, VH	Chong, AYL	1
Ooi, KB	Tan, BI	1
Ooi, KB	Chong, AYL	1
Tan, BI	Chong, AYL	1
Krauss, SE	Hamid, JA	1
Krauss, SE	Ismail, IA	1
Hamid, JA	Ismail, IA	1
Abdul-Majid, M	Saal, DS	1
Abdul-Majid, M	Battisti, G	1
Saal, DS	Battisti, G	1
Kumar, M	Kee, FT	1
Kumar, M	Manshor, AT	1
Kee, FT	Manshor, AT	1
Hassan, Z	Dollard, MF	1
Hassan, Z	Winefield, AH	1
Dollard, MF	Winefield, AH	1
Malek, MDA	Mearns, K	1
Malek, MDA	Flin, R	1
Mearns, K	Flin, R	1
Devi, S	Wong, ESK	1
Mokhtar, SSM	Yusof, RZ	1
Gould-Williams, J	Mohamed, RB	1
Md-Sidin, S	Sambasivan, M	1
Md-Sidin, S	Ismail, I	1
Sambasivan, M	Ismail, I	1
Zulhaidi, H	Zahidi, IM	1
Zulhaidi, H	Abu Bakar, S	1
Zahidi, IM	Abu Bakar, S	1
Katuk, N	Ku-Mahamud, KR	1
Katuk, N	Norwawi, N	1
Katuk, N	Deris, S	1

Vertex 1	Vertex 2	Edge Weight
Ku-Mahamud, KR	Norwawi, N	1
Ku-Mahamud, KR	Deris, S	1
Norwawi, N	Deris, S	1
Aini, MS	Fakhru'l-Razi, A	1
Ali, H	Abdullah, NAC	1
Ali, H	Subramaniam, C	1
Abdullah, NAC	Subramaniam, C	1
Abd Manap, M	Ramli, MF	1
Abd Manap, M	Redzwan, G	1
Ramli, MF	Redzwan, G	1
Zakuan, NM	Yusof, SM	1
Zakuan, NM	Laosirihongthong, T	1
Zakuan, NM	Shaharoun, AM	1
Yusof, SM	Laosirihongthong, T	1
Yusof, SM	Shaharoun, AM	1
Laosirihongthong, T	Shaharoun, AM	1
Williams, G	Zinkin, J	2
Bin Ahmad, MF	Yusof, SM	1
Asgari, B	Yen, LW	1
Wei, CC	Choy, CS	1
Wei, CC	Yew, WK	1
Choy, CS	Yew, WK	1
Sambasivan, M	Abdul, M	1
Sambasivan, M	Yusop, Y	1
Abdul, M	Yusop, Y	1
Sufian, F	Habibullah, MS	1
Chen, YW	Larbani, M	1
Larbani, M	Chang, YP	2
Rasiah, R	Krishnan, G	1
Abdullah, S	Muhammad, A	1
Thiruchelvam, K	Ahmad, KZ	1
Wickramasinghe, CN	Ahmad, Na	1
Wong, CY	Goh, KL	1
Ismail, A	Ibrahim, DKA	1
Ismail, A	Girardi, A	1
Ibrahim, DKA	Girardi, A	1
Bin Abdullah, MM	Uli, J	1
Bin Abdullah, MM	Tari, JJ	1
Uli, J	Tari, JJ	1
Tabassi, AA	Abu Bakar, AH	1
Wang, W	Hussin, B	1
Thornborrow, T	Brown, AD	1
Baharumshah, AZ	Almasaied, SW	1
Zamani-Farahani, H	Musa, G	1
Malairaja, C	Zawdie, G	1

Vertex 1	Vertex 2	Edge Weight
Chong, SC	Lin, BS	1
Da Silva, RV	Alwi, SFS	1
Rashid, Z	Ibrahim, S	1
Tambi, AMBA	Ghazali, MC	2
Tambi, AMBA	Yahya, NB	1
Ghazali, MC	Yahya, NB	1
Tambi, AMBA	Rahim, NABA	1
Ghazali, MC	Rahim, NABA	1
Abdullah, Z	Threadgold, T	1
Machold, S	Ahmed, PK	1
Machold, S	Farquhar, SS	1
Ahmed, PK	Farquhar, SS	1
Jack, R	As-Saber, S	1
Jack, R	Edwards, R	1
Jack, R	Buckley, P	1
As-Saber, S	Edwards, R	1
As-Saber, S	Buckley, P	1
Edwards, R	Buckley, P	1
Othman, R	Ghani, RA	1
Idris, F	Ali, KAM	1
Charoen, D	Raman, Mu	1
Charoen, D	Olfman, L	1
Raman, Mu	Olfman, L	1
Cheah, JET	Chan, WL	1
Cheah, JET	Chieng, CLL	1
Chan, WL	Chieng, CLL	1
Boon, OK	Arumugam, V	1
Boon, OK	Safa, MS	1
Boon, OK	Abu Bakar, N	1
Arumugam, V	Safa, MS	1
Arumugam, V	Abu Bakar, N	1
Safa, MS	Abu Bakar, N	1
Yahaya, SY	Abu Bakar, N	1
Moin, NH	Salhi, S	1
Ainuddin, RA	Beamish, PW	1
Ainuddin, RA	Hulland, JS	1
Ainuddin, RA	Rouse, MJ	1
Beamish, PW	Hulland, JS	1
Beamish, PW	Rouse, MJ	1
Hulland, JS	Rouse, MJ	1
Ali, KAM	Jemain, AA	1
Ali, KAM	Yusoff, RZ	1
Ali, KAM	Abas, Z	1
Jemain, AA	Yusoff, RZ	1
Jemain, AA	Abas, Z	1

Vertex 1	Vertex 2	Edge Weight
Yusoff, RZ	Abas, Z	1
Zadry, HR	Yusof, SM	1
Leong, P	Sriramesh, K	1
Reddy, YS	Rath, S	1
Zailani, S	Rajagopal, P	1
Ramasamy, B	Goh, KW	1
Ramasamy, B	Yeung, MCH	1
Goh, KW	Yeung, MCH	1
Boocock, G	Shariff, MNM	1
Kuk, G	Fokeer, S	1
Kuk, G	Hung, WT	1
Fokeer, S	Hung, WT	1
Zain, M	Rose, RC	1
Zain, M	Abdullah, I	1
Zain, M	Masrom, M	1
Rose, RC	Abdullah, I	1
Rose, RC	Masrom, M	1
Abdullah, I	Masrom, M	1
Vasant, P	Nagarajan, R	1
Vasant, P	Yaacob, S	1
Nagarajan, R	Yaacob, S	1
Ali, H	Davies, DR	1
Muda, MS	Hendry, L	1
Eng, QE	Yusof, SM	2
Nasirin, S	Birks, DF	1
Devlin, JF	Gwynne, AL	1
Devlin, JF	Ennew, CT	1
Gwynne, AL	Ennew, CT	1
Ahmed, ZU	Mohamad, O	1
Ahmed, ZU	Tan, B	1
Ahmed, ZU	Johnson, JP	2
Mohamad, O	Tan, B	1
Mohamad, O	Johnson, JP	1
Tan, B	Johnson, JP	1
Ahmed, ZU	Mohamed, O	1
Ahmed, ZU	Meng, LY	1
Mohamed, O	Johnson, JP	1
Mohamed, O	Meng, LY	1
Johnson, JP	Meng, LY	1
Kassim, NM	Bojei, J	1
TAN, LP	Tan, JKC	1
Husain, N	Abdullah, M	4
Husain, N	Idris, F	1
Husain, N	Sagir, RM	1
Abdullah, M	Idris, F	1

Vertex 1	Vertex 2	Edge Weight
Abdullah, M	Sagir, RM	1
Idris, F	Sagir, RM	1
Agus, A	Sagir, RM	1
Sudarsanam, S	Lai, J	1
Zain, ZM	Dale, BG	1
Zain, ZM	Kehoe, DF	1
Dale, BG	Kehoe, DF	1
Saeed, M	Ahmed, ZU	1
Saeed, M	Mukhtar, SM	1
Ahmed, ZU	Mukhtar, SM	1
Othman, R	Abdul-Ghani, R	1
Othman, R	Arshad, R	1
Abdul-Ghani, R	Arshad, R	1
Ang, CL	Davies, M	1
Ang, CL	Finlay, PN	1
Davies, M	Finlay, PN	1
TAN, LP	Gilbert, LTS	1
Sherman, A	Devlin, JF	1
Agus, A	Abdullah, M	2
Yusof, SM	Aspinwall, EM	1
Abu Bakar, A	Chinna, K	1
Abu Bakar, A	Awang, Y	1
Abu Bakar, A	Krishnan, SK	1
Chinna, K	Awang, Y	1
Chinna, K	Krishnan, SK	1
Awang, Y	Krishnan, SK	1
Endut, WJW	Abdullah, M	1
Endut, WJW	Husain, N	1
Agus, A	Krishnan, SK	2
Agus, A	Kadir, SLSA	2
Krishnan, SK	Kadir, SLSA	1
Abdullah, M	Al-Nasser, AD	1
Al-Nasser, AD	Husain, N	1
Husain, N	Kuman, S	1
Abdullah, M	Kuman, S	1
Kadir, SLSA	Abdullah, M	2
Krishnan, SK	Husain, N	1
Agus, A	Husain, N	1
Chinna, K	Kadir, SLSA	1
Chinna, K	Abdullah, M	1
Letchumanan, R	Kodama, F	1
Chong, CW	Ahmad, MI	1
Chong, CW	Abdullah, MY	1
Ahmad, MI	Abdullah, MY	1
Yahya, S	Kingsman, B	1

Vertex 1	Vertex 2	Edge Weight
Martinsons, MG	Chong, PKC	1
bin Idris, AR	Eldridge, D	1
Deris, SB	Omatu, S	1
Deris, SB	Ohta, H	1
Deris, SB	Samat, PABD	1
Omatu, S	Ohta, H	1
Omatu, S	Samat, PABD	1
Ohta, H	Samat, PABD	1
Buick, I	Muthu, G	1
Jegathesan, J	Gunasekaran, A	1
Jegathesan, J	Muthaly, S	1
Gunasekaran, A	Muthaly, S	1
Gupta, JL	Sulaiman, M	1
KOLAY, MK	SAHU, KC	1
ABDULLAH, SRS	KEENOY, T	1
ZABID, ARM	ALSAGOFF, SK	1
NAMBIAR, JM	GELDERS, LF	2
NAMBIAR, JM	VANWASSENHOVE, LN	2
GELDERS, LF	VANWASSENHOVE, LN	2
TAN, LP	FONG, CO	1
FONG, CO	SRINIVASAN, V	3
GUILTINAN, JP	REJAB, IB	1
GUILTINAN, JP	RODGERS, WC	1
REJAB, IB	RODGERS, WC	1

Annexure G: Topological Properties of top 200 authors in the Turkey network sorted on the Number of Works

Author Name	Degree	Betweenness Centrality	Closeness Centrality	PageRank	tie-strength	No. of Works	Times Cited
Sopian, K	102	59506.83216	0.000409	12.16588	2.67	63	108
Saidur, R	49	13469.45051	0.000274	6.656677	2.78	48	559
Lee, Kt	38	82098.1352	0.000381	6.260258	2.92	46	375
Masjuki, Hh	36	4912.404035	0.000272	4.895465	2.72	31	264
Zaharim, A	53	12103.15428	0.00038	5.678528	2.89	29	2
Mahlia, Tmi	46	37809.86817	0.000316	6.797598	1.80	28	184
Mohamed, Ar	27	12855.11442	0.00032	4.640972	2.59	27	211
Daud, Wrw	52	76936.83708	0.000422	6.686728	1.77	25	268
Bhatia, S	25	5696.501703	0.000324	4.418029	2.36	24	244
Alghoul, Ma	38	4031.180754	0.000373	4.031786	3.29	23	61
Sulaiman, My	32	123.148864	0.000333	3.251499	3.47	19	58
Ruslan, Mh	24	65.953601	0.000332	2.475722	4.08	18	27
Hameed, Bh	11	8246	0.000282	2.681635	2.09	17	100
Kamarudin, Sk	23	13531.5347	0.000392	2.980482	2.30	16	220
Rahim, Na	23	4570.757129	0.000272	3.026192	2.13	14	97
Tan, Kt	13	130.93539	0.000317	2.132182	2.77	14	203
Mekhilef, S	21	1868.619503	0.000271	2.76765	2.05	13	86
Daud, Wmaw	12	7129.5	0.000161	3.083613	1.83	13	188
Othman, My	27	2429.501008	0.000372	2.893249	2.41	12	20
Yusup, S	26	22664.56177	0.000363	4.039004	1.31	12	38
Amin, N	24	2406.878644	0.000372	2.793532	1.96	11	28
Aroua, Mk	12	13721.5	0.000177	2.940254	2.17	11	155
Yahya, M	22	31.683316	0.000332	2.205415	3.50	10	1
Mujeebu, Ma	13	12332.25	0.000248	2.411688	2.38	10	59
Mat, S	19	28.06552	0.000331	1.937029	3.16	9	5
Abdullah, Az	14	2713.721212	0.000315	2.46717	1.79	9	112
Abdullah, Mz	10	10535.25	0.000248	1.811829	2.80	9	49
Goh, Cs	8	4430.928571	0.000319	1.460763	2.13	9	60
Haseeb, Asma	7	3.333333	0.000234	1.135371	3.29	9	58
Fazal, Ma	7	3.333333	0.000234	1.135371	3.29	9	58
Ahmad, Mm	20	81523.65518	0.000406	2.871386	1.50	8	34
Che-ani, Ai	19	3149.106531	0.000334	2.282485	2.16	8	2
Hasanuzzaman, M	12	1046.572353	0.00027	1.563886	2.08	8	49
Mohammed, Ha	16	2865.472269	0.000271	2.136592	1.63	7	17
Hossain, Ms	15	48.357937	0.000237	1.931898	1.80	7	29
Kalam, Ma	13	11741.87147	0.000313	1.801284	2.15	7	86
Abbas, Hf	2	601	0.000147	0.776395	3.50	7	71
Zain, Mfm	21	2513.397885	0.000333	2.440725	1.33	6	1
Hashim, H	19	10687.22106	0.000265	3.546471	1.05	6	8

Author Name	Degree	Betweenness Centrality	Closeness Centrality	PageRank	tie-strength	No. of Works	Times Cited
Usman, Ims	17	3885.338734	0.000334	2.032321	1.94	6	0
Hassan, Ma	14	18831.73333	0.000245	2.167403	1.71	6	95
Daghigh, R	11	3.66829	0.00033	1.16765	2.27	6	6
Kamaruddin, Ah	10	4937.084125	0.000326	1.687116	1.50	6	94
Mohamad, Aa	9	1935.75	0.000246	1.696611	2.33	6	45
Islam, Mr	8	3.142857	0.000236	1.064603	2.75	6	32
Lam, Mk	6	35.033333	0.000313	1.050389	2.50	6	43
Zainal, Za	4	1800	0.000233	1.526633	1.50	6	6
Foo, Ky	1	0	0.000241	0.357217	6.00	6	24
Yatim, B	21	2409.964889	0.000371	2.403081	1.24	5	15
Abdullah, S	19	53210.18608	0.000359	2.815087	1.11	5	3
Haw, Lc	16	1799.941606	0.000331	1.825507	2.25	5	1
Fernando, Wjn	13	29816.61361	0.000331	2.242612	1.15	5	110
Ismail, M	11	3576.75	0.000339	1.700284	1.82	5	21
Yaakub, Z	10	457.845216	0.000369	1.375611	1.90	5	51
Kazi, Sn	10	1216.8	0.000237	1.554628	1.40	5	23
Sulaiman, Nmn	6	2012	0.000176	1.456978	2.33	5	13
Raman, Aaa	6	17731	0.000196	1.498626	1.83	5	19
Olutoye, Ma	3	4	0.000242	0.807859	2.33	5	15
Arof, Ak	19	5337.8	0.000258	1.867954	1.47	4	12
Tawil, Nm	15	1352.548646	0.000314	1.860185	1.27	4	0
Kadhum, Aah	14	268.905556	0.000352	1.705681	1.57	4	22
Rahim, Ra	14	7659.4	0.000215	1.929582	1.50	4	40
Rahman, Mm	14	4754.292857	0.000237	1.874167	1.43	4	18
Ali, B	13	11.105556	0.000331	1.389022	2.00	4	0
Surat, M	12	458.306716	0.000333	1.388208	2.00	4	0
Abdullah, Mo	12	5949	0.00024	2.464471	1.00	4	14
Abdullah, Nag	11	563.30741	0.000333	1.266186	2.18	4	0
Ibrahim, M	11	10134.02815	0.000377	1.775905	1.27	4	1
Hasran, Ua	10	7221.105455	0.000386	1.301963	1.70	4	49
Husnawan, M	10	36.654365	0.00027	1.411997	1.70	4	70
Jahirul, Mi	10	686.759524	0.00027	1.393189	1.70	4	42
Ahamed, Ju	10	53.892904	0.000237	1.284202	1.50	4	19
Rashid, U	10	7210.011485	0.000364	1.769828	1.20	4	4
Darus, Zm	9	4367.666667	0.00033	1.524986	1.22	4	0
Ahmad, Al	9	33500.50476	0.00033	1.73455	1.11	4	40
Jayed, Mh	8	19.538131	0.00027	1.132235	2.13	4	30
Chong, Ml	8	11.733333	0.000215	1.195889	2.13	4	86
Shirai, Y	8	11.733333	0.000215	1.195889	2.13	4	86
Atabani, Ae	7	25.558261	0.00027	1.0253	1.86	4	10
Foo, Dcy	7	1096.666667	0.000212	1.628798	1.57	4	57
Tan, Rr	7	1096.666667	0.000212	1.628798	1.57	4	57
Aziz, Ara	7	2393	0.00016	1.723889	1.57	4	2
Abu Bakar, Mz	6	138.75	0.000245	1.093408	2.67	4	42

Author Name	Degree	Betweenness Centrality	Closeness Centrality	PageRank	tie-strength	No. of Works	Times Cited
Zhao, Y	6	0.75	0.000282	1.033741	2.50	4	20
Dou, Sx	6	0.75	0.000282	1.033741	2.50	4	20
Yu, Xb	6	0.75	0.000282	1.033741	2.50	4	20
Basri, S	6	0	0.000368	0.837761	2.17	4	47
Salamatinia, B	6	97.364286	0.000272	1.133396	2.17	4	32
Moghavvemi, M	5	1.166667	0.000266	0.911336	2.40	4	11
Kansedo, J	5	11.454762	0.000312	0.909308	2.40	4	55
Zahedi, G	5	1499	0.000229	1.353552	1.40	4	2
Atadashi, Im	4	9	0.00016	1.020919	2.50	4	39
Mazandarani, A	4	0.333333	0.000266	0.74127	2.25	4	10
Lim, S	4	434	0.000312	0.814473	1.50	4	25
Lim, Ch	12	1.662309	0.00033	1.238959	2.00	3	0
Majlan, Eh	12	10.216667	0.000338	1.493409	1.33	3	24
Mohamad, Ab	11	174.405556	0.000352	1.360847	1.45	3	12
Ismail, R	11	2392.333333	0.00028	1.515881	1.18	3	0
Manan, Za	11	6620.06172	0.000291	1.818073	1.18	3	4
Ali, Mb	11	16.846115	0.000237	1.409246	1.18	3	3
Tahir, Mm	10	371.97384	0.000333	1.173232	2.00	3	0
Nor, Mfim	10	371.97384	0.000333	1.173232	2.00	3	0
Salwa, Agn	10	2.519048	0.00033	1.111451	1.80	3	0
Shahrul, Aw	10	2.519048	0.00033	1.111451	1.80	3	0
Isa, Mh	10	2392	0.000234	1.660689	1.30	3	26
Ali, Y	10	788.8	0.000308	1.625829	1.10	3	2
Uzir, Mh	10	1983.91829	0.000279	1.818952	1.00	3	1
Assadeq, J	9	4.73658	0.00033	1.035028	2.00	3	1
Buraidah, Mh	9	0.8	0.000224	1.005319	2.00	3	0
Majid, Sr	9	0.8	0.000224	1.005319	2.00	3	0
Ping, Hw	9	1797.2	0.000237	1.402813	1.44	3	37
Fudholi, A	8	0	0.00033	0.887814	2.50	3	14
Alfegi, Em	8	1.611111	0.00033	0.910445	2.25	3	12
Fayaz, H	8	3.142857	0.000236	1.064603	1.75	3	8
Mohd-tawil, N	8	3.391667	0.000313	0.968436	1.63	3	0
Hassan, Mf	8	599.2	0.000208	1.267008	1.63	3	26
Liu, Hk	8	599.2	0.000208	1.267008	1.63	3	26
Jamil, M	8	314.920022	0.000312	1.041752	1.50	3	0
Karim, Oa	8	209.666667	0.00033	1.271012	1.38	3	0
Saleem, M	8	2392.333333	0.000324	1.52822	1.25	3	4
Othman, Mr	8	951.3	0.000284	1.43262	1.25	3	67
Irfan, Mf	8	2396	0.000279	1.580176	1.00	3	5
Shuhaimi, M	8	4200.864094	0.000249	1.822192	1.00	3	6
Ibrahim, A	7	2.034957	0.00033	0.810234	1.86	3	7
Mohammadi, M	7	16.717857	0.00027	1.255073	1.43	3	23
Lahijani, P	7	2397.541667	0.00027	1.37438	1.29	3	11

Author Name	Degree	Betweenness Centrality	Closeness Centrality	PageRank	tie-strength	No. of Works	Times Cited
Silitonga, As	6	6.652056	0.000268	0.90598	1.83	3	7
Fadhel, Mi	6	120.308004	0.000367	0.735812	1.67	3	3
Matin, Ma	6	71.785015	0.000329	0.802756	1.67	3	8
Hassan, F	6	1194.25	0.000276	1.124402	1.67	3	0
Saruwono, M	6	1194.25	0.000276	1.124402	1.67	3	0
Chong, Wt	6	3	0.000266	1.060129	1.67	3	13
Jusoh, A	6	399	0.000257	1.182326	1.67	3	2
Endut, A	6	399	0.000257	1.182326	1.67	3	2
Ali, N	6	399	0.000257	1.182326	1.67	3	2
Khalil, M	6	18777	0.000219	1.247654	1.33	3	10
Safari, A	5	0.666667	0.000236	0.766946	1.80	3	8
Mohamed, A	5	1200	0.000329	1.093788	1.60	3	0
Yee, Kf	5	4.666667	0.000311	0.940351	1.60	3	38
Sahu, Jn	5	1200	0.000147	1.434975	1.40	3	27
Solangi, Kh	4	0	0.000236	0.603539	2.50	3	28
Tan, Ht	4	8.733333	0.000315	0.76346	2.00	3	5
Ashok, S	4	0	0.000217	0.810722	2.00	3	7
Sim, Jh	4	21.25	0.000278	0.771625	1.75	3	8
Dihrab, Ss	4	0	0.000329	0.519006	1.50	3	17
Chin, Lh	4	300.666667	0.00028	0.910268	1.50	3	50
Aziz, Aa	4	1200	0.00016	1.161959	1.50	3	45
Mazaheri, H	3	0	0.000314	0.58635	3.00	3	22
Mootabadi, H	3	0	0.000272	0.61057	3.00	3	32
Ong, Hc	3	0	0.000267	0.545854	2.33	3	12
Bazmi, Aa	3	299	0.000229	0.796179	1.67	3	2
Al-attab, Ka	1	0	0.000204	0.47441	3.00	3	1
Yusoff, R	14	595	0.000258	1.370522	1.21	2	19
Kamarulzaman, N	14	595	0.000258	1.370522	1.21	2	19
Blagojevic, N	14	595	0.000258	1.370522	1.21	2	19
Avdeev, M	14	595	0.000258	1.370522	1.21	2	19
Bustam, Ma	14	13317	0.000302	1.539727	1.00	2	18
Rahman, Na	11	5920	0.000215	1.659309	1.00	2	17
Najafpour, Gd	10	2664	0.000271	1.602892	1.10	2	6
Younesi, H	10	2664	0.000271	1.602892	1.10	2	6
Vikineswary, S	10	3576	0.000191	1.566637	1.00	2	8
Cheow, Sl	9	1.219048	0.00033	1.004291	1.44	2	0
Teo, Lp	9	0.8	0.000224	1.005319	1.44	2	0
Taha, Rm	9	0.8	0.000224	1.005319	1.44	2	0
Zaidi, Sh	9	2.811905	0.00033	1.020017	1.22	2	0
Ruslan, H	9	6.75	0.000329	1.083803	1.11	2	0
Majlis, By	9	24210.92673	0.000383	1.179927	1.00	2	0
Daud, Mn	9	166.306887	0.000313	1.110599	1.00	2	0
Noor, Mm	8	0	0.000224	0.900336	1.63	2	0
Careem, Ma	8	0	0.000224	0.900336	1.63	2	0

Author Name	Degree	Betweenness Centrality	Closeness Centrality	PageRank	tie-strength	No. of Works	Times Cited
Yusuf, Snf	8	0	0.000224	0.900336	1.63	2	0
Khairy, My	8	0.8	0.00033	0.910485	1.50	2	0
Abdulateef, Jm	8	0	0.00033	0.881512	1.38	2	12
Iyuke, Se	8	1	0.000338	1.024859	1.38	2	12
Alwi, Srw	8	5212.91172	0.00029	1.320312	1.13	2	2
Ibrahim, Mz	8	5337	0.000369	1.141511	1.00	2	14
Aris, I	8	5325.426559	0.00031	1.311523	1.00	2	3
Zakaria, R	8	27097	0.000284	1.402462	1.00	2	11
Alias, Ab	8	2985	0.000191	1.438331	1.00	2	13
Khamies, H	7	0	0.000329	0.798702	2.00	2	0
Supranto	7	0.166667	0.000329	0.790742	1.57	2	0
Aziz, Sa	7	2.4	0.000215	1.044351	1.57	2	16
Rahman, Naa	7	17	0.000214	1.108799	1.14	2	16
Ismail, A	7	13419.77344	0.000345	1.079546	1.00	2	1
Nik, Wbw	7	3576	0.000304	1.283254	1.00	2	2
Wazed, Ma	7	1200	0.000269	1.169165	1.00	2	6
Yasin, Nhm	7	20905	0.000282	1.307252	1.00	2	16
Johari, A	7	1797	0.000229	1.506883	1.00	2	2
Wang, Jz	6	0.2	0.000208	0.937345	1.67	2	12
Chou, Sl	6	0.2	0.000208	0.937345	1.67	2	12
Aliyu, Mm	6	71.785015	0.000329	0.802756	1.33	2	8
Chawdar, A	6	196.666667	0.00033	0.96395	1.33	2	0
Hashim, N	6	0	0.000368	0.837761	1.33	2	23
Yousif, Bf	6	1797	0.000308	1.325309	1.00	2	8
Annuar, Msm	6	1797	0.000172	1.313378	1.00	2	8
Liaquat, Am	5	0	0.000267	0.749291	1.60	2	10
Takrim, R	5	0.25	0.000237	0.974073	1.60	2	0
Md-darus, Z	5	0.25	0.000237	0.974073	1.60	2	0
Badruddin, Ia	5	0	0.000268	0.756067	1.60	2	5
Minggu, Lj	5	1.5	0.000337	0.888703	1.20	2	17

Annexure H: Topological Properties of top 200 authors in the Malaysia network sorted on the Number of Works

Author Name	Degree	Betweenness Centrality	Closeness Centrality	PageRank	Vertex Tie-strength	No. of works	Times Cited
Demirbas, A	10	10395.9304	0.000193	2.174331	1.00	64	750
Hepbasli, A	45	47755.5787	0.000212	8.951498	2.56	56	250
Balat, M	5	1015.5	0.000153	1.509035	4.80	39	459
Dincer, I	32	68280.5172	0.000223	6.225473	2.53	38	210
Kaygusuz, K	12	18361.2663	0.000222	2.734756	1.50	27	95
Sari, A	17	17805.9787	0.00022	3.390397	2.47	19	145
Canakci, M	7	17342.8892	0.00019	1.724115	4.43	17	154
Oktay, Z	8	1486.15047	0.000201	1.708125	4.13	17	64
Kok, Mv	8	4057	0.000121	2.838838	1.25	16	11
Ilkilic, C	6	2292.16739	0.000238	1.323525	2.67	15	64
Demirbas, Mf	4	5391	0.000171	1.2098	2.50	14	290
Guru, M	18	29511.3093	0.000237	3.748907	1.67	14	70
Aydin, H	14	74823.6929	0.000262	2.500278	1.71	13	48
Yilmaz, M	32	64415.2014	0.000248	6.292652	1.19	13	68
Karaipekli, A	7	4330.33653	0.000219	1.385353	3.86	12	143
Ozgener, L	4	533.883333	0.000195	0.974789	3.50	12	58
Ozkar, S	9	4053.5	0.000178	2.402908	2.22	12	219
Kanoglu, M	8	2710.33333	0.000194	2.000077	2.13	12	86
Gungor, A	6	7160.98991	0.000194	1.309955	1.67	12	38
Coskun, C	4	238.295238	0.000194	0.8953	5.50	11	32
Sayin, C	5	239.174359	0.000178	1.225739	4.00	11	107
Balat, H	5	1015.5	0.000153	1.509035	3.60	11	417
Ozgener, O	4	533.883333	0.000195	0.974789	3.50	11	62
Aksoy, F	8	14037.128	0.000237	1.683557	2.75	11	105
Keskin, A	11	15079.5883	0.000226	2.231619	1.82	11	122
Gumus, M	8	18654.5837	0.00019	2.159687	1.75	11	59
Sahin, B	15	42525.7467	0.000234	2.529972	1.60	11	56
Saydut, A	11	167.566667	0.000199	1.624706	3.18	10	40
Balta, Mt	12	1826.21905	0.000201	2.005667	2.17	10	58
Ozsezen, An	4	115.489805	0.000181	0.967158	4.75	9	75
Caliskan, H	4	407.609524	0.000201	0.885538	3.75	9	25
Bayramoglu, G	9	904.166667	0.000213	1.716443	2.78	9	91
Arica, My	9	904.166667	0.000213	1.716443	2.78	9	91
Hamamci, C	13	9665.06667	0.0002	1.982448	2.77	9	34
Ozturk, Hk	13	11047.7333	0.000196	2.186349	2.54	9	46
Ozturk, I	6	6709	0.000196	1.321131	1.83	9	89
Sozen, A	9	59240.8139	0.000246	2.136979	1.56	9	24
Yuksel, I	3	1357	0.000193	1.155071	1.00	9	39
Abusoglu, A	2	0	0.000172	0.630449	4.50	8	65

Author Name	Degree	Betweenness Centrality	Closeness Centrality	PageRank	Vertex Tie-strength	No. of works	Times Cited
Yilanci, A	10	3688.73333	0.000196	1.631635	3.00	8	39
Alkan, C	7	479.742981	0.000206	1.393632	3.00	8	86
Sorgun, M	6	13293	0.00016	1.621612	2.00	8	3
Behcet, R	7	24098.2904	0.000241	1.374553	1.86	8	38
Yucesu, Hs	13	84167.6203	0.000265	2.566867	1.69	8	32
Bakirci, K	7	36729.4292	0.000241	1.360563	1.14	8	49
Kalinci, Y	3	0	0.000201	0.626516	4.33	7	74
Karabulut, H	4	0	0.000236	0.843318	4.00	7	18
Kirtay, E	2	0	0.000139	0.663072	4.00	7	157
Cinar, C	8	13240.1095	0.000249	1.575541	2.63	7	30
Karakoc, Th	6	1358.83333	0.000186	1.536359	2.33	7	5
Bilgili, M	4	14879.9513	0.000224	0.923927	2.25	7	14
Ozek, N	8	1354	0.000191	1.692962	2.13	7	22
Kucukali, S	1	0	0.000193	0.397323	2.00	7	27
Ozbayoglu, Me	6	2013	0.000159	1.738628	2.00	7	2
Koc, M	9	4345.10723	0.000227	1.866089	1.89	7	30
Kaya, D	12	37199.222	0.00021	2.006029	1.83	7	42
Sencan, A	10	5333.95899	0.000194	2.120906	1.70	7	32
Kocar, G	6	2033	0.000186	1.649423	1.67	7	26
Turkcan, A	4	115.489805	0.000181	0.967158	3.75	6	60
Erbay, Z	7	167.566036	0.000189	1.244545	2.71	6	23
Cetin, E	10	3688.73333	0.000196	1.631635	2.60	6	9
Selbas, R	4	122.416246	0.000176	0.981246	2.50	6	34
Yumrutas, R	5	2784.62635	0.000197	1.186728	2.00	6	20
Erdogan, S	13	25604.9	0.000228	1.984258	1.77	6	28
Aydin, K	11	10944.8901	0.000209	2.480326	1.36	6	77
Ertekin, C	13	11484	0.000186	2.547634	1.31	6	10
Yanik, J	18	7172.66667	0.000165	3.1217	1.17	6	30
Soyhan, Hs	17	10150.6245	0.000193	2.960693	1.12	6	29
Hazar, H	4	3350.76886	0.000224	1.073474	1.00	6	35
Ozbayoglu, Em	6	3382	0.000144	1.930175	1.00	6	4
Rakap, M	2	0	0.000159	0.65555	3.50	5	51
Celiktas, Ms	2	0	0.000165	0.667249	3.00	5	24
Sahiner, N	6	1014	0.000156	1.279083	2.67	5	13
Aktas, N	6	1014	0.000156	1.279083	2.67	5	13
Ozturk, M	3	0.5	0.000169	0.736802	2.67	5	17
Colak, N	6	0.2	0.000185	1.059934	2.50	5	29
Turgut, Et	4	1.833333	0.000186	0.931137	2.50	5	3
Bayrakceken, H	4	12.7	0.000205	0.963951	2.25	5	75
Sogut, Z	4	204.834524	0.000185	0.929135	2.00	5	11
Akansu, So	6	7699.19775	0.000195	1.42227	2.00	5	24
Bayindir, H	3	405.177152	0.00024	0.657136	2.00	5	13
Bezir, Nc	7	676.5	0.000191	1.465914	1.86	5	21

Author Name	Degree	Betweenness Centrality	Closeness Centrality	PageRank	Vertex Tie-strength	No. of works	Times Cited
Arpa, O	5	2784.62635	0.000197	1.186728	1.80	5	19
Altun, S	3	339	0.000173	0.924143	1.67	5	194
Yilmaz, T	7	18805.6409	0.000196	1.674871	1.57	5	16
Bicer, A	11	17006.7409	0.000224	2.067315	1.55	5	17
Buyukalaca, O	8	18073.2	0.000192	1.686532	1.50	5	20
Argunhan, Z	6	6045.60801	0.000212	1.268483	1.50	5	10
Akkaya, Av	10	577.991017	0.000213	1.579951	1.30	5	19
Ekren, O	8	3379	0.000195	1.654922	1.25	5	50
Yilmaz, E	4	679	0.000213	1.067652	1.25	5	6
Aslan, A	5	13289.1173	0.000225	1.131835	1.20	5	22
Korkmaz, S	10	4721	0.00017	2.107106	1.20	5	13
Bozkurt, A	16	19236.9059	0.000234	2.339215	1.19	5	56
Ust, Y	8	1606.49048	0.000204	1.556808	1.13	5	14
Acaroglu, M	8	6062	0.000163	2.462037	1.13	5	32
Sahin, S	9	13963	0.000202	2.085458	1.11	5	80
Koca, A	11	9778.57775	0.000225	2.383692	1.09	5	53
Cakanyildirim, C	1	0	0.000204	0.327032	4.00	4	16
Acaravci, A	1	0	0.000173	0.33716	4.00	4	24
Ozay, O	4	0	0.000141	0.891142	3.25	4	6
Inger, E	4	0	0.000141	0.891142	3.25	4	6
Icier, F	6	0.2	0.000185	1.059934	2.50	4	14
Dur, E	4	21.5	0.000198	0.839829	2.50	4	10
Kaya, C	8	1.5	0.000199	1.1981	2.38	4	26
Tat, Me	3	0	0.000185	0.707805	2.33	4	17
Kafadar, Ab	8	161.566667	0.000199	1.199936	2.25	4	6
Kahraman, N	5	508.184615	0.000189	1.19274	2.20	4	23
Duz, Mz	6	160.5	0.000199	0.93209	2.17	4	10
Cora, On	4	1.5	0.000196	0.954399	2.00	4	4
Altintas, B	6	224.666667	0.000213	1.157842	2.00	4	32
Ekinci, K	8	33	0.000185	1.352572	1.88	4	11
Metin, O	4	672	0.000178	1.048043	1.75	4	87
Aksoy, L	3	0	0.000205	0.733995	1.67	4	79
Ozcanli, M	6	1019.13846	0.000202	1.358826	1.67	4	59
Irmak, S	8	1122	0.000173	1.460142	1.63	4	11
Arcaklioglu, E	5	4.5	0.000211	1.298683	1.60	4	6
Hesenov, A	9	1798.5	0.000173	1.660073	1.56	4	8
Esen, H	4	1356	0.000173	1.269332	1.50	4	37
Keles, S	4	1	0.000193	1.026828	1.50	4	4
Erdem, Hh	9	136.481494	0.000213	1.391685	1.44	4	15
Akin, S	5	6045	0.000132	1.625959	1.40	4	4
Cakmak, G	8	9325.5	0.00021	1.690877	1.38	4	6
Rosen, Ma	6	1324.39784	0.000201	1.314812	1.33	4	2
Baris, K	3	679	0.000222	0.872906	1.33	4	23
Oztop, Hf	6	1694	0.000196	1.586166	1.33	4	24

Author Name	Degree	Betweenness Centrality	Closeness Centrality	PageRank	Vertex Tie-strength	No. of works	Times Cited
Sahin, Hm	7	1016	0.000178	1.549704	1.29	4	4
Ata, A	15	6666.22684	0.000226	2.056669	1.20	4	42
Oner, C	6	3133.58673	0.000196	1.595211	1.17	4	68
Ozyurt, O	6	15553.376	0.000238	1.218617	1.17	4	9
Teke, I	14	9707.49431	0.000214	2.393936	1.14	4	59
Gunes, S	15	13887	0.000171	2.403254	1.13	4	16
Yakut, Ak	9	10253.9789	0.000214	1.872226	1.11	4	5
Inan, A	10	2033	0.000202	1.791098	1.10	4	2
Dizge, N	12	5389	0.00017	2.559181	1.08	4	47
Cetin, M	6	8043	0.000126	1.567517	1.00	4	21
Demirbas, T	3	1357	0.000153	1.277329	1.00	4	33
Alptekin, E	1	0	0.000168	0.359357	3.00	3	31
Ceper, Ba	3	0	0.000173	0.773377	2.67	3	6
Yoru, Y	3	0	0.000185	0.734601	2.33	3	4
Altiparmak, D	3	0	0.000216	0.688259	2.33	3	7
Oner, Y	5	0	0.000173	0.846265	2.20	3	6
Colak, M	7	5.4	0.000174	1.136197	2.14	3	6
Kasikci, I	7	5.4	0.000174	1.136197	2.14	3	6
Ozdemir, K	3	0	0.000189	0.704178	2.00	3	6
Eskin, N	3	0	0.000189	0.704178	2.00	3	6
Ekren, By	2	0	0.000173	0.570626	2.00	3	47
Alp, I	2	0	0.000221	0.542403	2.00	3	10
Inalli, M	2	0	0.000155	0.72997	2.00	3	17
Zahmakiran, M	3	0.5	0.000159	0.918562	2.00	3	81
Iscan, Ag	2	0	0.000112	0.785437	2.00	3	2
Ozturk, Hh	8	33	0.000185	1.352572	1.88	3	9
Tonbul, Y	7	0.4	0.000199	1.05774	1.86	3	4
Aydogan, H	3	1014	0.000147	1.018543	1.67	3	48
Hascakir, B	3	669	0.000132	1.00623	1.67	3	2
Aydin, F	8	9352.5	0.0002	1.279956	1.63	3	3
Hancioglu, E	9	4	0.000186	1.507356	1.56	3	10
Varol, Y	4	338	0.000196	1.036667	1.50	3	22
Kabul, A	2	0	0.000187	0.568385	1.50	3	3
Erbatur, O	8	1122	0.000173	1.460142	1.50	3	8
Midilli, A	5	220.593557	0.000212	1.07717	1.40	3	9
Bicak, N	8	2031	0.000213	1.598581	1.38	3	22
Ulgen, K	3	2031	0.000185	0.958615	1.33	3	14
Atmaca, M	3	185.222222	0.00018	0.845988	1.33	3	6
Kandilli, C	3	679	0.000165	1.140181	1.33	3	3
Parlak, A	9	5388.78255	0.000204	1.510269	1.33	3	5
Sarac, Hi	6	1356	0.000171	1.337725	1.33	3	16
Yaldiz, O	9	8114.5	0.000186	1.588678	1.33	3	8
Yasar, A	6	15437.1091	0.000229	1.332594	1.33	3	3
Kar, Y	3	0	0.000191	0.711809	1.33	3	1

Author Name	Degree	Betweenness Centrality	Closeness Centrality	PageRank	Vertex Tie-strength	No. of works	Times Cited
Yasar, H	10	1011.10596	0.000186	1.651133	1.30	3	20
Dundar, F	10	1462.79277	0.00021	1.538065	1.30	3	10
Can, O	7	9377.04795	0.000247	1.515399	1.29	3	22
Eyidogan, M	4	18107.1553	0.000197	0.912493	1.25	3	9
Aydin, S	8	45931.0657	0.000254	1.482005	1.25	3	19
Buyukutku, Ag	4	679	0.000192	1.028425	1.25	3	0
Guney, Ms	4	0	0.000209	0.882461	1.25	3	11
Acar, M	4	679	0.000213	1.098773	1.25	3	0
Karaca, H	4	679	0.000213	1.098773	1.25	3	1
Sen, N	5	16758.011	0.000216	1.107197	1.20	3	4
Ar, I	6	1359	0.000204	1.539971	1.17	3	1
Dikmen, E	6	3308.35571	0.000182	1.362326	1.17	3	26
Acir, A	6	3709	0.000178	1.354642	1.17	3	3
Sen, U	13	6700	0.000203	1.401518	1.15	3	36
Demirel, Ih	7	7363.5	0.000192	1.560613	1.14	3	0
Ozturk, T	7	6040.5	0.000185	1.615616	1.14	3	6
Comakli, K	7	25927.3406	0.000232	1.388243	1.14	3	51
Keskinler, B	7	2024	0.00017	1.690723	1.14	3	1
Ucar, S	8	11919	0.000184	1.564363	1.13	3	17
Comakli, O	9	27603.814	0.000235	1.733332	1.11	3	19
Ozdemir, A	8	55917.0178	0.000234	1.793665	1.00	3	4
Kucuk, H	7	7220.15848	0.000215	1.446345	1.00	3	0
Icli, S	14	8051	0.000174	2.308663	1.00	3	10
Ceylan, H	8	5388	0.000174	1.720481	1.00	3	15
Aktacir, Ma	4	677.52381	0.000174	0.980032	1.00	3	10
Bulut, H	5	799.15	0.00017	1.255969	1.00	3	3
Sariciftci, Ns	13	6057	0.000154	2.322928	1.00	3	16
Demir, A	6	2033	0.000139	1.59424	1.00	3	5
Eryilmaz, T	7	11692.1446	0.000207	1.649346	1.00	3	60
Ogut, H	6	9348	0.000182	1.708096	1.00	3	15

Annexure I: List of Universities in Malaysia with their Acronyms

Acronym	Unofficial translation in English	Official Name in Malay	Location
PUBLIC UNIVERSITIES			
UTM	University of Technology, Malaysia	Universiti Teknologi Malaysia	Skudai, Johor
UTHM	Tun Hussein Onn University of Malaysia	Universiti Tun Hussein Onn Malaysia	Batu Pahat, Johor
UUM	Northern University, Malaysia	Universiti Utara Malaysia	Sintok, Kedah
UMK	University of Malaysia, Kelantan	Universiti Malaysia Kelantan	Pengkalan Chepa,Kelantan
UPNM	National Defence University of Malaysia	Universiti Pertahanan Nasional Malaysia	Kuala Lumpur
UM	University of Malaya	Universiti Malaya[8]	Kuala Lumpur
UTeM	Technical University of Malaysia, Melaka	Universiti Teknikal Malaysia Melaka	Durian Tunggal, Malacca
USIM	Islamic Science University of Malaysia	Universiti Sains Islam Malaysia	Nilai, Negeri Sembilan
UMP	University of Malaysia, Pahang	Universiti Malaysia Pahang	Kuantan, Pahang
USM	Science University, Malaysia	Universiti Sains Malaysia	Gelugor, Penang
UPSI	Sultan Idris University of Education	Universiti Pendidikan Sultan Idris	Tanjung Malim, Perak
UniMAP	University of Malaysia, Perlis	Universiti Malaysia Perlis	Arau, Perlis
UMS	University of Malaysia, Sabah	Universiti Malaysia Sabah	Kota Kinabalu, Sabah
UNIMAS	University of Malaysia, Sarawak	Universiti Malaysia Sarawak	Kota Samarahan, Sarawak
IIUM	International Islamic University of Malaysia	Universiti Islam Antarabangsa Malaysia	Gombak, Selangor
UKM	National University of Malaysia	Universiti Kebangsaan Malaysia	Bangi, Selangor
UiTM	MARA University of Technology	Universiti Teknologi MARA	Shah Alam, Selangor
UPM	Putra University, Malaysia	Universiti Putra Malaysia	Serdang, Selangor
UNISZA	Sultan Zainal Abidin University	Universiti Sultan Zainal Abidin	Kuala Terengganu,Terengganu
UMT	University of Malaysia, Terengganu	Universiti Malaysia Terengganu	Kuala Terengganu,Terengganu
PRIVATE UNIVERSITIES			
AIMST	AIMST University	Universiti AIMST	Bedong
AIU	Albukhary International University	University Antarabangsa Albukhary	Alor Setar
KUIN	Insaniah University College	Kolej Universiti Insaniah	Alor Setar
AeU	Asia e University	—	Kuala Lumpur
UCTI	Asia Pacific University College of Technology and Innovation	—	Kuala Lumpur
BERJAYA UCH	BERJAYA University College of Hospitality	—	Kuala Lumpur
HELP	HELP University College	—	Kuala Lumpur
INCEIF	International Centre for Education in Islamic Finance	—	Kuala Lumpur
IMU	International Medical University	Universiti Perubatan Antarabangsa	Kuala Lumpur
IUCTT	International University College Of Technology Twintech	Kolej Universiti Teknologi Antarabangsa Twintech	Kuala Lumpur
KLMUC	Kuala Lumpur Metropolitan University College	Kolej Universiti Metropolitan Kuala Lumpur	Kuala Lumpur

Acronym	Unofficial translation in English	Official Name in Malay	Location
OUM	Open University Malaysia	Universiti Terbuka Malaysia	Kuala Lumpur
UTAR	Tunku Abdul Rahman University	Universiti Tunku Abdul Rahman	Kuala Lumpur
UCSI	UCSI University	Universiti UCSI	Kuala Lumpur
UniKL	University of Kuala Lumpur	Universiti Kuala Lumpur	Kuala Lumpur
MMU	Multimedia University	Multimedia University	Melaka
INTI-IU	INTI Laurette International University	Universiti INTI	Nilai
NUC	Nilai University College	Kolej Universiti Nilai	Nilai
UCL	Linton University College	Kolej Universiti Linton	Mantin
STM	Malaysia Theological Seminary	Seminari Theoloji Malaysia	Seremban
WOU	Wawasan Open University	Universiti Terbuka Wawasan	Penang
Curtin	Curtin University of Technology	—	Miri
Swinburne	Swinburne University of Technology	—	Kuching
MEDIU	Al-Madinah International University	—	Shah Alam
BUCME	Binary University College of Management and Entrepreneurship[30]	—	Puchong
CUCMS	Cyberjaya University College of Medical Sciences	Kolej Universiti Sains Perubatan Cyberjaya	Cyberjaya
UNISEL	Industrial University of Selangor	Universiti Industri Selangor	Bestari Jaya
KLIUC	Kuala Lumpur Infrastructure University College	Kolej Universiti Infrastruktur Kuala Lumpur	Kajang
KDU	KDU University College	Kolej Universiti KDU	Petaling Jaya
LUCT	Limkokwing University of Creative Technology	Universiti Teknologi Kreatif Limkokwing	Cyberjaya
MUST	Malaysia University of Science and Technology	Universiti Sains dan Teknologi Malaysia	Petaling Jaya
MSU	Management and Science University	—	Shah Alam
Monash	Monash University	—	Subang Jaya
MMU	Multimedia University	Universiti Multimedia	Cyberjaya
UNiM	University of Nottingham	Universiti Nottingham Kampus Malaysia	Semenyih
SEGi	SEGi university college	Kolej Universiti SEGi	Kota Damansara
KUIS	Selangor International Islamic University College	Kolej Universiti Islam Antarabangsa Selangor	Bandar Sri Putra Bangi
—	Sunway University	—	Subang Jaya
—	Taylor's University	Kolej Universiti Taylor's	Subang Jaya
UNITEN	Tenaga Nasional University	Universiti Tenaga Nasional	Putrajaya
UNITAR	Tun Abdul Razak University	Universiti Tun Abdul Razak	Petaling Jaya
TATiUC	TATI University College	Kolej Universiti TATI	Kemaman