To Form a Smaller World in the Research Realm of Hierarchical Decision Models

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***Abstract*- People use hierarchical decision models (HDMs) in industrial and academic fields. The closer collaborative relationships among the researchers have the world of research in HDM shrinking. We want to identify the clusters of the researchers and the central member of them in order to build up connection, trying to make the new research widely known and the collaboration done.**

The social network analysis method is employed to analyze the network of HDM researchers who are connected by co-authorship in the selected papers. We find out the most important researchers with the highest degree centralities and publication frequencies; we also identify the core researchers in the Top 8 components. By acting as the "information gatekeeper" and connecting the identified researchers, the average distance between the vertices is significantly eliminated and we form a smaller world in the research realm of HDMs.

***Keywords*- *Social Network Analysis; Small World; Co-Authorship;* Hierarchical Decision Models; Analytical Hierarchy Process**

I. INTRODUCTION

To decompose problems into hierarchical levels in decision making, many hierarchical decision models (HDMs) [1] have been well developed. The methodology is used widely in academic and industrial fields. A great number of researchers use HDMs to conduct their research. The new development of this methodology has significant impact to the researchers as long as it is known to them who regularly employ this method.

It is wished that the new research [2] about the method of HDMs is to be known by the people who are familiar with it and frequently use it as soon as possible. Diffusing the knowledge among the researchers' network is a tough job.

In order to diffuse the new knowledge among the HDM research circle, an in-depth study using the network of co-authorship in the papers about HDMs and the social network analysis (SNA) methodology [3] is conducted to identify the crucial nodes in the network. A large number of researchers have been recognized in the social network since we find a big number of co-authorship connections among the authors of the papers. The degree centrality and the frequency of publications are used as the indicators of the influencing power of a node in the co-authorship network. The key nodes in the isolated components of the researchers' network are regarded as significant as we can find ways to diffuse the knowledge to their groups when the connection to them is built up.

The authors have planned to contact the central persons and act as an *information gatekeeper*, who functions as a centre to exchange information among the key nodes, in this way a sub-network among the most influencing persons is set up. The average distance between the nodes of the network will be sharply decreased enabling the knowledge to diffuse more easily and thus form a smaller world in the research field of HDMs. It is also believed that new knowledge will emerge more easily through the cooperation and the accelerated information exchange in this research realm of HDMs.

II. METHODOLOGY

As a quantitative research method, social network analysis (SNA) is based on mathematics and graph theory. People have used the concept of social network since a century ago. Social network is a social structure constituted by individuals or organizations which are called nodes. They are connected by one or more specific types of relationship. SNA is a set of analytical tools used to map networks of relationship, originating from social science research providing a significant means of assessing and promoting collaboration in strategically important groups [4, 5].

SNA uses graphs to represent networks, in which the individual actors are represented by the nodes and the relationship are represented by ties between the actors in the networks. The data are visualized by the social network charts [6, 7]. The visualization of the social network gives the abstract of the relationship of the co-authors and an overall outline of the status of connections between the authors.

Two types of graphs are commonly used in SNA, i.e., simple graphs and directed graphs. Simple graphs connect nodes that have relationship with each other, meanwhile, directed graphs use arrows to indicate the direction when the relationship occurs from one to another [5, 8].

Several social network metrics are employed that enable to measure the characteristics of a network, including components analysis and centrality analysis. Explanations for component analysis and the metrics used are as follows.

A. Component Analysis

A component of a network is a substructure in which there is at least a path connecting a node and any other node. A network may include some components which are isolated from each other without any connections. The size of a component indicates the number of nodes it contains. Component analysis is used to study the network structure. The component analysis is employed to study academic circles of the HDM/AHP research in this paper.

B. Centrality Analysis

The earliest pursued category of methodology in the social network analysis is the *centrality* of individuals and organizations in their social networks [3, 9]. Different kinds of centralities including *degree*, *betweenness* and *closeness*, give rough indications of the social power from several different viewpoints of a node based on how well they "connect" the network [10, 11].

Degree centrality denotes the number of ties connected to a node in the network. Important nodes usually have high degree. $C_D(n_i)$ is the degree of node n_i and is calculated by the equation as follows.

$$C_D(n_i) = \sum_{i \neq j} X_{ij}$$

X_{ij} equals *0* or *1*, *0* means actor *i* has no tie with actor *j*, while *1* means they do have a tie.

The normalized value of degree centrality of actors in the network can be calculated by the formula as follows.

$$C_D{}'(n_i) = \frac{\sum_{i \neq j} X_{ij}}{g-1}$$

The *g* represents the total number of the actors in the network.

Betweenness indicates the extent to which a particular node lies between the various other nodes in the network. For instance, among *3* nodes, *A*, *B* and *C*, *A* is connected with *C* and *B* is connected with *C*, but no connection exists between *A* and *B*. Therefore, *C* is the key node between *A* and *B* when *A* and *B* want to connect to each other. The role of *broker* or *gatekeeper* is played by the actor with high betweenness who at same time is endowed a potential for control over others.

The *betweenness centrality* of a node in a network is calculated by the following formula.

$$C_B(n_i) = 2\sum_{j \prec k} g_{jk}(n_i)/g_{jk}$$

The normalized value of the *betweenness centrality* of a node in a network is calculated by the following formula.

$$C_B{}'(n_i) = 2\frac{\sum_{j \prec k} g_{jk}(n_i)/g_{jk}}{(g-1)(g-2)}$$

The g_{jk} is the number of shortest paths between actor *j* and actor *k*. $g_{jk}(n_i)$ is the number of the shortest paths between *j* and *k* which contain node n_i.

The metric of *closeness* measures how close a node is to all other nodes in a network, indirectly or directly. It is used only in the connected network, in which every node has at least one path to the other.

The normalized number of steps is indicated by the centrality of *incloseness/outcloseness*, i.e., the number of required steps to access every other node from a given node in a directed network. The *outcloseness centrality* considers only the outdegree of a node. The *incloseness centrality* considers only the indegree of a node. They are calculated by the similar formula, shown as follows.

$$C_C{}'(n_i) = \frac{g-1}{\sum_{j=1}^{g} d_I(n_i, n_j)}$$

The *distance* of one node is defined as follows.

$$C_{Distance}'(n_i) = \frac{\sum_{j=1}^{g} d_I(n_i, n_j)}{g-1} = \frac{1}{C_C'(n_i)}$$

The node n_i is connected to all other nodes n_j:$j=1,\ldots,m$ by its shortest paths $d_I(n_i,n_j)$, where $j \neq i$ and the Node n_i is regarded as central when its closeness centrality is calculated. The calculation of *incloseness/outcloseness* is then standardized on the size of the network g.

The $d_I(n_i,n_j)$ is the number of ties included in the shortest directed path from a Node n_j to Node n_i and $d_I(n_i,n_j) \neq d_I(n_j,n_i)$. The bigger the *clossness* of one node is, the closer the nodes are connected to other nodes. In another word, the smaller the clossness one node has, the greater distance of the node to others is.

Assuming that the $d_I(n_i,n_j)$ of Node i and Node j, which are in different networks not connected, to be infinite, they will have immense distance to each other. In this situation, the *clossness* of one node in the network which is not connected approaches 0.

The *degree centrality* is used to find out the key researchers in the co-authorship network, *betweenness centrality* is used to measure the connecting power of an *information gatekeeper* who connects the key nodes and then the *closeness centrality* is used to measure the distance of steps between the nodes in the biggest component.

III. TO FORM A SMALL WORLD IN THE RESEARCH REALM OF HDM

Our objective of this research is to identify the clusters of the researchers in HDM and the central members of them in order to build up connection, trying to make the new research widely known and the collaboration done.

In order to approach the objective, the following steps are going to be completed:

- To form the network of main researchers and examine the average distance of the researchers in the network
- To find out the central researchers and connect us with the central researchers in order to form a smaller world network
- To measure the distance of the researchers in the improved network and verify the effect of the action

A. Generating the HDM/AHP Co-authorship Network

The co-authorship network is an important category of social networks. The scientific collaboration is shown by the connections via co-authorship which can indicate the authors' status [4]. It is used to analyse the important researchers and academic groups [12, 13].

There are many database which present good quality of co-authorship, such as Science Citation Index Expanded (SCI) database, Compendex database, INSPECT database, ScienceDirect database, ProQuest Dissertations & Theses (PQDT) database and so on.

The similar co-authorship network could be applied to many databases. However, among these databases, we choose to use the SCI database to conduct research for three reasons: (1) this database has long history and qualified papers to cite; (2) SCI database has high recognition in the academic and research arena across the world; (3) the data are accessible by the authors of this paper.

SCI database is used as the data origin to generate the HDM/AHP co-authorship network in order to convey the SNA study. SCI is a citation index originally produced by the Institute for Scientific Information (ISI) and created by Eugene Garfield in 1960, owned by Thomson Reuters. More than 6,500 notable and significant journals, which are regarded as the world's leading journals of science and technology because of a rigorous selection process, are covered by the larger version (Science Citation Index Expanded), across 150 disciplines, from 1900 to the present. All the papers are selected from the database of SCI.

As the world has become more complex, decision problems must contend with increasingly complex relationships and interactions among the decision elements. To assist decision makers and analysts, different methods have been developed to decompose problems into hierarchical levels and formulate hierarchical decision models (HDM). Analytical Hierarchy process (AHP) was developed by Saaty [1, 14] and was widely spread. Hierarchical Decision Models (HDMs) are based on the same basic concept of dealing with multiple decision levels but using different pairwise comparison scales and judgment quantification techniques. HDMs were developed concurrent with or shortly after the introduction of AHP [15, 16, 17, 18, 19, 20, 21].

The keywords of *hierarchical decision model* and *analytical hierarchy process* were used in order to search in the abstracts of the papers from 1980 to April 2011. 3,235 authors in 1,561 papers were found out. The selection of keywords is based on the suggestion of 4 researchers and the main related keywords for the hierarchical decision models.

Then the network is constructed in the following way. For instance, there are three papers: *P1*, *P2* and *P3*. *P1* has two authors: *a1* and *a2*. *P2* has three authors: *b1*, *b2* and *a1*. *P3* has three authors: *c1*, *c2* and *a1*. It is shown like this:

P1 {a1, a2}

P2 {b1, b2, a1}

P3 {c1, c2, a1}

Since the first author of a paper is the most important one, he/she is tied with other co-authors. Wherever, the other co-authors are not tied. The co-author such as *b2* with *a1*, *c2* with *a1* are not linked, who are not the first authors although they do have a co-authorship. We only link *a1* to *a2*, *b1* to *b2*, *b1* to *a1*, *c1* to *c2* and *c1* to *a1*. The links are directed, the arrows point from the first authors to the other(s). The network is drawn like Fig. 1.

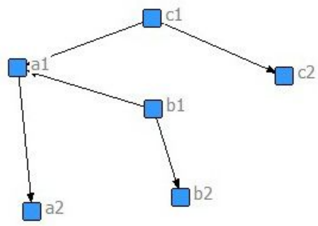

Fig. 1 A Co-authorship Network As an Example

The whole co-authorship network is generated with the SNA software UCINET 6.0 and the result is obtained. Then the pendant and isolated nodes are removed for several times until no more nodes can be removed. A simplified network shows up which is clearer, as shown in Fig. 2 [22, 23, 24]. The size of the nodes indicates the degrees centrality of the nodes. The different shape or colour identifies that the nodes belong to different components of the network.

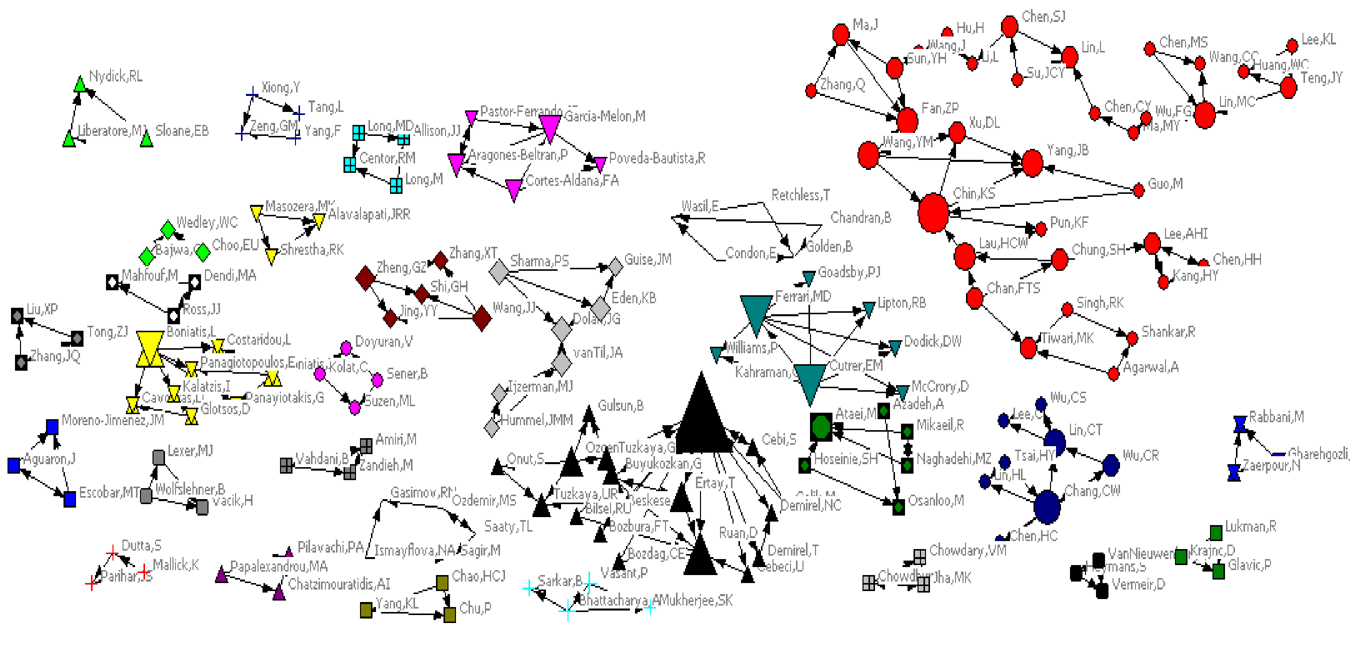

Fig. 2 Simplified HDM/AHP Co-authorship Network

It is obvious that there are some key nodes which have much bigger degrees than the other ordinary nodes. Each node's *degree centrality* is calculated so that the key nodes in the network are found out. The *betweenness* centrality is calculated so that the most powerful nodes which have the most power of *broker* or *gatekeeper* are identified.

The *closeness centrality* is used to measure the distance of nodes in the network. The nodes' *closeness centrality* approaches 0 since there are several isolated groups in the network which are not connected.

B. Key Authors Analysis

The key authors are identified in the co-authorship network by degree centrality ranking and frequency ranking. Authors with high degrees are important since they have more relationship with the others. The authors who have published a big number of papers are also significant. So we work over the degrees of the authors and the frequencies of publications of the authors in SCI database [25, 26].

The software is used to find out all the degree centralities of the authors in the network and then the authors are ranked by descending degree. As the result, the Top 11 authors are found out with the Top 10 highest degree shown in Tab. I.

TABLE I TOP 11 AUTHORS BY DEGREE

No.	Name	Degree
1	Wang, YM	30
2	Kahraman, C	30
3	Chan, FTS	23
4	Chin, KS	20
5	Chang, CW	20
6	Lin, CT	18
7	Wu, CR	17
8	Bhattacharya, A	16
9	Hu, H	15
10	Lee, AHI	15
11	Shin, T	15

The other metric is the frequency indicating the count number of papers by each author. The frequency is calculated and the authors are arranged by descending ranking. The Top 13 authors are selected with the 10 highest frequencies, which are shown in Tab. II.

TABLE II TOP 13 AUTHORS BY FREQUENCY

No.	Name	Frequency
1	Kahraman, C	29
2	Wang, YM	21
3	Lin, CT	16
4	Chan, FTS	15
5	Chin, KS	15
6	Lee, AHI	14
7	Wu, CR	14
8	Buyukozkan, G	13
9	Chang, CW	12
10	Ayag, Z	10
11	Saaty, TL	10
12	Ruan, D	10
13	Tzeng, GH	10

Tab. I and Tab. II are combined considering both degree centrality and frequency and found the 16 key authors shown in Tab. III. The sequence of the authors are listed firstly by the decreasing order of frequency and secondly by the descending order of the degrees of the authors.

TABLE III THE 16 MOST IMPORTANT AUTHORS IN THE RESEARCH OF HDM/AHP IN THE SCI DATABASE

No	Name	Frequency	Degree
1	Kahraman,C	29	30
2	Wang,YM	21	30
3	Lin,CT	16	18
4	Chan,FTS	15	23
5	Chin,KS	15	20
6	Wu,CR	14	17
7	Lee,AHI	14	15
8	Buyukozkan,G	13	12
9	Chang,CW	12	20
10	Ruan,D	10	10
11	Tzeng,GH	10	10
12	Saaty,TL	10	9
13	Ayag,Z	10	5
14	Bhattacharya,A	9	16
15	Shin,T	3	15
16	Hu,H	1	15

The most important authors of HDM/AHP are found out by the SNA of co-authorship network. They are important because they are high in either degree centrality or frequency of papers. Some of them are high in both degree and frequency.

C. Research Circle Analysis

This research is done in order to connect the scattered researchers of HDM together and enable the information to be exchanged in the network more easily which will enable knowledge to diffuse more quickly. Many research groups are isolated from each other, hampering the diffusion of knowledge from one group to another. The most influencing nodes are identified in the bigger groups and connected together.

Components analysis is used to find out research groups of HDM/AHP [27, 28]. There are 780 components in the network which cover 98.9% of the nodes. We select the Top 8 components with the biggest sizes, with each component having more than 18 authors. 15 out of the 16 important authors have already been found out in the previous research. The 8 components and important authors are shown in Tab. IV. The proportion indicates the percentage of the authors' number of different components in the total number of the authors.

TABLE IV TOP 8 COMPONENTS IN THE CO-AUTHORSHIP NETWORK OF THE HDM/AHP RESEARCH IN SCI

Component	Location	Nodes	Proportion	Important Authors
1	China and Hong Kong	310	9.6%	Chan, FTS; Chin, KS; Hu, H; Lee, AHI ; Tzeng, GH; Wang, YM
2	Turkey	50	1.5%	Buyukozkan, G; Kahraman, C ; Ruan, D
3	Taiwan	37	1.1%	Chang, CW; Lin, CT; Wu, CR
4	USA	35	1.1%	Saaty, TL
5	Taiwan	27	0.8%	Chao, HCJ (representative)
6	Europe	24	0.7%	Bhattacharya, A
7	Canada	22	0.7%	Zhang, GQ (representative)
8	Republic of Korea	18	0.6%	Shin, T

Components 1, 2, 3, 4, 6 and 8 all have the key authors identified by degree centrality and frequency methods as the leading researchers. However, no key researchers in Components 5 and 7 have been identified.

Component 5 has 27 authors without identified important authors. It contains authors like Wey, W.M.; Tseng, H. Y.; Yeh, C. H.; Wang, S. Y.; Chao, H. C. J.; Yang, K. L.; Chu, P. and so on. This is a Taiwanese academy circle. We choose Chao, H. C. J. as the representative of this component because he/she has the biggest out degree in the refined network after eliminating the pendent nodes.

Component 7 has 22 authors without identified important authors. It has authors like Amin, S. H.; Razmi, J.; Zhang, G. Q. who are the scholars in Canada. We choose Zhang, G. Q. as the representative since he has the biggest degree in this circle.

We add Chao, H. C. J. and Zhang, G. Q. as the representative of Components 5 and 7 respectively through component analysis. The number of identified key researchers increases from 16 to 18.

D. To Connect the Most Influencing Nodes

18 researchers have been selected who have the most influencing power in the realm of HDM. We want to connect them in order to form a powerful subnet in which the communication between the key researchers is improved efficiently. This action not only facilitates the information exchange among the 18 researchers but also enables the information to exchange more quickly because of the spillover effect of knowledge that the key researchers bring to their academic circles.

As a node in the network, we add ourselves as the *information gatekeeper* node in the network, trying to facilitate the information exchange among the network. The main actions include sending emails to the selected researchers about the new research of us, initiating discussions within the subnet by online social network or by conferences. There is a high possibility that the new research will interest them because they all have used the HDMs to do research. If this action goes smoothly, they will be willing to take part in the discussion and pass the knowledge to others who have close relationship with them through their network.

IV. RESULT

The co-authorship network is renewed and depicted as Fig. 3, assuming that close cooperation links are set up among each of the 18 authors and the relationship links are added to the network.

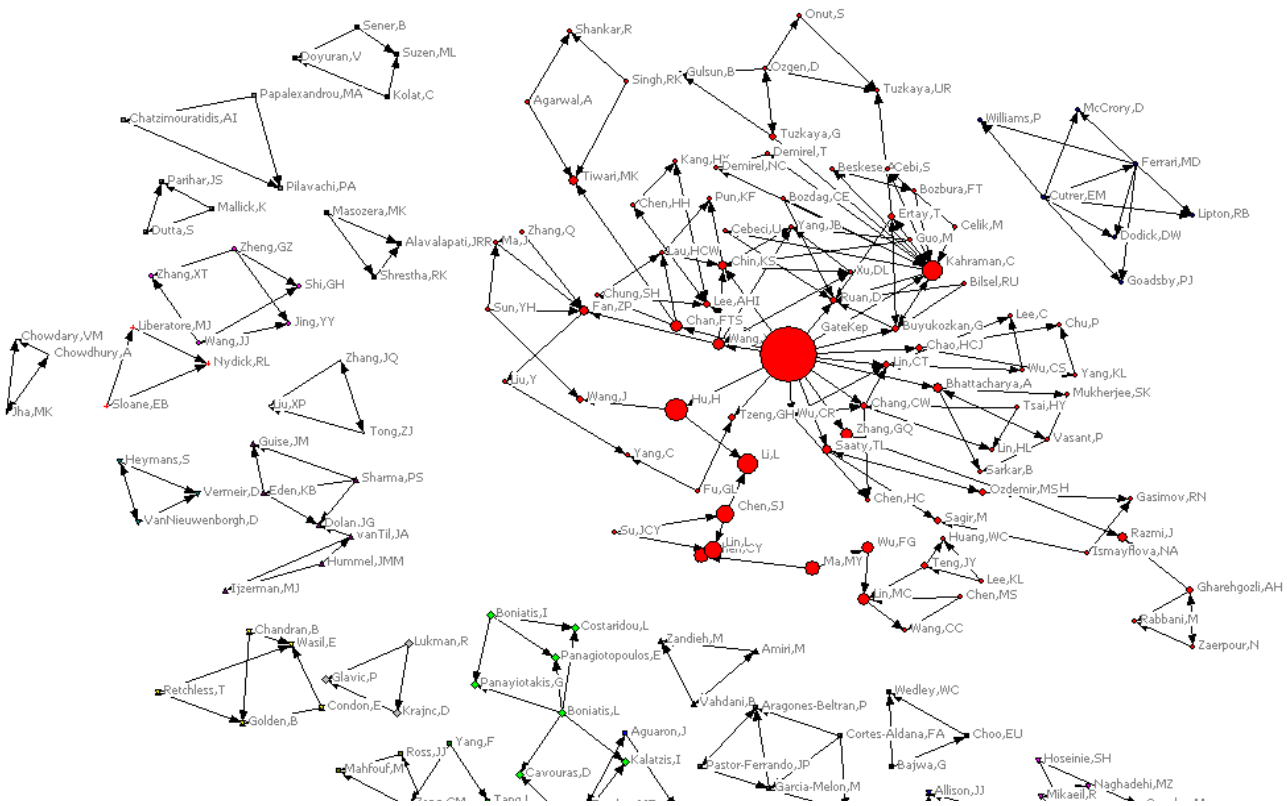

Fig. 3 Updated HDM/AHP Co-authorship Network

The size of the nodes indicates the betweenness centrality of the nodes and the different shapes of the nodes indicate that the nodes belong to different research groups. This updated network meshed 526 authors together, with the proportion of 16.25% in the total authors, after adding the arrows between the information gatekeeper and the 18 selected influencing nodes. Acting as the information gatekeeper, we have the highest betweenness centrality in this network which is 2,880. There are several other information gatekeepers in this net, Hu H., Li L., Kahraman C., with the highest betweenness centralities which are 999, 852 and 834 respectively.

This action of connecting influencing researchers efficiently connects the 8 isolated research groups into a connected network by communicating directly with the selected 18 central nodes using the star graph topology structure.

The average *incloseness* and *outcloseness* of the biggest component which contains 526 authors are 0.191 and 0.192 respectively. Because that the original network's clossness approaches 0, it can be seen clearly that the action has shortened the distance between the researchers and the result verifies the effect of our action.

Furthermore, this action will also facilitate the communication among the 19 nodes. If we know each other and are communicate with any other nodes, a fully connected network will be formed among the 19 vertices. The average incloseness and outcloseness of the biggest component which contains 526 authors will further increase to 0.201 and 0.204 respectively, showing that the 526 researchers in the main component are getting even closer.

V. CONCLUSION

The co-authorship social network of the HDM/AHP research circle is depicted by obtaining the data from SCI database. There are 18 most important authors in the network identified by three metrics, i.e., degree centrality, publication frequency and component analysis. The 18 important authors are going to be connected by email, online social network and conferences, to form a smaller world in the research realm of HDM and facilitate the knowledge diffusion by closer academic cooperation. This action will endow us with the power of information gatekeeper in the network. The SNA results provide researchers in the research realm with a clear view of the map around the world and help the related conference organizers with a mean to facilitate the HDM/AHP research collaboration. The research is applied to other research topics other than HDM/AHP. The social network about one research topic could be monitored so as to understand the dynamic evolution of the research circle and facilitate the research cooperation.

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