A Study on the Determination of R&D Priorities in the Fields of Wind Power using Network Analysis

Young-Il Kwon, Dae-Hyun Jeong

***Abstract*—** The increasing interest in the environment and the preparation for the ultimate exhaustion of fossil fuels have promoted the technology development for renewable energy sources. Advanced countries are offering various policies and incentives to support the technology development for renewable energy sources. For the countries that have started late technology development to catch up the advanced countries, it is efficient to select the limited research fields and spend the limited R&D costs on them. When developing wind power-related component parts, network analysis with patent data was applied to investigate which component part should be developed first in order for technology to have large spread effects.

In this study, methods for determining R&D priorities were presented with comprehensive consideration of the components in the fields of wind power, along with degree centrality and betweeness centrality of IPC.

***Keywords*—** Network analysis, Patent analysis, Technology trend, Wind power,

I. Introduction

Since responsibilities for greenhouse gas reductions, such as worldwide enforcement of environmental law on using fossil fuels in response to the global warming, need to be fulfilled according to the “Climate Change Agreements”, increasing attention has been given to renewable energy that can minimize the environmental costs. Because national growth depends on the stable acquisition and management of energy resources in the future, major advanced countries are promoting the policy on the extended use of renewable energy sources for sustainable economic development. Upon recognizing the importance of stable energy supply due to the recent drastic changes in oil price, the development of technologies for renewable energy has been actively pursued.

Wind energy is an eco-friendly renewable energy source that does not cause environmental pollution, and therefore it is spreading fast worldwide. Wind energy has a cheaper power generation unit cost than other renewable energy sources.

Young-Il Kwon is with the Korea Institute of Science Technology Information, Hoegi-ro 66, Dong Daemun-gu ,Seoul, KOREA (phone: +82-2-3299-6031 ; fax: +82-2-3299-6117 ; e-mail: ylkwn@kisti.re.kr).

Dae-Hyun Jeong is with the Korea Institute of Science Technology Information, Hoegi-ro 66, Dong Daemun-gu ,Seoul, KOREA (corresponding author’s phone: +82-2-3299-6238 ; fax: +82-2-3299-6117 ; e-mail: gregori79@kisti.re.kr).

Wind power is an electricity generation technology that involves the conversion of kinetic energy of air molecules into mechanical energy, using a wind power generator that converts wind energy into electrical energy. The wind rotates the blades in the wind power generator, and the rotation power of the blades generates electricity.

In Europe where R&D has long been conducted, many onshore wind power generators have already been used, and recently, offshore wind power generators have also been developed and used[1].

A. Components of Wind Power Generator

A wind power generator consists of a momentum conversion device that absorbs and converts wind energy, as well as a power-delivery device and a control device, and each component is interconnected to function as a complete system[2].

TABLE I
COMPONENTS OF WIND POWER SYSTEM

Configuration	Function
Mechanical device	Consists of a rotor with blades and shafts that convert kinetic energy of air molecules into mechanical energy, and a gearbox that changes mechanical energy to proper speeds
Electrical device	Consists of a power generator and a power system stabilizer for stable power supplies
Control device	Consists of a control system that controls the wind power generator by setting it to unmanned operation, and a monitoring system that controls remote areas and discerns system statuses on the ground

Patent information is used as important science and technology indicator for the analysis of technological trends and the measurement of R&D achievements by providing abundant and objective information covering a wide range of fields and by offering easy access to data. In addition, since patent information is also characterized as information on rights, it plays an important role as strategic information for establishing management strategies or decision-making in R&D processes for new technologies.

II. Analysis Theory

A. Network Analysis

Degree centrality used in this study can be used to analyze how central each node is positioned in a network by measuring the degree of connection between a node in the network and another node directly linked to the previous node. It can be said that nodes with high values of centrality play as connectors or hubs among nodes[3].

Degree centrality shows how central a node is in its role in an organizational network, closeness shows the direct or indirect relationship between a node and another node in the entire network and betweeness centrality shows a controlling aspect of mediating information flow [4]-[8].

Network centrality analysis is divided into degree centrality, closeness centrality, and betweeness centrality between nodes. Degree centrality is a measure of how close to the center a node is positioned in a network; that is, a measure of the degree of connection between one node and another node directly connected, therefore making the number of connected nodes the absolute standard. It is numerically expressed as follows: the degree centrality $Dc(p_k)$ of one arbitrary node p_k is the sum of the other nodes adjacent to p_k as calculated below, where $(p_i, p_k)=1$ represents the connection between p_i and p_k, while $(p_i,p_k)=0$ represents the disconnection.

$$D_c(p_k) = \frac{\sum_{i=1}^{n} p_i, p_k}{n-1} \qquad (1)$$

Lastly, unlike degree centrality analysis that measures the centrality of one node, betweeness centrality is a measure of centrality with the betweeness of a specific node connecting one node to another in a network. The betweeness of specific nodes is expressed as the ratio of the number of specific nodes existing in the actual shortest distance to the number of shortest distances between pairs of other nodes. In other words, betweeness centrality measures the degree of betweeness among other nodal points. Its numerical expression is as follows: when $i<j$, $b_{ij}(p_k) = d_{ij}(p_k)$, and its denominator is the number of geodesic connecting p_i and p_j, and its numerator is the number of geodesic connecting p_i and p_j while including p_k.

$$B_c(p_k) = \frac{2\sum_{i}^{n}\sum_{j}^{n} b_{ij}(p_k)}{n^2 - 3n + 2} \qquad (2)$$

B. Cluster Analysis

Cluster analysis is an exploratory analysis method to help understand the structure of entire data by grouping similar individual members into several groups and investigating the characteristics of each group. This analysis technique solely depends on data, dividing entire data through clusters. Clusters should be formed in a way that individual members in each cluster have unique characteristics according to their clusters. This cluster analysis can find meaningful information without prior information on the internal structure of given data. If the distance between observation units is defined according to a data type, it can be applied to almost all types of data. However, the interpretation of cluster analysis is difficult because the analysis results largely depend on the distance that represents similarity between the observation units.

Cluster analysis can be largely divided into hierarchical and nonhierarchical cluster analyses. Single linkage method, complete linkage method, average linkage method, and ward method are used for hierarchical cluster analysis, and K-means is used for nonhierarchical cluster analysis.

In addition, betweeness centrality is frequently used in network analysis. Cluster analysis using betweeness centrality repeatedly eliminates betweeness centrality values between nodes in the applicable network structure until a cluster is formed by the changes in the network structure as other betweeness centrality values change. Since this clustering is caused by the relationship between the nodes, it is different from network classification that uses a cut-off value[9],[10].

III. Determination of R&D Priorities in the Fields of Wind Power

A. Analysis Data

With Korean patents, U.S. patents, Japanese patents, European patents, and PCT patents, which have been disclosed between January 1, 2000 and May 31, 2012, data were established for quantitative analysis.

The patents analyzed in this study include both registered and disclosed patents. If a disclosed patent is registered, correction was made by eliminating the disclosed patent to avoid duplicate analysis, whereas allowing duplicate patents in each technology field. Patents were searched with keywords and IPC (International Patent Classification).

TABLE II
Data Set for Patent Analysis

Division	Country	Search period	Number of patent
Disclosed/ registered patent	Korea	2000.1.1 ~ 2012.5.31	4,317
	Japan		5,854
	USA		6,690
	Europe		4,026
	China		11,635
	PCT International patent(WO)		5,503
Total			38,025

B. Network Analysis for Wind Power Components

The Ward method, a hierarchical clustering method, was used for calculating the similarity among 13 major wind power components.

In this study, the Netminer 3.0 developed in Cyram was used for cluster analysis. Clustering was done over the best cut-off value of 4.5, and it was concluded that classification into four groups was optimal.

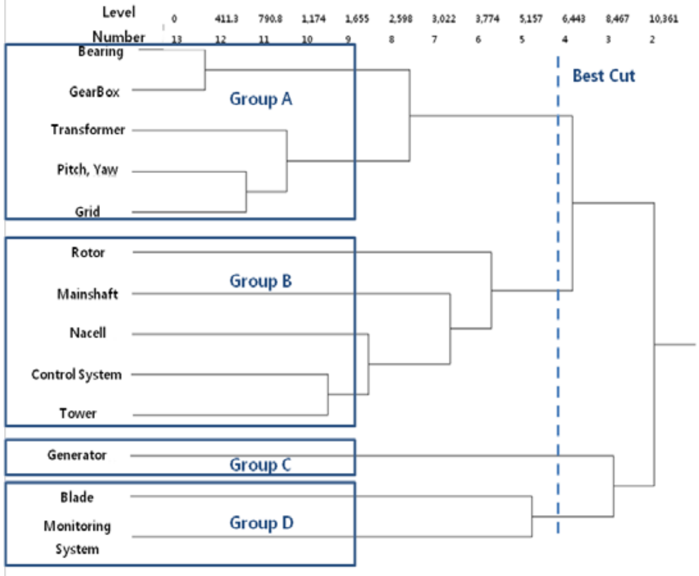

Fig. 1 Selection of Optimal Groups by Hierarchical Clustering

Four clusters were formed according to the technological similarity between components, in which line widths indicate connection intensities.

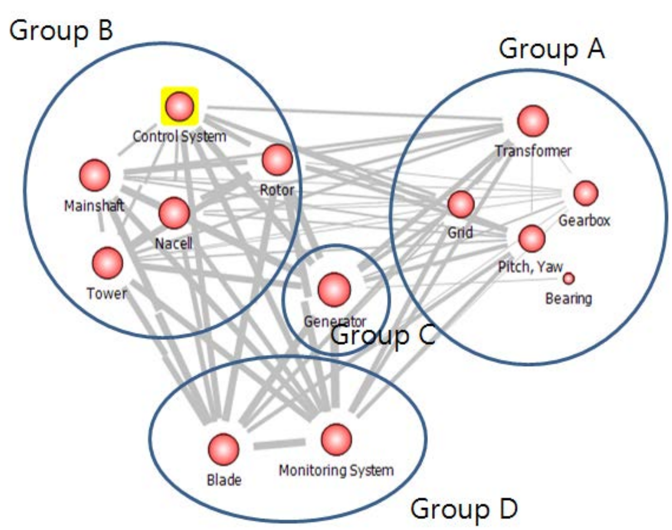

Fig. 2 Grouping of Components using Network Analysis

C. Selection of Priority Areas for Technology Development Considering Degree Centrality

It was concluded that generators have the highest degree centrality among components, functioning as hubs in the entire wind power components.

In Group A, it was estimated that transformers with the highest degree centrality are key components, of which technology development is expected to be a priority. The development priorities include Nacell, tower, main shaft, and rotor in Group B, generator in Group C, and monitoring system and blade in Group D. Overall, 8 components having degree centrality over 0.92 need to be developed.

TABLE III
DEGREE CENTRALITY OF WIND POWER COMPONENTS

Group	Component	Degree centrality
A	Transformer	0.92
	Grid	0.75
	Pitch, Yaw	0.75
	Gearbox	0.67
	Bearing	0.08
B	Nacell	0.92
	Tower	0.92
	Mainshaft	0.92
	Rotor	0.92
	Control system	0.83
C	Generator	1
D	Monitoring system	0.92
	Blade	0.92

D. Priority Areas for Technology Development Considering Degree Centrality and Betweeness Centrality

The followings are key technology fields determined by network analysis by IPC in each group.

1) Analysis of Group A

The IPC network structure of Group A showed that F03D (Wind motors) and H02K (Generator, motor) have high degree centrality. Technologies for F03D-009/00 (Adaptations of wind motors for special use), F03D-011/00 (Component parts, accessories), and F03D-011/04 (Mounting structures) were estimated to have high degree centrality and betweeness centrality. Particularly, although H02K-007/18(turbine) does not belong to the F03D field, it showed high degree centrality and betweeness centrality, and therefore, it was considered to be an important element in technology development in Group A.

For developing transformers, H02J-003/38 (Arrangements for parallelly feeding a single network by two or more generators, converters, or transformers) was found to be key technology. For developing gearboxes, F16H-001/28 (gears having orbital motion) technology was considered important.

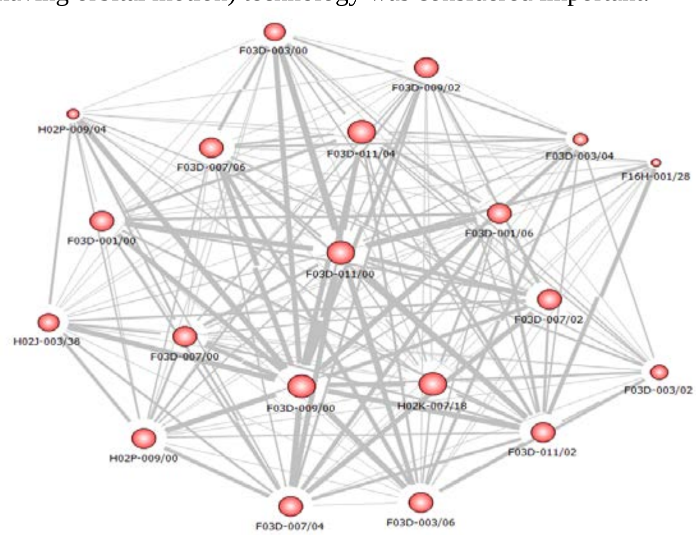

Fig. 3 IPC Network Analysis of Group A

TABLE IV
DEGREE CENTRALITY AND BETWEENESS CENTRALITY BY IPC IN GROUP A

IPC Class	Degree centrality	Betweeness centrality
F03D-009/00	1	0.007
F03D-011/00	1	0.007
F03D-011/04	1	0.007
H02K-007/18	1	0.007
F03D-001/00	0.947	0.006
F03D-007/04	0.947	0.006
F03D-011/02	0.947	0.006
F03D-001/06	0.947	0.005
F03D-003/06	0.947	0.005
F03D-007/00	0.947	0.005
F03D-007/02	0.947	0.005
F03D-007/06	0.947	0.005
F03D-009/02	0.947	0.004
H02P-009/00	0.947	0.004
F03D-003/00	0.895	0.004
H02J-003/38	0.895	0.004
H02P-009/04	0.737	0.003
F03D-003/02	0.842	0.001
F03D-003/04	0.789	0.001
F16H-001/28	0.684	0.001

2) Analysis of Group B

The IPC network structure of Group B showed that F03D (Wind motors) and H02P (Control, regulation of electric motors, generator) have high degree centrality.

F03D-009/00 (Adaptations of wind motors for special use) technology with the highest degree centrality and betweeness centrality was considered to be key technology in Group B. F03D-007/04 (wind motor's automatic control, regulation), F03D-011/00(Component parts, accessories), and F03D-011/04 (Mounting structures) technologies showed high degree centrality and betweeness centrality.

In Group B, technologies with high degree centrality and betweeness centrality mostly belonged to F03D technology field, and technology development was centered on wind motor’s control and actuation devices and other components. Specially, it is concluded that H02P-009/00 (Generator's control device) technology needs to be developed.

TABLE V
DEGREE CENTRALITY AND BETWEENESS CENTRALITY BY IPC IN GROUP B

IPC Class	Degree centrality	Betweeness centrality
F03D-009/00	1	0.099
F03D-007/04	0.895	0.063
F03D-011/00	0.895	0.037
F03D-011/04	0.895	0.037
F03D-011/02	0.842	0.028
F03D-007/02	0.737	0.031
F03D-009/02	0.737	0.017
F03D-001/06	0.632	0.009
F03D-003/06	0.632	0.008
F03D-007/00	0.632	0.017
F03D-001/00	0.579	0.009
F03D-003/04	0.579	0.007
F03D-007/06	0.579	0.005
H02P-009/00	0.579	0.015
F03D-001/02	0.526	0.006

3) Analysis of Group C

The IPC network structure of Group C (Generator) showed that F03D (Wind motors), H02P (Control, regulation of electric motors, generator) and H02K (Generator, motor) have high degree centrality.

F03D-009/00 (Adaptations of wind motors for special use) technology with the highest degree centrality and betweeness centrality was considered to be key technology in Group C. F03D-011/00 (Component parts, accessories) technology showed high degree centrality and betweeness centrality. Particularly, H02K-007/18(turbine) technology showing high degree centrality and betweeness centrality in Group A was found to be included in Group C as well.

TABLE VI
DEGREE CENTRALITY AND BETWEENESS CENTRALITY BY IPC IN GROUP C

IPC Class	Degree centrality	Betweeness centrality
F03D-009/00	1	0.232
F03D-011/00	0.895	0.091
F03D-011/02	0.789	0.057
F03D-011/04	0.789	0.048
F03D-007/04	0.632	0.04
F03D-001/06	0.579	0.019
F03D-003/06	0.579	0.013
H02P-009/00	0.263	0.01
F03D-003/04	0.526	0.009
F03D-009/02	0.368	0.009
F03D-007/00	0.316	0.006
F03D-001/04	0.421	0.005
F03D-001/00	0.421	0.004
F03D-003/00	0.474	0.002
H02K-007/18	0.421	0.002

4) Analysis of Group D

The IPC network structure of Group D showed that F03D (Wind motors) and H02P (Control, regulation of electric motors, generator) technologies have high degree centrality.
F03D-009/00 (Adaptations of wind motors for special use) technology having the highest degree centrality and betweeness centrality was considered to be key technology in Group D. F03D-011/00 (Component parts, accessories) technology was found to have high degree centrality and betweeness centrality.

In Group D, similarly to Group B and C, technology development was centered on wind motor’s control and actuation devices and other components.

TABLE VII
DEGREE CENTRALITY AND BETWEENESS CENTRALITY BY IPC IN GROUP D

IPC Class	Degree centrality	Betweeness centrality
F03D-009/00	1	0.073
F03D-011/00	0.947	0.051
F03D-007/04	0.895	0.045
F03D-011/02	0.895	0.032
F03D-011/04	0.895	0.032
F03D-007/02	0.789	0.028
F03D-009/02	0.737	0.021
F03D-001/06	0.684	0.009
F03D-003/06	0.684	0.012
F03D-007/00	0.684	0.015
H02P-009/00	0.632	0.013
F03D-001/00	0.579	0.007
F03D-003/04	0.579	0.006
F03D-007/06	0.579	0.006
F03D-001/02	0.526	0.005

E. Determination of R&D Priorities by Comprehensive Analysis

The comprehensive analysis on degree centrality and betweeness centrality of IPC in Groups A, B, C, and D concluded that government R&D investments should be made mainly for the development of generators and blades first, and then rotors and energy storage apparatus.

Although energy storage apparatus was not mentioned in the TABLE III, the analysis of degree centrality and betweeness centrality of IPC showed the need of its technology development, demanding an intensive development in the future.

TABLE VIII
SELECTION OF FINAL COMPONENTS FOR DEVELOPMENT THROUGH IPC ANALYSIS

Category	IPC Class	Technology description	Component
Priority 1	F03D-007/00	Controlling wind motors	Generator
	F03D-007/04	Wind motor's automatic control, regulation	Generator
	F03D-009/00	Adaptations of wind motors for special use	Generator
	F03D-011/02	Transmission of power, e.g. using hollow exhausting blades	Blade
	H02P-009/00	Electric generator's control device	Generator
Priority 2	F03D-001/00	Wind motors with rotation axis substantially in wind direction	Generator
	F03D-001/06	Rotors	Rotor
	F03D-009/02	Wind energy storage apparatus	Energy storage apparatus

As a result of comprehensive consideration of degree centrality of components, and degree centrality and betweeness centrality of IPC in the fields of wind power, it was concluded that 4 components (Generator, Blade, Rotor, energy storage apparatus) should be technology development priorities. Comprehensive analysis of the network of IPC detailed technology showed that the development of 8 technologies (F03D-001/00, F03D-001/06, F03D-007/00, F03D-007/04, F03D-009/00, F03D-009/02, F03D-011/02, H02P-009/00) will have large spreading effects.

TABLE IX
SELECTION OF DETAILED TECHNOLOGIES FOR DEVELOPMENT PRIORITIES

Group	Component	Consideration of degree centrality	Consideration of degree and betweeness centralities	IPC Class
A	Transformer	0.92		
B	Nacell	0.92		
	Tower	0.92		
	Mainshaft	0.92		
	Rotor	0.92	Selected	F03D-001/06
C	Generator	1	Selected	F03D-001/00 F03D-007/00 F03D-007/04 F03D-009/00 H02P-009/00
D	Monitoring system	0.92		
	Blade	0.92	Selected	F03D-011/02
Other	Energy storage apparatus	-	Selected	F03D-009/02

Ⅳ. CONCLUSION

The cluster analysis by component in the fields of wind power showed a total of 4 divisions, with generators playing as hubs. The cluster analysis by IPC technology showed that key technology in the wind power technology fields was F03D-009/00 (Adaptations of wind motors for special use), which was closely connected with other technologies in the fields of wind power. In addition to the field of wind motor, technologies for H02J-003 (circuit device, Circuit arrangements for ac mains, ac distribution networks), H02K-007 (actuation motor, mechanical driving motor, auxiliary dynamo-electric machine), and H02P-009 (generator's control device, Electric generator's control device) in electronic systems need to be developed, which play as connectors between clusters.

When considering the wind power components and IPC classification, it was concluded that priority areas for technology development should be set for 4 components. In addition, the comprehensive analysis of the network of IPC detailed technology revealed that the prioritization of development of 8 detailed technologies would have large spreading effects.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea Grant founded by the Korean Government (MEST) (NRF-C1AAA002-2012-0001006).

REFERENCES

[1] L. Fried, S. Shukla, S. Sawyer, *Global Wind Report : Annual market update 2011*, GWEC, 2012

[2] KDB Economic Research Institute, *Global trends and prospects of wind power industries*, 2008

[3] Sanghun Lee Jong-Seob Sim Sung-Yong Kim , "Information Resource Analysis and Development Strategies of Portal", Journal of Agriculture & Life Science, vol.42. pp.45-56, 2006

[4] Il Young Choi, Yong Sung Lee, Jae Kyeong Kim, "A Usage Pattern Analysis of the Academic Database Using Social Network Analysis in K University Library" Journal of information management, vol. 27, pp.25–40, April 2010

[5] Dong-Won Son, *Analysis of Social Network* , 2010

[6] Kwon O-J, Noh K-R, Lee B-R, Koh B-R, Moon Y-H, "Measurement convergence intensity between technology fields by analysis of betweeness centrality", Journal of Korea Contents Conference, vol.1. pp. 1-5, 2007

[7] Monge, P.R., & Contractor, N.S.. *Theories of communication networks*. New York: Oxford University Press. 2003

[8] Greg Madey, Vincent Freeh, Renee Tynan "The Open Source Software Development Phenomenon: An Analysis Based On Social Network Theory", AMCIS, 2002

[9] Kim Eun-ju, "An Efficient Hierarchical Multi-Hop Clustering Scheme in Non-uniform Large Wireless Sensor Networks", Journal of KIISE, v.39 no.3, 2012

[10] Aaron Clauset, M.E.J.NEWMAN, Cristopher Moore, "Finding community structure in very large networks", Physical Review , pp.69-70, 2004

Network Analysis of LED Fusion Technology

Young-Duk Koo, Dae-hyun Jeong

***Abstract*—** This study investigates not only the LED lighting field but also the networks of fusion technologies of vehicle-transportation, of medicine-environment, of communications, and of agriculture & life science-other field. Data were analyzed for interconnectivity and technological importance through the IPC classification since the year of 2000, of Korean, U.S., Japanese, European, Chinese, and other international patents.

Key technology for each technology field was also discovered through IPC network analysis, and the internal and external intensities between technologies were examined through network density and Gini index.

It is concluded that key fusion technology of medicine-environment and of agriculture & life science-other field is “photoelectric-related semiconductor device” technology, and that of vehicle-transportation, and of communications is “photoelectric circuit device control” technology. In the network structure of LED fusion technologies, the similarities between fusion technologies of agriculture & life science-other field and of medicine-environment were estimated to be high. It is estimated that in the LED technology field, R&D has more technological variety when centering on other technologies, such as control device, instead of the conventional photoelectric semiconductor technology field, consequently having a better aspect of fusion.

***Keywords*—** LED fusion technology, fusion technology of vehicle-transportation, fusion technology of medicine-environment, fusion technology of communications, fusion technology of agriculture & life science-other field, patent analysis

I. Introduction

A social network can be expressed as a network of relationships where people are connected. It is the most important for people to establish a relationship, whether intentional or inevitable. A social network is established on the foundation of these social relationships among people, usually including role- or behavior-based relationships, or cognitive or emotional relationships. The social network theory is based on the graph theory, which is a mathematical model representing the relationships between element pairs in a specific set, expressed by the nodes and the links connecting between the nodes (KISTEP, 2008:14).

The entire structure of a network, the characteristics of the links, and the influences of nodes can be explained by analyzing the shapes of nodes or links. Social network analysis is one of the analysis methods based on this network theory, which is widely employed in various fields today, such as sociology, anthropology, geology, and medicine [4].

The objectives of network analysis include investigating the relationships between social beings such as persons, organizations, or countries through a network, and finding the shapes and content of the network structure. Network analysis is a quantitative method for analyzing the interactions between the nodes using a graph that visualizes the relationships between the nodes in a system. Particularly, this method has provided a powerful analysis means to social network researchers who have been studying social bonding, connections, and networks through quantitative analysis of the specific concepts such as density, centrality, and structural equivalence. In the studies of organization theory and policy network, this method has been used for social Network Analysis (SNA) or network theory [1-3].

In this study, analysis elements will be examined on the micro level, and the network theory will be investigated mainly with betweeness centrality.

Betweeness centrality is a measure of centrality with the betweeness of a specific node connecting one node to another in a network. The betweeness of specific nodes is expressed as the ratio of the number of specific nodes existing in the actual shortest distance to the number of shortest distances between pairs of other nodes. In other words, betweeness centrality measures the degree of betweeness among other nodal points. Its numerical expression is as follows: when i□< □j, bij□(pk)□= dij□(pk) dij, and its denominator is the number of geodesic connecting pi and pj, and its numerator is the number of geodesic connecting pi and pj while including pk.

$$B_c(p_k) = \frac{2\sum_{i}^{n}\sum_{j}^{n} b_{ij}(p_k)}{n^2 - 3n + 2}$$

Network density is measured based upon the concepts of inclusiveness and degree. Inclusiveness represents the number of actors interconnected in a network, and is calculated with the remaining numbers after subtracting the number of isolated nodes from the total number of nodes in the network. Degree signifies an extent that one node is connected to another node. In other words, the degree of a node indicates the number of other nodes directly connected to the specific node. To examine the accurate density of a network, inclusiveness and degree should be considered simultaneously. That is, in order to accurately measure density, the following two factors should be

Young-Duk Koo is with Korea Institute of Science & Technology Information, Hoegi-ro 66, Dong Daemun-gu ,Seoul, Korea (phone: +82-02-3299-6035 ; fax: +82-02-3299-6117 ; e-mail: ydkoo@kisti.re.kr).

Dae-hyun Jeong is with Korea Institute of Science & Technology Information, Hoegi-ro 66, Dong Daemun-gu ,Seoul, Korea (phone: +82-02-3299-6238 ; fax: +82-02-3299-6117 ; e-mail: gregori79@kisti.re.kr).