Concept and Application of UCINET Software to Study Network Relationship in Construction Projects
แนวคิดและการประยุกต์ใช้โปรแกรม UCINET เพื่อศึกษาความสัมพันธ์แบบเครือข่ายในคณะทำงานพัฒนาโครงการก่อสร้าง

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Abstract

As extensively recognised in the reviewed literature, the fragmentation of the project development team and the multi-stage project development process are two underlying factors that significantly affect the construction industry's unsatisfactory performance and competitiveness. The addressed problems are potentially solved by strong network relationship and effective knowledge management at the pre-design appraisal development stage. This paper focuses on the concept and application of UCINET social network software to study quantitative network relationships among appraisal development team members in selected OTL commercial residential projects in Bangkok, Thailand. Key network characteristics like network density, reciprocity, reachability, geodesic distance as well as personal and subgroup characteristics such as degree centrality, network centralisation, clustering coefficients, cliques, ego network and brokerage can be used to improve project development performance and the industry's competitiveness based on more effective knowledge creation and transfer.

บทคัดย่อ

จากการศึกษาวรรณกรรมที่เกี่ยวข้องสรุปได้ว่า สาเหตุสำคัญสองประการที่ทำให้อุตสาหกรรมการก่อสร้างมีผลประกอบการตกต่ำและสูญเสียความสามารถในการแข่งขัน ได้แก่ โครงสร้างที่แตกแยกของคณะทำงานพัฒนาโครงการและการทำงานเป็นขั้นตอนที่ซับซ้อน แต่ขาดความต่อเนื่องจากโครงการหนึ่งไปสู่อีกโครงการหนึ่ง ปัญหาดังกล่าวมีแนวโน้มที่จะได้รับการแก้ไขด้วยการเสริมสร้างความสัมพันธ์แบบเครือข่ายที่แข็งแกร่งในคณะทำงาน และการบริหารจัดการความรู้ที่มีประสิทธิภาพ โดยเฉพาะอย่างยิ่งในขั้นตอนการกำหนดเนื้อหาโครงการ บทความนี้จะกล่าวถึงแนวคิดและการประยุกต์ใช้โปรแกรม UCINET เพื่อศึกษาความสัมพันธ์เชิงปริมาณแบบเครือข่ายของคณะทำงานพัฒนาโครงการก่อสร้างอาคารพักอาศัยเชิงพาณิชย์ OTL ที่ตั้งอยู่ในกรุงเทพมหานคร ลักษณะสำคัญของความสัมพันธ์แบบเครือข่ายโดยรวม อาทิ network density, reciprocity, reachability, geodesic distance รวมถึงลักษณะเฉพาะของเครือข่ายในระดับบุคคลและในระดับกลุ่มย่อย ได้แก่ degree centrality, network centralisation, clustering coefficients, cliques, ego network และ brokerage จะช่วยให้เกิดการเสริมสร้างความรู้และพัฒนาการในการส่งต่อความรู้ที่มีประสิทธิภาพ อันจะนำไปสู่การพัฒนาโครงการที่ดียิ่งขึ้น และความสามารถในการแข่งขันของอุตสาหกรรมการก่อสร้างของไทยที่สูงขึ้นต่อไป

Keywords

Construction Industry (อุตสาหกรรมก่อสร้าง), Project Development Performance (ประสิทธิภาพในการพัฒนาโครงการ), Network Relationship Characteristics (ลักษณะความสัมพันธ์แบบเครือข่าย)

1. Introduction: The Importance of Network Relationship Analysis in Construction Projects

Apart from the study of organisational knowledge management, relationships among insularised professional project members whose self-esteem is strongly cultivated by their unique skills and professional training (Davenport & Prusak, 2000) is another key factor that has been increasingly investigated to improve the construction industry's performance. There are studies of relationship issues at a large scale, such as a comparative study of inter-firm relationships to establish networks between the UK and French construction industries (Benhaim, 1997). However, smaller-scale studies of relationships at the pre-design stage need also to be encouraged. As seen in Boonyanan (2010), this is because the relationships among key building professionals and collaborating organizations, including research organisations, planning authorities, legal advisors, financiers and higher education institutions, are likely to have a more significant impact on project appraisal development, architectural design and construction that meet clients' and users' expectations through effective teamwork and knowledge sharing.

A task driven construction project development procedure is always perceived and managed as a time-related linear process to deal with an interdependent group of work packages (Pryke & Smyth, 2006). Most of the relationship analysis approaches that follow the linear path of project development seem to overlook the complex nature of relationships. For example, statistical analysis is used to reveal the current average value and predict probability distributions in a relationship of selected samples at a specific period of time. On the other hand, critical path analysis normally concentrates on identifying and prioritizing critical tasks that need to be completed in successive sequences. Process mapping also focuses on a linear sequential working process from the early stage of data input to the subsequent data processing that produces the ultimate outputs. In order to clearly understand and effectively manage non-linear and complex overlapping relationships at the pre-design stage of construction project development, relationships have to be perceived and analysed as a network where people, organisations and ongoing social processes are the main units of analysis (Webster, 1992; as cited in Seufert et al., 1999).

2. The Principle of Network Relationship Analysis Using UCINET Software

A quantitative study of network relationship has been developed from a number of theoretical ideas. As concluded by Scott (2000), it can be traced back as early as J. L. Moreno's sociogram in 1933 that introduced social configurations in graphic form. At around the same time, Kurt Lewin initiated the mathematical based field theory in 1936 as the predecessor of the currently adopted graph theory, providing the exact value of relationship or sociometry in the 'field' or 'social space' within a particular context.

There are a number of network relationship quantitative analysis softwares available for different scopes of work. In this academic oriented context, the long established and widely used UCINET software was chosen to study complex relationships at a more advanced level. Flexibility of data input was among the primary reasons. The fundamental binary value of affiliation (1) and non affiliation (0) among group members in the relationship adjacency matrix (Figure 1) can be easily prepared and stored in txt or xls formats. Apart from the usual numeric value, network relationships can also be conveniently presented as a network graph using either the incorporated NetDraw programme or other visualisation platforms to further read and display other aspects of network characteristics.

Affiliations		A	B	C	D
Affiliations	A	0	1	0	0
	B	1	0	0	1
	C	0	0	0	0
	D	0	1	0	0

Figure 1. Matrix diagram presenting affiliation in binary value.

Using rows as the main units of analysis, it can be seen that A sends information only to B (the first row) while also receiving information from B. At the same time, B passes on and receives information from both A and D (the second row). Apparently, C does not send or receive information to or from any members (the third row). D only sends information to and receives information from B (the fourth row). The information is then analysed and interpreted digitally, based on social network theory, to reveal a number of meaningful network relationship characteristics in 3 different areas: the general level, project members' level and subgroup level, as shown in Table 1.

3. OTL Project: A Case Study of Network Relationship Analysis

3.1 General Network Characteristics

The first network characteristic that can be immediately identified in OTL commercial residential projects in central Bangkok developed by S1, an established developer registered in the Stock Exchange of Thailand (SET), is network size based on the number of people involved. As seen in Table 2, twelve people in shaded rows were theoretically identified as members of the project appraisal development team. They included the client executive, user, architect, external investment and legal consultants, project manager, interior and landscape designers, planning authority, structural, mechanical and electrical (M&E) engineers and professional organisations. Information on the existence of relationships is also used to identify *network density* or the ratio of existing relationships compared to all possible pairs of ties. In the OTL project, eight key project members in shaded rows (numbers 1, 2, 3, 6, 7, 10, 11, and 12) had at least one relationship with other members identified in columns. Investment and legal consultants (row 4), legal consultants (row 5), interior and landscape designers (rows 8 and 9) were not connected to anyone. The overall network density 0.2045, out of a maximum of 1 (Table 3), was considered low because only around 20.45 per cent of the maximum 132 ties[1] among project members were established. A low density network means there is limited interaction and low participation in project development. It is likely to lead to poor decision making.

Level of reciprocity or the proportion of project members with reciprocated ties to all the possible pairs in OTL project was rather high. It was 0.6875 out of the maximum 1 or approximately 69 per cent of all established links. It implied a high potential for information and knowledge transfer via communication among project members. Reachability, on the other hand, reveals each project member's direct and indirect paths of connection no matter how many others are in between the source and the target. The mediocre reachability of eight key project members in the OTL project, including the client, user, architect, project manager, planning authority, structural as well as M&E engineers and professional organisation, who mostly only reached five to six others[2], suggested a high division of the network into smaller subgroups. It also meant that the potential for effective knowledge transfer was not very high.

Table 1. Summaries of all network characteristics.

Network characteristics	Definitions
General network characteristics	
Network size	Number of people involved in a project development.
Network density	Ratio between present ties and all possible unique pairs of ties among key members.
Reciprocity	The potential for knowledge transfer among project members through the proportion of project member pairs with reciprocated ties or mutual connections to all the possible pairs.
Reachability	The existence of paths that can be traced from source to target no matter how many other members are in between. A higher number of paths suggests a greater network capability of knowledge transfer.
Geodesic distance	The number of relations through which information can be effectively passed on, using the shortest possible path from one project member to another. The longer the path, the lower the efficiency of knowledge transfer among project members.
Project members' network characteristics	
Degree centrality	Project members' dependency and power, associated with their location in a star network. A higher degree means less dependency on acquiring resources and power in negotiations. Based on 'out and in degrees' that indicate the number of directed ties possessed by individual members, the measurement can be categorised into 'out and in degree' centrality.
Out degree centrality	The sum of sending connections from one project member to others. Members who have the most out degree tend to be the most influential members in a network.
In degree centrality	The sum of receiving connections from project members. Members who have the most in degree tend to be the most prominent members in a network.
Network centralisation	A network's variance in percentage compared to a same size star network recognised by its complete centralisation. High figures suggest a concentrated network with a limited number of smaller groups.
Clustering coefficients	The average densities of all members' local adjacent neighbourhood that affects the efficiency of inter-organisational knowledge transfer and management.
Node clustering coefficients	Density of each project member's adjacent neighbourhood, indicating their capability to perform inter-organisational knowledge management.
Subgroup characteristics	
Cliques	Groups of project members with all possible direct ties and create a maximum complete subgroup. The application of a slightly loosened rule that allow members with a certain number (n) of indirect connections, usually two, to be included creates N-clique.
Ego network	Relationship among a particular project member and others who have one step out connection in a neighbourhood and form a tight social unit. The ego network of the most prominent figure, like a project manager, possesses a rather high node clustering coefficient. It can certainly lead an effective inter-organisational knowledge management process.
Brokerage	Number of pairs not directly connected in a project member's ego network. A high number means it is very likely that a broker is needed to perform one of five roles - coordinator, consultant, broker, representative and liaison - to create links among members.

Table 2. Existence of relationship in OTL project.

No.	OTL	Client executives	User	Architect	External investment and Financial consultant	Legal consultant	Project manager	Planning authority	Interior designer	Landscape designer	Structural engineer	M&E engineer	Professional organisation
		1	2	3	4	5	6	7	8	9	10	11	12
1	Client executives		0	1	0	0	1	0	0	0	1	1	0
2	User	1		0	0	0	0	0	0	0	0	0	0
3	Architect	1	0		0	0	1	0	0	0	1	1	0
4	Investment and financial consultant	0	0	0		0	0	0	0	0	0	0	0
5	Legal consultant	0	0	0	0		0	0	0	0	0	0	0
6	Project manager	1	0	1	0	0		1	0	0	1	1	0
7	Planning authority	0	0	0	0	0	1		0	0	0	0	0
8	Interior designer	0	0	0	0	0	0	0		0	0	0	0
9	Landscape designer	0	0	0	0	0	0	0	0		0	0	0
10	Structural engineer	1	0	1	0	0	1	0	0	0		1	0
11	M&E engineer	1	0	1	0	0	1	0	0	0	1		0
12	Professional organisation	1	0	1	0	0	0	0	0	0	1	1	

References: 0 = no relationship, 1 = relationship detected

Table 3. Network size, density, reciprocity and reachability in OTL project.

Project	Network size	Network density	Reciprocity	Project members	Number of project members reached
OTL	12	0.2045	0.6875	1. Client	5
				2. User	6
				3. Architect	5
				4. Investment and financial consultant	0
				5. Legal consultant	0
				6. Project manager	5
				7. Planning authority	5
				8. Interior designer	0
				9. Landscape designer	0
				10. Structural engineer	5
				11. M&E engineer	5
				12. Professional organisation	6

Geodesic distance normally shows the shortest possible path between project members who effectively pass on information. The average distance of 1.405 (Table 4) means any two project members in the OTL project were less than two steps apart. This is sufficiently far in small and low density networks for the efficiency of information transfer to be potentially affected. In terms of compactness, with larger values indicating the greater cohesiveness of a network, 0.259 out of the full scale of 1 suggested that the OTL project network was not very close. However, one-edge connections with one relation or tie between two project members with established close collaboration appeared more frequently (27.000) than two-edge connections with two relations (13.000) and three-edge connections with three relations (2.000), suggesting minimal collaboration. The proportion of one-edge connections in the OTL project was also high - around 64 per cent of all existing connections, compared to 31% of two-edge connections and 4.8% of three-edge connections.

3.2 Project Members' Network Characteristics

Both *out* and *in degree centrality* reveal a project member's position and their potential ability to pass on information and knowledge in a network. *Out degree centrality* is the sum of connections sent from one project member to others. Members with the highest out degree tend to have sufficient information to make them the most influential member. On the contrary, *in degree centrality* is the sum of connections received from other project members. Members with the highest in degree normally become the most powerful and prestigious members due to the possessed information that others want to share. In the OTL project, the most influential project manager had the highest out degree centrality score (5.000) (Table 5). This means the manager had outward connections with five, out of a maximum of eleven, other project members. In terms of in degree centrality, it was the client with the most information needed at the early stage of a project development who had the highest score of six (6.000), out of the highest possible total of eleven inward connections with others.

Network centralisation is a measurement of inequality or variance in percentage of a graph centralisation compared to a complete (100%) 'star' network of a similar size. High centralisation figures suggest high concentration in a network with few smaller groups. However, the relatively low percentage of network centralisation (27.273%

Table 4. Summaries of geodesic distance characteristics in OTL project.

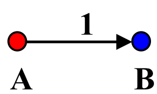
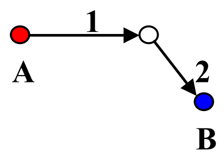
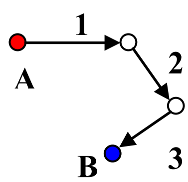
Project	Average distance among reachable pairs	Distance based compactness	One-edge connection 		Two-edge connection 		Three-edge connection 	
			Frequency	Proportion to all connections	Frequency	Proportion to all connections	Frequency	Proportion to all connections
OTL	1.405	0.259	27.000	0.643	13.000	0.310	2.000	0.048

Table 5. Out and in degree centrality, network centralisation, clustering and node clustering coefficients in OTL project.

Project	Project members	Out degree centrality (out of 11)	In degree centrality (out of 11)	Out degree centralisation (%)	In degree centralisation (%)	Node clustering coefficient	Number of pairs	Overall clustering coefficient
OTL	1. Client	4.000	6.000	27.273	37.190	0.500	15.000	0.725
	2. User	1.000	0.000				0.000	
	3. Architect	4.000	5.000			0.750	10.000	
	4. Investment and financial consultant	0.000	0.000				0.000	
	5. Legal consultant	0.000	0.000				0.000	
	6. Project manager	5.000	5.000			0.600	10.000	
	7. Planning authority	1.000	1.000				0.000	
	8. Interior designer	0.000	0.000				0.000	
	9. Landscape designer	0.000	0.000				0.000	
	10. Structural engineer	4.000	5.000			0.750	10.000	
	11. M&E engineer	4.000	5.000			0.750	10.000	
	12. Professional organisation	4.000	0.000			1.000	6.000	

out degree and 37.190% in degree) suggested that the OTL project team was structurally fragmented. This characteristic is likely to have a significant impact on information and knowledge transfer like *clustering coefficients* or the average local adjacent neighbourhood density of all members in a network. In the OTL project, a high degree of clustering coefficients (0.725 out of the maximum 1.000) suggested that very dense local neighbourhoods could be an obstacle to information and knowledge transfer in a small and low overall density network. Each project member's adjacent neighbourhood density or node clustering coefficients can also be analysed to reveal the capability to transfer information and knowledge. *Node clustering coefficients* in the OTL project suggested that the professional organisation had the highest value (1.000). Even though 6 out of 21 pairs of possible connections (nPairs) were not the largest network neighbourhood, it was the highest density and the most efficient in information and knowledge transfer since all the members related to the professional organisation were 100% present. On the contrary, the client with the largest neighbourhood (15 out of 21 pairs) had the lowest score of node clustering coefficients because only half of the connections (0.500) were present. As most of the key project members such as the architect, project manager and building engineers were identified as those who had large neighbourhoods, it can be difficult to establish effective inter-organisational information and knowledge transfer beyond the immediate circle.

3.3 Subgroup Network Characteristics

A group of project members who have all possible ties among themselves and create a maximum complete subgraph can be seen as a *clique*. Based on the analysis of relationship existence using UCINET software, there were two cliques in the OTL project (Table 6). Clique 1 was composed of members 1, 3, 6, 10 and 11 while members 1, 3, 10, 11 and 12 were in clique 2. Multi-membership was noted as an actor can be a member of more than one clique. As a result, information and knowledge transfer can be achieved more quickly and in a wider scope. *The clique proximities* suggested adjacency in the percentage of members in rows to other members in each clique. It can be seen that the client, architect and building engineers were connected to all members in both cliques. Hence, their clique proximities were 1.000 or 100%. On the other hand, the absence of any link to all others reduced the user's proximity score to 0.000 or 0 per cent.

Table 6. OTL project cliques and clique proximities.

OTL project		Clique 1	Clique 2
No.	Project member	1 3 6 10 11	1 3 10 11 12
1	Client	1.000	1.000
2	User	0.200	0.200
3	Architect	1.000	1.000
4	Investment consultant	0.000	0.000
5	Legal consultant	0.000	0.000
6	Project manager	1.000	0.800
7	Planning authority	0.200	0.000
8	Interior designer	0.000	0.000
9	Landscape designer	0.000	0.000
10	Structural engineer	1.000	1.000
11	M&E engineer	1.000	1.000
12	Professional organisation	0.800	1.000

One step out connection from a particular project member to others in a neighbourhood to form a tight social unit is known as an *ego network.* In the OTL project (Table 7), the project manager had the largest ego network size (five) and a 60 per cent density. However, the client, architect, building engineers and professional organisation with significantly higher density ego networks (100) were likely to perform the information and knowledge transfer more effectively.

The brokerage score shows the numbers of pairs indirectly connected in each ego network. In Table 7, there were 4 pairs in the OTL project manager's ego network that were not directly connected to others. Therefore, it was very likely that the project manager would perform one or more brokerage roles to create links among members. In this case, the role of *liaison* - where the project manager was an autonomous broker who created a connection between two members from two different groups – was the most frequently adopted (eight times in brokerage scores). Other roles included the *coordinator*, who connects members from the same group; the *gatekeeper*, who supports information transfer from other sources to members in a group; the *representative*, who passes on information from one group to members of other groups; and the *consultant*, who is not a member of a group but has to create a relationship between two members of that particular group were not as popular.

4. Conclusions

From the case study, it can be seen that network relationship in a project can be effectively analysed using quantitative approaches. The key network characteristics identified can be used to develop stronger collaborative arrangements to improve information transfer and knowledge management. In a small OTL project appraisal development team, it is essential to first improve the

Table 7. Ego network and brokerage scores in OTL project.

Project	Project members	Ego network size	Density (Ties/Pairs)	Average distance	Diameter	Brokerage	Brokerage scores (time)					
							Coordinator	Gatekeeper	Representative	Consultant	Liaison	Total
OTL	1. Client	4.00	12.00/12.00x 100 = 100.00	1.00	1.00	0.00	0	0	0	0	5	5
	2. User	1.00	0.00/0.00x100 = 0.00	0.00	0.00	0.00	0	0	0	0	0	0
	3. Architect	4.00	12.00/12.00x100 = 100.00	1.00	1.00	0.00	0	0	0	0	1	1
	4. Investment and financial consultant	0.00	0.00/0.00x100 = 0.00	0.00	0.00	0.00	0	0	0	0	0	0
	5. Legal consultant	0.00	0.00/0.00x100 = 0.00	0.00	0.00	0.00	0	0	0	0	0	0
	6. Project manager	5.00	12.00/20.00x100 = 60.00			4.00	0	0	0	0	8	8
	7. Planning authority	1.00	0.00/0.00x100 = 0.00	0.00	0.00	0.00	0	0	0	0	0	0
	8. Interior designer	0.00	0.00/0.00x100 = 0.00	0.00	0.00	0.00	0	0	0	0	0	0
	9. Landscape designer	0.00	0.00/0.00x100 = 0.00	0.00	0.00	0.00	0	0	0	0	0	0
	10. Structural engineer	4.00	12.00/12.00x100 = 100.00	1.00	1.00	0.00	0	0	0	0	1	1
	11. M&E engineer	4.00	12.00/12.00x100 = 100.00	1.00	1.00	0.00	0	0	0	0	1	1
	12. Professional organisation	4.00	12.00/12.00x100 = 100.00	1.00	1.00	0.00	0	0	0	0	0	0

general network characteristics. *Network density* and *centralisation* have to be fundamentally increased by engaging all relevant stakeholders. As a result, clustering as well as *node clustering coefficients* can also be reduced. The wider scope of connection also supports the development of multi-membership among *cliques'* closely knitted members that helps to increase the speed of information distribution. Moreover, high level of *reciprocity* or the numbers of members with reciprocated ties should be maintained while the path of connections among members should be enhanced to reduce numbers of subgroups and increase level of *reachability*. At the same time, the average geodesic distance between project members, preferably as one-edge connections, and the team's compactness should be further managed to be closer to one (1) to ensure a better flow of information.

Each project member's network and subgroup characteristics can be used to single out members with the most appropriate qualifications to perform the usual project development tasks more efficiently. Based on out *degree centrality*, the most influential members such as the project manager can be appointed as the prominent leader to unify and consolidate the team. At the same time, contacts among team members and the prestigious client with high in *degree centrality* have to be managed to conveniently retrieve further details on project requirements. The project manager can be the first point of contact to spread information quickly within its naturally large ego network. Finally, quantitative analysis also reveals other brokerage roles that have not been fully explored and implemented.

To further improve the construction industry's performance, network relationship analysis has to be applied to other phases beyond the project appraisal development of different project types. For example, lessons learned from members' relationships and the network characteristics of a team assigned to work on design development and construction of non-commercial buildings would be an invaluable supplement to establish new comprehensive standards of relationship and collaboration for a construction project.

Note

[1] This figure was calculated from the equation k*k-1 where k = number of project members. For this example, 12*(12-1) = 12*11 = 132

[2] It was considered from the maximum 11 paths (k-1) where k = number of project members.

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