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Governance Mechanism of Weighted Network Primitives for National Major Cluster Projects

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Abstract: *In order to optimize the stakeholder relationships of national major cluster projects and to improve cluster project network management, this study uses complex network theory to construct an undirected weighted network for projects of the National Quality Engineering Award, retrieves weighted 3-node and 4-node subgraphs, analyses the composition and practical significance of the subgraphs, and makes suggestions for network governance of national major cluster projects. The results show that contractual governance occupies a more central position in the network governance of cluster project organizations and that relational governance remains an important tool for improving cluster project management performance. Nevertheless, relational governance cannot replace contractual governance as the central position in the public project governance framework. A combination of both strategies can be used in the corresponding practical situations.*

Keywords: *National major cluster project, Social network analysis (SNA), Weighted motif, Governance mechanisms*

1. Introduction

With the development trend of project clustering, major cluster projects are gradually coming into view. Turner considers that cluster projects are intrinsically linked projects that are organized and managed in a unified and coordinated manner for the purpose of expanding benefits [1]. Major cluster projects at the national level manage multiple large-scale projects based on strategic objectives in a synergistic manner and achieve functions and benefits that cannot be achieved by individual projects through clustered project investment and construction, so as to ensure sustainable national economic and social development and public security [2]. Cluster projects are characterized by long implementation cycle, huge investment scale, many participating units, and strong interaction with external environment [3], which gives obvious network complexity characteristics to the information and material flow of project organization.

Complex networks can describe many real systems, such as social networks [4], trade networks [5] and transportation networks [6]. As a subgraph of local statistically significant features of complex networks, the motif exists in many real networks and can effectively reflect the overall function of the network [7, 8]. In the E. coli transcriptional regulatory network, each type of motif is closely associated with a specific gene expression function [9]. In animal social networks, the motif can reflect the pattern of dominance hierarchy of animal groups, thus revealing the process of social order formation [10]. In directed biological networks, it is possible to measure the importance of a node based on the number of times it appears in different types of motifs [11].

In this paper, we will construct a weighted network of national major cluster projects based on the theory and method of complex network motif, take the National Quality Project Awards (NQEA) as the research object, include the number of cooperation among stakeholders as the weight of edges into consideration, retrieve 3-node and 4-node weighted motif and analyze them, and make suggestions for the governance of national major cluster project networks.

2. Models and Methods

2.1 Complex Network Motif

Complex networks portray the associative qualities between subjects by taking subjects as points and

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relations between subjects as edges. The complex network is introduced in the cluster project organization network by taking the contractor organization as the subject and the organization cooperation relationship as the edge. The data used in the research process are the construction contractor data in the list of NQEA winners. The NQEA is the earliest and highest specification national quality award in China's engineering construction field, which is cross-industry and cross-discipline, and represents a class of examples of China's major engineering clusters projects.

In this study, the data of NQEA accumulated from 2003 to 2012 are extracted, and the detailed data are shown in Table1. The network maximum connectivity cluster is the maximum connectivity network formed by the direct or indirect linkage of contractors. The largest cluster in the project organization network by 2012 covers 79.3% of the award-winning projects with 752 nodes (contractors) and 4713 edges (contractor partnerships), and its global topology is shown in Figure 1.

Table 1: Statistical characteristics of the organizational network of the group of national quality engineering projects from 2003 to 2012.

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Number of award-winning projects per year	54	74	86	116	155	138	149	145	191	199
Number of award-winning contractors per year	91	142	158	201	237	210	296	273	333	281
Cumulative number of awards	54	128	214	330	485	623	772	917	1108	1307
Cumulative number of award-winning contractors	91	207	286	400	500	590	680	767	863	948
Cumulative largest collaboration	7	47	77	196	334	434	509	599	695	752
Cluster (%)	7.7	22.7	26	49.5	66.8	73.6	74.9	78.1	80.5	79.3
Cumulative number of collaborative sides	10	285	417	1213	1903	2354	2847	3359	4336	4713

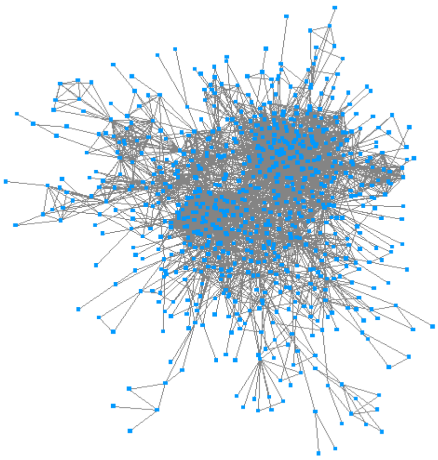

Figure 1: Organizational network of NQEA award-winning projects accumulated to 2012.

2.2 Weighted Motif Approach

The basic motif is the topological form that occurs frequently in the complex network and has statistical significance, and are without regard to the weights of edges. In order to better fit the actual situation of the cluster project network, this study will assign weights to the edges based on the number of times of cooperation between contractors: the number of cooperation 1~3 times, 4~5 times, and more than 5 times correspond to strong, medium, and weak relationships, respectively, and the edges are distinguished by the different widths of the lines (as in Table 2).

The discovery of weighted motif is divided into three steps: random network modeling, subgraph search and motif evaluation. In the first step, a random network with the same degree sequence is generated based on the statistical properties of the real network; in the second step, subgraphs of the desired size are searched in the real and random networks to determine which subgraphs are isomorphic,

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and the isomorphic subgraphs are classified into categories; in the third step, the statistical significance of each category of subgraphs is determined by comparing their frequency of occurrence in the real and random networks to define whether the category of subgraphs is a network motif.

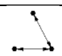
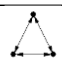
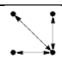
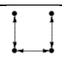
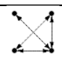
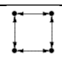
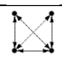
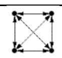
Table 2: Contractor partnership strength and corresponding edge width.

Partnership strength	Weak	Medium	Strong
Width of the line	________	▬▬▬▬	████

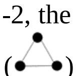
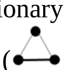
3. Weighted Motif Presentation and Analysis

Table 3 lists the 3- and 4-node weighted subgraphs and their related parameters in the cluster project organization network. The analysis shows that the weighted motif of the cluster project organization network has highly consistent properties with the unweighted network motif, as shown by the fact that the ratio of the number of motif topology to the number of submap topology shows great differences. In the ratio of the number of motif topology to the number of submap topology, a class with a value close to or equal to 0 indicates that the four subgraph forms of 3-1, 4-1, 4-2 and 4-4, which belong to the unweighted network anti-motif, are also almost anti-motif after being assigned weights. The other class has a ratio close to or equal to 1, indicating that the four subgraph forms of 3-2, 4-3, 4-5 and 4-6, which are unweighted network motif, also tend to be motif when given weights. This shows that the tendency of the cluster project organization network does not change depending on the affinity of the cooperative relationship, and the fully connected form ( and ) and the linear form ( and ) have a stable development status. The distribution characteristics of each motif mode are elaborated as follows.

Table 3: Weighted network subgraphs and motif parameters.

		Quantity				Ratio			
		Submap topology	Submap mode	Motif topology	Motif mode	Submap topology / Subgraph mode	Motif topology / Motif mode	Motif mode / Subgraph mode	Motif topology / Submap topology
3-1		69,640	5	0	0	13928.1	-	0	0
3-2		24,817	10	24,817	10	2481.7	2481.7	1	1
4-1		618,217	5	0	0	123643.4	-	0	0
4-2		791,697	11	421	2	71972.5	210.5	0.182	0.001
4-3		794,061	41	779,777	16	19367.3	48736.1	0.390	0.982
4-4		5,957	6	0	0	992.8	-	0	0
4-5		144,488	44	144,022	27	3283.8	5334.1	0.614	0.997
4-6		130,323	71	130,323	71	1835.5	1794.9	1	1

3.1 Node subplots

The weighted motif patterns of the 3-node subgraphs accumulated to 2012 are shown in Table 4, all in the form of subgraph 3-2, while all in the subgraph 3-1 are anti-motif and not statistically significant. This implies that in the cooperation model involving three contractors, only the three parties form a closed loop of cooperation is the specific local cooperation structure surfaced in the development of the cluster project organization network. In contrast, among the 10 motif modes in subfigure 3-2, the mode in which all three parties maintain a low-frequency cooperative relationship with each other () ranks first in both the frequency and z-score columns, at 16.51% and 223.78. This means that cooperation is in the preliminary stage is the most common state of tripartite cooperation today, and it is also the evolutionary direction of the cooperative network. In addition, the frequency and z-score of the two motifs ( and ) ranked third and fourth, reflecting that the deepening of the relationship between

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two parties in the tripartite is also a more frequent phenomenon in the cooperative network, which also reflects the future trend of cooperation.

Table 4: Weighted motif modes for subfigure 3-2.

Figure	Frequency	Z-score	Figure	Frequency	Z-score
	16.51%	223.78		0.61%	57.883
	4.32%	192.3		0.35%	40.28
	2.48%	109.6		0.25%	35.91
	0.76%	49.433		0.23%	33.644
	0.63%	32.596		0.12%	13.437

3.2 Node subgraph

Table 5: Weighted motif modes for subfigure 4-3.

Pattern	Frequency	Z-score	Pattern	Frequency	Z-score
	23.87%	134.38		0.17%	13.887
	2.78%	107.67		0.12%	4.1353
	1.40%	61.105		0.11%	5.6534
	1.26%	29.965		0.11%	35.801
	0.64%	11.146		0.01%	28.083
	0.44%	55.469		0.01%	47.705
	0.24%	3.3987		0.01%	59.031
	0.21%	5.7332		0.01%	9.4239

Table 6: Weighted motif modes for subfigure 4-5.

Pattern	Frequency	Z-score	Pattern	Frequency	Z-score
	2.66%	350.18		0.08%	105.3
	0.90%	267.56		0.06%	41.873
	0.67%	239.52		0.05%	16.506
	0.47%	165.76		0.05%	18.914
	0.17%	63.409		0.03%	55.68
	0.14%	114.95		0.02%	9.4128
	0.14%	287.29		0.01%	52.545
	0.13%	53.663		0.01%	23.596
	0.12%	63.715		0.01%	78.109
	0.09%	42.486		0.00%	137.66

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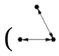
The three weighted network motifs composed of 4 nodes are shown in Table 5 (subfigure 4-3), Table 6 (subfigure 4-5), and Table 7 (subfigure 4-6). Because of the large number of motif modes in subfigures 4-5 and 4-6, the top 20 modes in terms of frequency and their parameters are listed in this study. Subplot 4-2 has only two motifs, and both the frequency and Z-score are too low relative to the other motifs, as shown in Table 8, indicating that the overall is not the preferred local cooperative structure for network development.

The analysis shows that the various types of modes of subgraph 4-3, subgraph 4-5 and subgraph 4-6 are mostly motif. This indicates that two line types ( and ) and one fully connected type () are the favored combination types in contractor collaboration. These three types of 4-node motifs can be combined from the 3-node motifs. The 3-node subgraphs , , and , which are anti-motifs, all lack the ternary closed structure and can be seen as composed of 3-node anti-motif (). This demonstrates that the higher-level (anti-) motifs are usually combinations of lower-level (anti-) motifs, implying a bottom-up combination mechanism of the basic components of the cluster project organization network. The closed structure of the 3-node motif improves communication efficiency and speeds up the flow of resource information. This structure extends to the 4-node motif, and one or more core role contractors are formed. The core contractors participate in the collaboration with the rich resources, information and technology they possess and take the lead.

By looking at the motif mode rankings of each of subfigures 4-3, 4-5 and 4-6, it is found that the similarities lie in the fact that the modes at the top of the frequency are all cooperative low-frequency types with 23.87%, 2.66% and 1.82%, respectively. while from the perspective of Z-score, these three are also the motif modes with larger Z-score in their respective types. This indicates that the two linear ( and ) and one fully connected () motif modes that maintain low-frequency cooperation are crucial to the formation of the network structure. By comparing the overall Z-score, the patterns of the fully connected () have the largest Z-core, then  has the second largest Z-score, and  is the smallest. This order is consistent with the structural access and decentralization ranking ( >  > ), The opposite frequency and Z-score ranking indicates that the number of fully connected patterns is small but plays a key role.

Table 7: Weighted motif modes for subfigure 4-6.

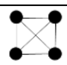
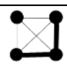
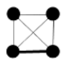
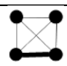
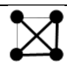
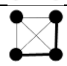
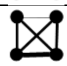
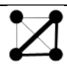
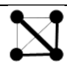
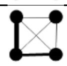
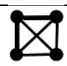
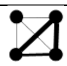
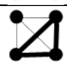
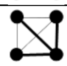
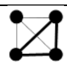
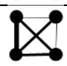
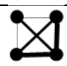
Pattern	Frequency	Z-score	Pattern	Frequency	Z-score
	1.82%	25221		0.06%	2300.1
	0.76%	8904.9		0.05%	106.2
	0.36%	6603.9		0.05%	324.12
	0.36%	4738.4		0.04%	132.21
	0.32%	625.41		0.04%	1696.8
	0.29%	3065.2		0.03%	101.03
	0.19%	291.79		0.03%	93.205
	0.15%	315.21		0.03%	2793.2
	0.14%	439.8		0.03%	79.208
	0.08%	287.96		0.03%	72.557

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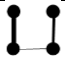
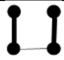
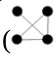
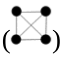
Table 8: Weighted motif modes for subfigure 4-2.

Pattern	Frequency	Z-score	Pattern	Frequency	Z-score
	0.01%	2.5636		0.00%	11.862

4. Governance mechanisms

The embeddedness of social networks includes relational and structural embedding, with relational embedding referring to the influence of relationships between participants in a social network on economic activities and structural embedding referring to the structural characteristics between participants in a social network and other participants [12].

From the perspective of relationship embedding, the weighted cooperation between contractors often shows weak relationship as the main body, which reflects the phenomenon that the cooperation frequency of contractors in the cluster project organization network is generally low. This phenomenon just accords with the characteristics that qualified contractors such as railway, highway and electric power need cross-regional cooperation when building linear projects, which will reduce the probability of clustering. Weak relationships tend to lead parties to adopt legally protected means (such as contracts, etc.), which may trigger contractors to implement formal contractual governance mechanisms.

From the perspective of structure embedding, the 3-node weighted motif of the cluster project organization network is mainly an equal network motif (), that is, a trilateral regulation structure. However, the 4-node weighted motif has partially decentralized () and completely decentralized () structures. As the highest frequency motif in the evolution process, partially decentralized motif shows the most common cooperation form in the weighted motif of the network. As the highest Z-score motif in the evolution process, the fully decentralized motif reflects the development preference of the network, that is, the trend of flat decentralized cooperative evolution. This reflects that contract governance may limit the potential opportunistic behavior of contractors to a certain extent. But virtually, the contractual relationship constrains the contractor's actions. This will easily lead to the slow improvement of the performance of cluster project management. Therefore, the introduction of trust, cooperation, commitment, communication as the core of relationship governance means, can integrate appropriate flexible elements into the cluster project governance system. In this way, the contract governance can not only inhibit the potential opportunistic behavior of the contractor, but also reduce the operating cost of checking the contractor's performance behavior.

To sum up, from the perspective of formal system-based contract governance and informal system-based relationship governance, contract governance occupies a more core position in cluster project group organization network governance, while relationship governance is still an important means to improve project group management performance. This is instructive to the governance of major engineering projects, which should be fully reflected in practical operation. Even so, relational governance cannot replace the core position of contractual governance in the governance framework of public projects. In practice, we can combine the advantages of the two and adopt mixed governance.

5. Conclusion

Based on the edge-weighted nature of the network, this study further reveals the characteristics of motif in the organization network of NQEA project from the micro perspective of complex networks. hen, combined with the project governance theory, the governance model analysis based on weighted motif is realized. The research expands the analysis path of cluster project network governance.

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