ICCEPM 2022
The 9th International Conference on Construction Engineering and Project Management
Jun. 20-23, 2022, Las Vegas, NV, USA

Assessing Contractor Competition in Competitive Bidding for Highway Construction Projects Using Network Analysis

Chau Le[1]*, Minakshi Arya[2], Muhammad Ali Moriyani[3], Tuyen Le[4]

[1] *Department of Civil, Construction and Environmental Engineering, North Dakota State University, 202L CIE, Fargo, ND 58102, USA,* E-mail address: chau.le@ndsu.edu
[2] *Department of Computer Science, North Dakota State University, 258 Quentin Burdick Building, Fargo, ND 58102, USA,* E-mail address: minakshi.arya@ndsu.edu
[3] *Department of Civil, Construction and Environmental Engineering, North Dakota State University, 208 CE, Fargo, ND 58102, USA,* E-mail address: muhammad.moriyani@ndsu.edu
[4] *Glenn Department of Civil Engineering, Clemson University, 316 Lowry Hall, Clemson, SC 29634, USA,* E-mail address: tuyenl@clemson.edu

Abstract: State highway agencies (SHAs) typically apply a competitive procurement procedure to select contractors for their design-bid-build projects. Since the level of competition affects construction bid prices and project outcomes, the Federal Highway Agency (FHWA) suggests SHAs seek ways to improve competition among contractors continuously. However, they rarely conduct an empirical assessment of the current competition level necessary to identify room for improvement. Besides the number of bidders on a project, other factors such as winning or losing rates among the contractors in previous projects can also indicate the degree of competition; only a few contractors may have won the majority of the projects in a specific region. However, few studies have investigated such factors. This paper proposes a network analysis-based approach to evaluating contractor competition levels of highway projects using historical bid tabulation data. The proposed method provides insights into overall competition levels, the determination of competitive contractors, and winning rate distribution among contractors.

Keywords: procurement, bidding, contractor competition, bid tabulation, network analysis.

1. INTRODUCTION

Merriam Webster dictionary defines competition as "the effort of two or more parties acting independently to secure the business of a third party by offering the most favorable items." In construction, various contractors usually compete by bidding to win a contract. Many studies have concluded that a certain level of saturation in the market is required to produce efficiency, innovation, reduced costs, and client satisfaction [1-3]. On the other hand, lack of competition usually results in a monopoly that reduces efficiency and wastes resources [3]. In this connection, the Competition in Contracting Act (CICA) was approved by Congress in 1984 to stimulate competition in public procurement. The primary purpose of CICA is to enable the government to procure a fair price and give chances to small companies to participate [4].

Improved competition is encouraged in the bidding process because of its promising benefits on the bid prices and outcomes of the project [5]. To further enhance competition among contractors, it is essential first to evaluate the current level of competition to identify room for improvement

[1]. However, few studies have conducted an empirical assessment of contractor competition levels. Previous studies have mainly been focused on determining or examining the factors influencing contractor competition. For example, a study conducted by Carr [1] showed that the number of competitors might lower a contractor's probability of winning and its profit. Kim and Reinschmidt [6] found that risk attitude is one of the most influential factors in determining contractors' competitiveness. Another research examined the effect of prequalification on the competition. They concluded that prequalification increases the risk of reducing the competition as the number of bidders is restricted [7]. Some other factors are the experience of bidders or inequality in the sizes of bidders [2, 3].

Major public project owners such as State Highway Agencies (SHAs) have used the number of bidders as a single competition indicator of a contract [8, 9]. Besides the number of bidders on a project, other factors such as their historical winning or losing rates can also indicate the degree of competition. For example, only a few contractors may have won the majority of the projects in a specific region, particularly a very rural area where the local contractor community is small. However, few studies have investigated such factors. This paper proposes a network analysis-based approach to evaluating contractor competition levels of highway projects using historical bid tabulation data.

Social Network Analysis (SNA) is defined as a process of describing the interrelationships of different groups, organizations, or actors [10]. A relationship is represented by a system of nodes, also known as actors, connected by connections, also known as ties or edges [11]. SNA also explains the mathematics between the relationships of those actors [10]. There can be different types of ties describing relationships. Non-directional ties represent symmetrical relationships. Comparably, directional ties represent non-symmetrical relationships. Directional ties can further be classified as inward and outward ties. SNA is considered to possess the extraordinary capability to solve problems involving complex relationships such as showing interdependence between project organizations, multilevel analysis, and integration of qualitative and quantitative data. Since its inception, SNA has been widely used in social sciences and economics. SNA has also been adopted in the construction industry. Zheng et al. [12] conducted a structured review of 63 papers published between 1997 to 2015 that utilized SNA in the construction project management research. The paper reports that SNA has been mainly used to solve issues related to performance and effectiveness in the construction industry. El-adaway et al. [13] has reported that mostly in civil engineering, SNA has been used to investigate interactions between individual persons and particular organizations (as actors). Keeping in view the potential of SNA in understanding the interrelationships, this paper proposes to use the SNA in analyzing the contractor's competition for SHAs. The proposed method is expected to provide insights into overall competition levels, the determination of competitive contractors, and winning rate distribution among contractors.

2. METHODOLOGY

2.1. Historical bid tabulation data

The bid tabulation data of an SHA was collected, including 1,499 contracts with at least two bidders from 2009 to 2019. Data attributes include contract information and bids submitted by bidders. Data attributes used in this study include the following.

- General contract characteristics, e.g., whether a contract was conducted in an urban or rural area.
- Names of the contractors or bidders who submitted a bid for each contract.
- Name of the winning bidder of each contract.

2.2. Competition network modeling

A contractor competition network can be developed for a set of contracts using their bid tabulation data. The list of all contractors involved in those contracts can be easily identified. Each contractor is given an identification number (ID) and modeled as a node in a competition network. For each pair of contractors, the number of wins or losses between them in past contracts is then determined. A relationship that contractor m beat contractor n in r past contracts is represented as an edge directed from node m to node n with a weight of r (see Figure 1). The opposite link directed from node n to node m with a weight of q represents that contractor n beat contractor m in q other past contracts.

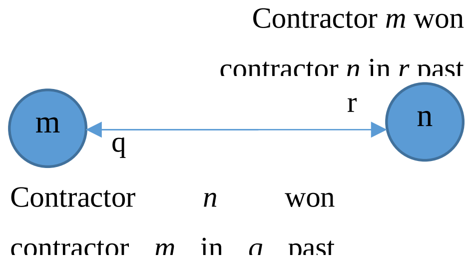

Figure 1. Competition between two contractors

Connecting all of the pairs of contractors forms a contractor competition network for the contracts of interest. Figure 2 shows the competition network for all 1,499 contracts in the dataset, with 248 contractors given ID from 1 to 248. The network was developed using the Python package Network X. The weights were hidden to gain more visibility for the network. If only competition among a few contractors is of interest, a sub-network can be extracted from the whole network to show only interactions among those contractors.

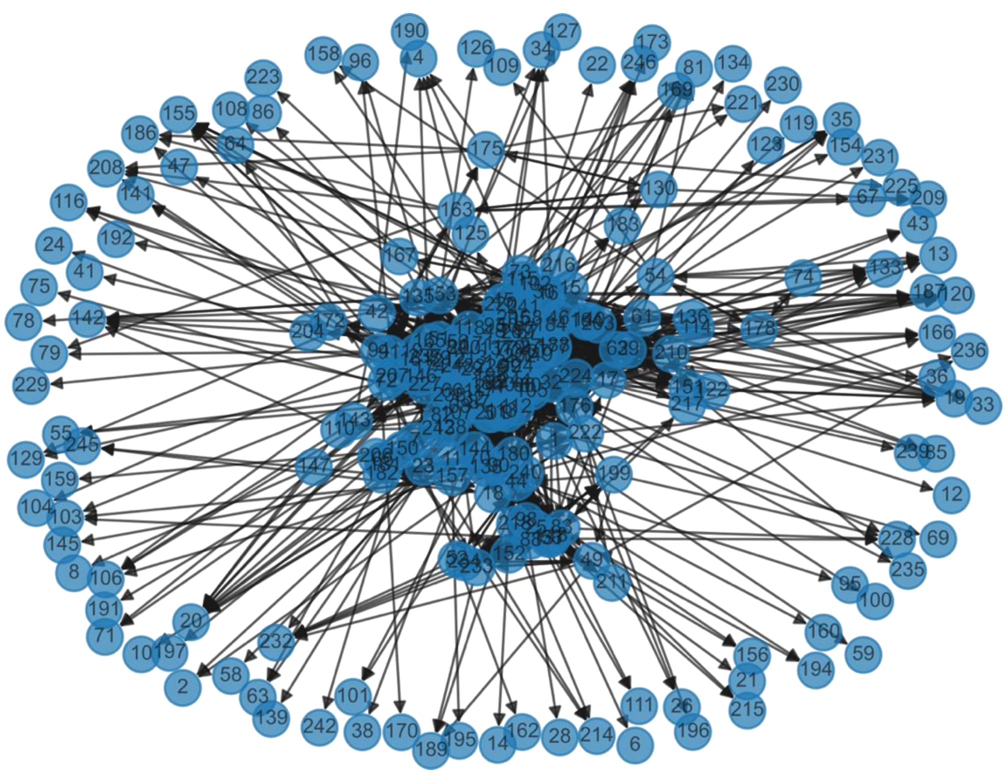

Figure 2. Contractor competition network for all 1,499 contracts

2.3. Network measures of competitiveness

Degree centrality measures are used to evaluate the importance of a node/contractor, including the following.

- Node out-degree of a contractor is the number of unique contractors it won in the past contracts.
- Node out-degree with edge weights of a contractor is the number of times it won other contractors in the past contracts.
- Node in-degree of a contractor is the number of unique contractors it lost in the past contracts.
- Node in-degree with edge weights of a contractor is the number of times it lost other contractors in the past contracts.

A contractor's winning ratio is proposed to help reflect the competitiveness level of the contractor, as shown in Equation 1. A contractor with a high winning ratio has a higher chance of winning a new project than that with a low winning ratio.

$$Winning\ ratio = \frac{Out\text{−}degree\ with\ edge\ weights}{Out\text{−}degree\ with\ edge\ weights + In\text{−}degree\ with\ edge\ weights} \quad (1)$$

3. RESULTS AND DISCUSSION

Figure 2 shows competition among 248 contractors in 1,499 past contracts. These past competition results may provide insights for evaluating the competition among bidders for a new project. For example, contractors 17, 39, 140, and 210 bid on the SHA's new project. In current literature and practice, the number of bidders (i.e., 4 in this example) is used to reflect the level of competition for the new project. However, it is not sufficient. Figure 3 illustrates the competition between the four contractors in past projects. As shown in the figure, contractor 39 lost contractors 17, 210, and 140 in 24, 19, and 28 past contracts, respectively, and it has never won the three contractors in any projects. Therefore, the competition for the new project is probably only among three contractors (i.e., 17, 140, and 210), not four.

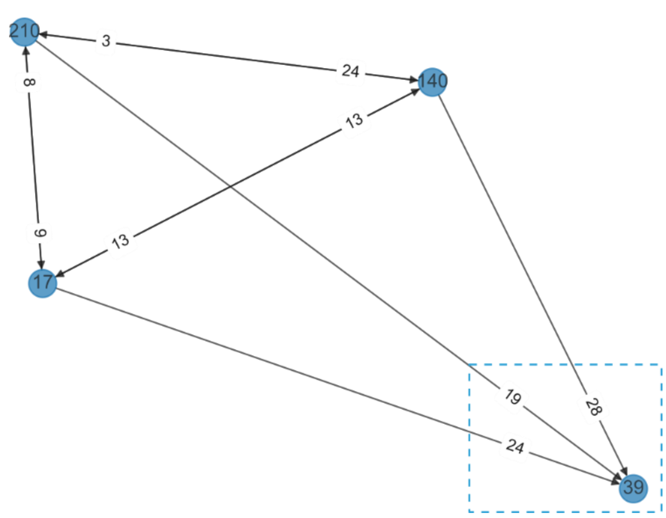

Figure 3. Example of competition among a group of contractors

The node measures can also be used to reflect the competitiveness of contractors. Table 1 shows the top competitive contractors by different measures. The differences in the top contractors among the measures indicate that a single measure is not sufficient to reflect a contractors' competitiveness level. For example, contractor 27 has the most wins (i.e., 257 times), but its winning ratio is not among the top, just about 0.46 (46%). Conversely, contractor 110 has a winning ratio of 100%, but its total number of wins is only 11.

Table 1. Top competitive contractors by node measures

No.	Out-degree	Out-degree with edge weights	Winning ratio
1	43 (Contractor 32)	257 (Contractor 27)	1.00 (Contractor 110)
2	37 (Contractor 87)	202 (Contractor 210)	1.00 (Contractor 113)
3	35 (Contractor 27)	185 (Contractor 140)	1.00 (Contractor 1)
4	30 (Contractor 9)	150 (Contractor 17)	1.00 (Contractor 147)
5	30 (Contractor 177)	149 (Contractor 87)	1.00 (Contractor 51)

Therefore, the out-degree with edge weights and winning ratio measures were plotted together to evaluate contractors more comprehensively, as shown in Figure 4. Considering both measures, contractor 210 seems to be the most competitive. Its number of wins against other contractors is 202 (the second highest among contractors), while its winning ratio is also very high, at 91.4%. Some contractors have a winning ratio of 100%, but their numbers of wins are small, not guaranteeing a high level of competitiveness.

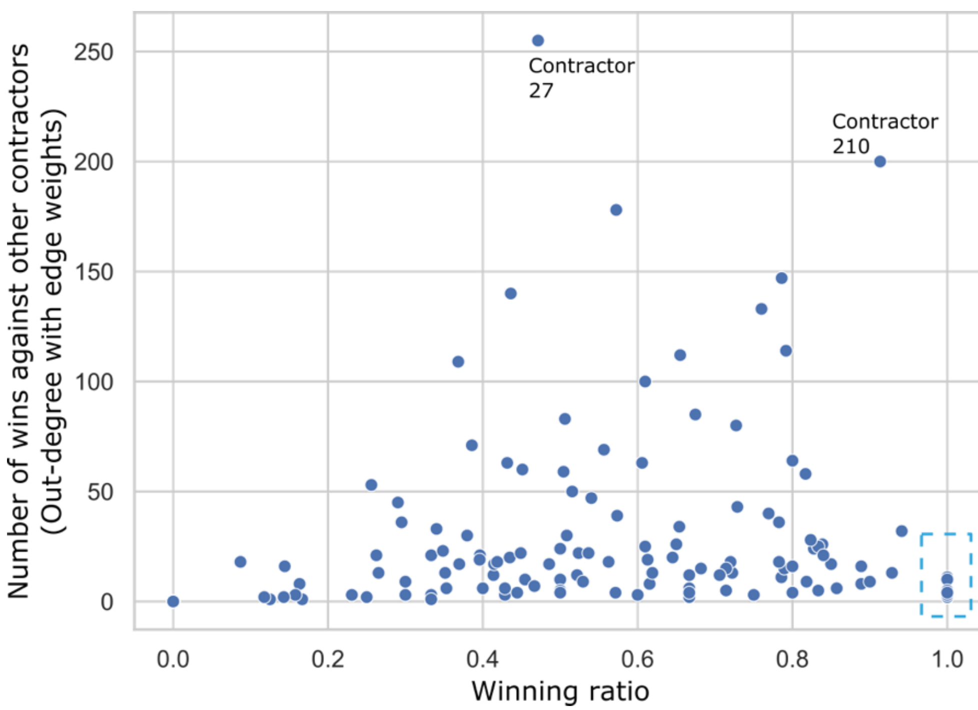

Figure 4. Winning ratio vs. Out-degree with edge weights

The effect of contract and project characteristics on contractor competition level can also be evaluated. In this study, the proposed methodology can be applied separately to contracts in urban and rural areas to have two contractor competition networks: one for urban and one for rural contracts. Network measures can then be used to compare between two groups. Figure 5 shows no significant difference in the contractors' winning ratios between urban and rural contracts by comparing their mean winning ratios.

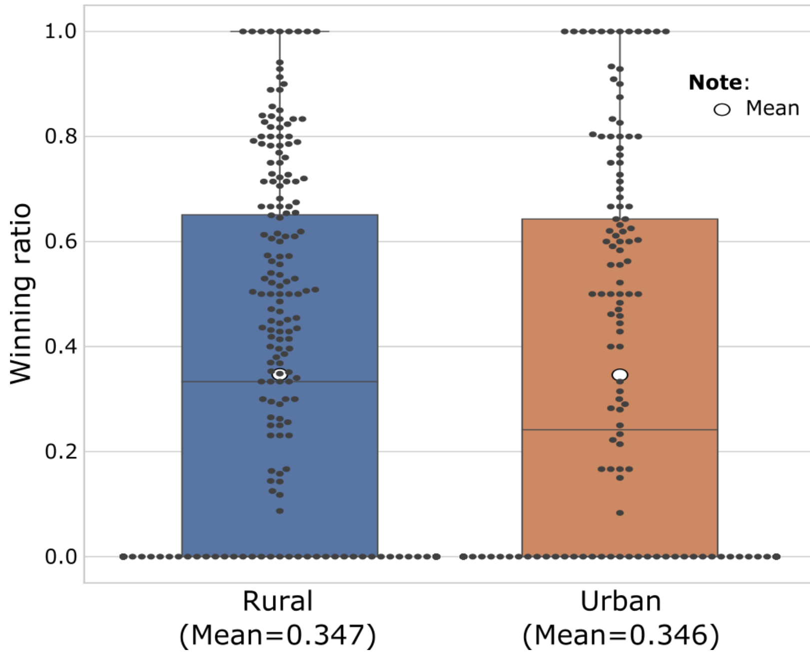

Figure 5. Comparing winning ratios between rural and urban contracts

4. CONCLUSIONS

The primary contribution to the body of knowledge of this study is a novel application of SNA to evaluate contactor competition in highway projects using historical bid tabulation data. Past wins and losses among contractors are embedded into a contractor competition network to provide insights into assessing competition between bidders in a new project. It complements the use of the number of bidders to represent the level of competition in a contract. Network centrality measures and winning ratios, a new measure proposed by the authors, can be used to evaluate the competitiveness of a specific contractor. Winning ratio distributions among contractors also provide valuable information to decision-makers. For example, the existence of many contractors with large wins against other contractors and high winning ratios indicates some levels of monopolies, signaling the need to improve competition. Effects of a factor on contractor competition can also be evaluated. In this study, the difference in competition levels between urban and rural contracts is shown to be insignificant.

Future research might explore the effect of other factors, such as project work types, contract sizes, and locality, on contractor competition. Other node and whole-network measures in the SNA literature will also be examined to determine additional measures that can be used to evaluate contractor competition more comprehensively. A composite indicator of a contract's overall level of competition will be proposed. Furthermore, additional data regarding contracts' performances in the bidding phase (e.g., the relative difference between the engineer's estimate and the lowest bid or the coefficient of variance of bid prices) or at the end of construction (e.g., schedule growth or cost overrun) will be collected to examine the relationships and correlations between competitive measures and contract performances. Other possible directions include incorporating more detailed information into contractor competition networks (e.g., Figure 2) or employing a synthetic dataset in model development or validation.

REFERENCES

[1] P. G. Carr, "Investigation of Bid Price Competition Measured through Prebid Project Estimates, Actual Bid Prices, and Number of Bidders," *Journal of Construction Engineering and Management,* vol. 131, no. 11, pp. 1165-1172, 2005, doi: doi:10.1061/(ASCE)0733-9364(2005)131:11(1165).

[2] W. K. Fu, D. S. Drew, and H. P. Lo, "Competitiveness of Inexperienced and Experienced Contractors in Bidding," *Journal of Construction Engineering and Management,* vol. 129, no. 4, pp. 388-395, 2003, doi: doi:10.1061/(ASCE)0733-9364(2003)129:4(388).

[3] S. O. Cheung and L. Shen, "Concentration Analysis to Measure Competition in Megaprojects," *Journal of Management in Engineering,* vol. 33, no. 1, 2017, doi: 10.1061/(asce)me.1943-5479.0000464.

[4] W. S. Cohen, "The Competition in Contracting Act," *Pub. Cont. LJ,* vol. 14, p. 1, 1983.

[5] K. Honek, E. Azar, and C. C. Menassa, "Recession Effects in United States Public Sector Construction Contracting: Focus on the American Recovery and Reinvestment Act of 2009," *Journal of Management in Engineering,* vol. 28, no. 4, pp. 354-361, 2012, doi: doi:10.1061/(ASCE)ME.1943-5479.0000075.

[6] H.-J. Kim and K. F. Reinschmidt, "Effects of Contractors' Risk Attitude on Competition in Construction," *Journal of Construction Engineering and Management,* vol. 137, no. 4, pp. 275-283, 2011, doi: doi:10.1061/(ASCE)CO.1943-7862.0000284.

[7] L. Sheng, J. R. Foulger, and P. W. Philips, "Analysis of the Impacts of the Number of Bidders Upon Bid Values," *Public Works Management & Policy,* vol. 12, no. 3, pp. 503-514, 2008, doi: 10.1177/1087724x07312144.

[8] AASHTO, "Practical guide to cost estimating," ed: AASHTO Washington, DC, 2013.

[9] M. Yaw, H. D. Jeong, and K. Choi, "Effects of Flexible Notice-to-Proceed Provisions on the Performance of Transportation Infrastructure Projects," *Transportation Research Record,* p. 03611981211065736, 2022, doi: 10.1177/03611981211065736.

[10] S. Pryke, *Social network analysis in construction*. John Wiley & Sons, 2012.

[11] C. Le, H. D. Jeong, and I. Damnjanovic, "Network Theory—Driven Construction Logic Knowledge Network: Process Modeling and Application in Highway Projects," *Journal of Construction Engineering and Management,* vol. 147, no. 10, p. 04021114, 2021, doi: doi:10.1061/(ASCE)CO.1943-7862.0002143.

[12] X. Zheng, Y. Le, A. P. C. Chan, Y. Hu, and Y. Li, "Review of the application of social network analysis (SNA) in construction project management research," *International Journal of Project Management,* vol. 34, no. 7, pp. 1214-1225, 2016, doi: 10.1016/j.ijproman.2016.06.005.

[13] I. H. El-adaway, I. S. Abotaleb, and E. Vechan, "Social Network Analysis Approach for Improved Transportation Planning," *Journal of Infrastructure Systems,* vol. 23, no. 2, 2017, doi: 10.1061/(asce)is.1943-555x.0000331.