Influence of Organizational Characteristics on Construction Project Performance Using Corporate Social Networks

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ABSTRACT

This exploratory research examines the relationship between project performance and organizational characteristics in construction companies. Nine Chilean construction firms were involved in this study. Key performance indicators (KPIs) were introduced to periodically capture the project performance of 41 projects in these companies. Furthermore, their organizational characteristics were evaluated using social network analysis metrics. A correlation analysis revealed the relationships among four metrics from six social networks and nine KPIs. Significant correlations were found between the density, average degree, diameter and average path length of social networks and the medians and standard deviations of KPIs. The results confirm that a relation exists between high connectivity and short communication paths within the social networks of a construction company and high KPIs of construction project performance. Additionally, high inverse correlations were observed, suggesting that connectivity may be a consequence of poor project results, such as for the accident KPI. The results indicate that high connectivity and closeness inside corporate social networks are not necessarily related to good performance in construction projects. Thus, corporate social networks do not possess an ideal condition that enables optimal company performance in all areas.

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INTRODUCTION

Project organization is a critical project success factor (Torp et al. 2004), so considerable research has focused on project organization and project performance, mainly pointing to factors that emphasize effectiveness (cost, schedule, quality, etc.), client satisfaction, or financial indicators (Bassioni et al. 2004; Chinowsky et al. 2010). The use of social network analysis (SNA) as a tool to study the temporary organizations that are formed to implement the construction projects has grown in recent years. Additionally, SNA has been used to identify the relationships among the characteristics of such organizations and their performance in many aspects of project development (Zheng et al. 2016). Specifically, research has focused on the characteristics that allow ideal flow of information among its members because information is a central element of construction processes (Alarcon et al. 2013; Alsamadani et al. 2013; Priven and Sacks 2016; Pryke 2012; Ruan et al. 2013).

However, research on the influence of corporate organization characteristics and project performance is still limited and in the early development stage (Alarcon et al. 2013; Alsudiri et al. 2013; Eriksson 2013; Zheng et al. 2016). In particular, there is a lack of data regarding the relation between information flow inside corporate organizations and project performance aspects defined as key issues in construction projects, such as cost, schedule, quality, and accidents (Nassar and Abourizk 2014). The last is especially important because the performance of construction projects is closely linked to the performance of the construction company and its success and permanence depends on that factor (Gann and Salter 2000; Yu et al. 2007).

This study aims to answer the following research question: how do corporate organizational characteristics influence construction project performance?

To answer this question, this paper is organized as follows. In the next section, a literature review of the relationship between corporate social networks and project performance is summarized. Then, the research methods are explained considering both construction project performance and the organizational characteristics of a construction company; this section includes the following subsections: an overall explanation of the research, sample selection, the justification of the project performance indicators used in this study, the explanation of the social network approach, and the correlation analysis between the variables of these two facets. Next, the results are presented, followed by a section discussing these results. Finally, the paper concludes by summarizing its main contributions, recommendations for practitioners, limitations and future research.

LITERATURE BACKGROUND

Companies in the construction industry are project oriented (Gann and Salter 2000; Skibniewski and Ghosh 2009; Winch 2006); this type of company is flexible and reconfigurable (Hobday 2000). The production of these companies is based on temporal or "unstable" projects teams accomplishing specific goals in a short period of time (Campero and Alarcón 2014; Chinowsky et al. 2008; Pellicer 2007; Wegelius-Lehtonen 2001) because they are better able to address project risks and uncertainties (Hobday 2000). The success of these companies depends on the performance of their projects (Alsudiri et al. 2013; Gann and Salter 2000); therefore, project performance measurement indicators are a key issue for the overall success of construction companies (Skibniewski and Ghosh 2009; Wegelius-Lehtonen 2001).

Company performance is usually measured based on a set of key performance indicators (KPIs), which are ratios representing key aspects of the company activities (Ali et al. 2013; Badawy et al. 2016; Horta et al. 2010). Similarly, construction project performance is assessed using an appropriate set of KPIs, which include cost, time, quality, safety, and productivity (Radujković et al. 2010; Yeung et al. 2013). Using company KPIs and project KPIs separately does not provide insight into how to improve corporate performance, and they have limited application for internal management decisions (Beatham et al. 2004; Ramırez et al. 2004). Project KPIs provide information for performance analysis; however, they are not used for corporate organizational performance analysis, and they receive limited use during project construction only (Ahmad et al. 2016).

The business management of project-oriented companies in the construction industry faces specific issues, such as difficult long-term planning, the variability of short-term planning, interaction and competition among projects within the company, and the organizational integration of project members within the company hierarchy (Gann and Salter 2000; Pellicer et al. 2009; Shi and Halpin 2003). The latter is of utmost importance for understanding how organizational issues influence the performance of construction projects (Alarcon et al. 2013; Chinowsky et al. 2011; Flores et al. 2014). Previous contributors have cited organizational-related characteristics, such as communication and information flow, as sources of project performance (Chinowsky et al. 2008, 2011; Skibniewski and Ghosh 2009; Wegelius-Lehtonen 2001; Winch 2006).

Traditionally, managers evaluate organizational characteristics considering the effective communication needed to coordinate and integrate efforts among different units (Daft 2012). However, in addition to the formal organization, the so-called informal organization consists of the employee social networks that make the work possible (Krackhardt and Hanson 1993). The characteristics of job-site social networks, and especially their connectivity, are key elements for corporate performance (Pentland 2014). In addition, other characteristics, such as link density, the distance between members and member centrality, are factors that influence the ease of information flow (Cherven 2015). In recent years, many studies have sought to understand the social network characteristics of construction projects, considering that projects are temporary network-based organizations. SNA is suitable for analysing these types of social structures under constant dynamic changes (Zheng et al. 2016). SNA metrics are related to the ease of information flow, such as the degree of centrality, density, diameter and average path length (Cherven 2015; Hickethier et al. 2013; Priven and Sacks 2013; Pryke 2012; Scott 2013). In turn, information flow has been linked to trust and commitment among the participants in an organization (Chinowsky and Meredith 2000; Zeffane et al. 2011). Commitment is a key issue for planning and performance compliance in construction projects (Ballard, 2000; Zavadskas, Vilutien, Turskis, & Šaparauskas, 2014). In addition, timely information flow is critical for the spread and combination of new ideas that drive innovation, which is the most important driver of long-term performance (Pentland 2014).

RESEARCH METHODS

Sample Selection

This study was performed during a one-year period and involved, initially, nine construction companies operating in Chile, although only five of these companies allowed us to analyse their corporate social networks. The companies were part of a benchmarking exercise within the "Building Excellence Group," which was a temporary collaborative group of companies that develop applied research with the Center for Excellence in Production

Management (GEPUC). A collaborative benchmarking group is a set of firms that share knowledge to improve their performance through what they learn from each other (Lankford 2002). The advantages of collaborative benchmarking among construction companies have been described in the literature (Costa et al. 2006; Yun et al. 2016). This methodology provides efficient, high-quality information sharing and learning motivation (Albertin et al. 2015).

Overall Approach

To accomplish the research goal, a literature review was conducted to identify the most commonly used indicators and metrics of construction project performance and corporate social networks. This analysis of previous contributions aimed to identify the key project performance indicators and organizational metrics.

For project performance assessment, the research team selected nine companies as the sample for this research. First, semi-structured interviews were conducted with 21 project managers at these nine companies to obtain the nine final indicators of the 23 original possibilities. Later, each company selected a group of current projects to compare similar indicators. The projects were required to have been in place for at least three months and to have at least three months remaining before the end of the project to avoid the biases of activities that were ending or had recently started. Project performance was evaluated for 41 construction projects ranging from USD $5 million to $100 million and included housing and industrial projects.

To perform the project management and organizational analyses, personnel with decision-making abilities, ranging from CEOs to field engineers, were surveyed (410 employees) to determine the social network characteristics at a corporative level. These employees were from five of the nine companies selected because the other four declined to provide sensitive organizational information. Later, SNA was performed using four basic metrics for the five companies (within the group of the original nine companies).

Descriptive statistics were obtained for both the performance indicators and network metrics. Different analyses were conducted to establish correlations between qualitative factors derived from the SNA and quantitative factors derived from the project performance indicators. Finally, the contributions, recommendations, limitations and future research are highlighted. The research methodology is summarized in Fig. 1.

Project Performance Indicators

Construction project performance is measured by gathering data to produce KPIs, which are measures used to monitor project performance and conduct benchmarking over time in regard to the attainment of the stated project goals (Costa et al. 2014). KPIs can be used to identify improvement opportunities and to set performance targets. Construction companies seem to list common KPIs, including both leading or process indicators and lagging or outcome indicators (Costa et al. 2014; Nassar and Abourizk 2014; Yeung et al. 2013), regardless of their project management perspective (Radujković et al. 2010).

The project performance evaluation was based on the project KPIs used as the leading or process indicators. The selection of the performance indicators was based on extensive previous studies from the literature review and a survey of 21 project managers from the nine construction companies. In this survey, the managers were asked to prioritize nine KPIs out of a 23-item list taken from the literature review and from their daily practice; the questionnaire is attached in Appendix S1. The selection criteria included the importance of monitoring projects and the availability of information to calculate the indicators. Thus, construction companies took advantage of indicators that could be measured without excessive work for their employees

(Badawy et al. 2016). Table 1 details the items considered, as well as the corresponding KPI and formula for computing each of them. The chosen KPIs are cost deviation, scheduled deviation, accident frequency, accident gravity, planning effectiveness, constraint release, quality, productivity, and contract bid change. The planning effectiveness index is the percent plan complete (PPC), which measures the predictability of work delivered on time (Yun et al. 2016). The project managers of the construction projects filled out forms containing the nine KPIs indicated in Table 1 for every project during three consecutive months and then reported to the research team.

Social Network Analysis

SNA is a subset of network graph analysis that is frequently used to map peer networks (Cherven 2015). In SNA, a social network is a set of actors (nodes) and a set of relationships (edges) connecting pairs of actors, so construction participants can be seen as nodes within an interconnected network, forming a social structure (Lin 2015), such as that shown in Fig. 2. SNA techniques and software references are becoming increasingly user friendly and more frequently used (Abraham et al. 2009). In the construction industry, specific uses of SNA have been published in the past several years (Alarcon et al. 2013; Chinowsky et al. 2008, 2011; Priven and Sacks 2015)

SNA is considered an appropriate tool for analysing organizations involved in construction projects based on a relational, contextual and holistic approach (Zheng et al. 2016). Additionally, SNA is a validated method for analysing the quantitative relationships within a social network and the general network topology through a visualization and modelling technique that can capture the relationships, interactions and attributes of network constituents (Chinowsky et al. 2008). In addition, SNA combines analyses of other qualitative and quantitative methods to understand social roles, positions and behaviours in the construction project environment (Zheng et al. 2016). SNA is a set of methods that investigates the relational aspects of social structures and provides a vocabulary and set of metrics for relational analysis (Scott 2013). Four social networks metrics, diameter, density, average path length and average degree, are used in this research (Alarcon et al. 2013; Easley and Kleinberg 2010); they are further described in the subsequent text.

The diameter is the maximum number of connections required for the two most distant nodes in the network to reach one another. Notably, the diameter is the longest of all the calculated path lengths (the thick line in Fig. 2). The average path length provides a measure of communication efficiency for an entire network by averaging the shortest possible path between all nodes. Density is a measure of the number of connected edges within a network divided by the total possible value, and the total possible value is the total number of nodes multiplied by the total number of nodes minus one. The degree measures the number of neighbours connected to a specific node (for example, the degree of node 37 in Fig. 2 is 4). In contrast, the average degree is a measure indicating the average number of neighbours per node in a network; the average degree is related to the ability to communicate and is closely related to the density (Cherven 2015). Network metric calculations are tedious, so a variety of computer software is available for SNA; one that is easily available is the open source software Gephi (Bastian et al. 2009), which is used in this study.

SNA was used to understand the relationship patterns within the organizations. The analysis determined whether the social networks were tightly bounded, diversified or constricted based on their metrics (Abraham et al. 2009). In this manner, the authors determined how the network structure was related to the efficient flow of information.

A survey was designed to capture the interactions among the people working in the construction companies; the questionnaire is attached in Appendix S2. Considering the importance of information flow, innovation, trust and commitment for the planning and performance of construction projects (Ballard 2000; Pentland 2014; Zavadskas et al. 2014; Zeffane et al. 2011), this questionnaire explored the information flow for the following six issues: personal confidence, innovation development, full interaction, relevant information exchange, planning and problem solving, and frequency of interaction. Through an online survey, each member reported with whom he/she exchanges information, instead of relying on online information exchange. Multiple studies have shown that a user's real-world behaviours (face-to-face interactions) vary dramatically from their cyber behaviours (Pentland 2014).

Correlation Analysis

Before performing the correlation analysis, the companies' performance indicators were defined as the median of the series of each KPI of all their projects, and the respective standard deviation was used as the measure of KPI variability. Considering the reduced sample size, non-parametric Spearman correlation analysis was applied to the median KPIs, standard deviations of KPIs and social network metrics after ranking the raw data (Moses 1952). In the case of median KPIs, a ranking was assigned from 1 for the worst performance up to N for the best performance. Since high variability is a signal of poor process control, a ranking of 1 was assigned to high variability (poor performance) and N to low variability (optimal performance). Regarding the social network metrics, based on the literature, the best rankings were assigned to the metrics that facilitate information flow between members of social networks. Notably, it is better to have high average degrees and densities, but large diameters and long average path lengths are not ideal.

Using Spearman correlation analysis, the metrics of every social network were correlated to the previously described median KPIs and KPI variability values for each company. The Spearman method is based on a null hypothesis that assumes the independence of the two variables being studied, which can be discarded if the p-value or significance is less than 5%. In addition, the Spearman correlation coefficient r varies between 1 and 0. When there is a clear correlation between the analysed variables, the value of r tends to 1, and when not, it tends to 0. A positive r value indicates a direct correlation, and a negative value reflects an inverse correlation between the two variables. The strength of the correlation is described using the guide that Evans (2012) suggested for the absolute value of r: 0.00-0.19 is “very weak”; 0.20-0.39 is “weak”; 0.40-0.59 is “moderate”; 0.60-0.79 is “strong”; and 0.80-1.00 is “very strong”. Only the correlation values with a corresponding significance of the pairwise p-value for each variable that was equal to 0.05 or less were considered highly significant relationships. The free software R version 3.1.2 was used to obtain the correlations and p-values.

RESULTS

The medians of all the KPIs for every company were obtained and used as representatives of company performance. Additionally, the standard deviation of each KPI was calculated as a measure of variability of the results obtained for the projects of each company. Tables 2 and 3 show the results obtained (median and standard deviation, respectively) for each one of the nine KPIs selected, summarizing the projects per company (from E1 to E9).

The SNA results that were applied to capture the interactions among the people (social networks) working in the five analysed construction companies are displayed in Table 4. These results reflect the informal interactions that the personnel are involved in at work. Social network characteristics such as the density of links, the connection distance between members and the centrality of the members were associated with the metrics of density, path length, diameter and average degree, respectively. To analyse the associated relationships, the organization (each company) was considered a set of six social networks: personal confidence, innovation development, full interaction, frequent interaction, relevant information exchange, and planning and problem solving. These factors are summarized in Table 4.

Next, we calculated the Spearman correlation r values between each of the social network metrics, and the project median KPIs were computed. Table 5 shows the Spearman r values of those correlations with pairwise p-values <0.05 between social network metrics and median KPIs. In Table 5, the social networks with the highest densities and average degrees, as well as short diameters and short average path lengths, are those that exhibit the worst performances in their construction projects. In general, it is assumed that the abovementioned social network characteristics should favour communication between the members of a network and consequently generate good performance; however, the performance of the business organizations measured from their construction projects is not applicable for KPIs such as the accident frequency, contract bid change, planning effectiveness and productivity. Notably, a high average degree for a company's networks is positively related to the constraint release of their construction projects. In the first case, the KPIs (accident frequency, contract bid change, planning effectiveness and productivity) are directly related to the production processes of the projects, in which the influence of the corporate organization seems scarce. However, the constraint release on the projects of the companies studied largely depends on the processes performed to facilitate the supply of inputs, hiring of labour and the provision of updated information for the execution of the projects; therefore, it is important to note that the favourable conditions of corporate networks have facilitated this aspect of project performance.

The KPI variability (measured by the standard deviation) for all the projects of each company was also correlated to the corresponding social network metrics. Table 6 shows the Spearman r correlation coefficients between social network metrics and KPI standard deviations with pairwise p-values <0.05. High social network densities are related to low variability (or a low standard deviation) in the contract bid change indicator. However, high average degrees of social networks are related to poor quality and accident performance. Additionally, short diameters and average path lengths, which facilitate information flow, are associated with low variability in KPIs (accident gravity and contract bid change).

Considering the close relationship between the density and the average degree of a social network (Cherven 2015), these results suggest that the structures of the social networks can be affected by a high concentration of connections in a few members, even if the other members have few connections, as shown in nodes 43 and 46 of Fig. 2. In these structures, a few members act as hubs, concentrating connection lines and power and hindering the flow of information. Poor information flows and communication failures affect the results of the processes (Radosavljevic and Bennett 2012). In addition, particular social network structures are better for certain KPIs and worse for others. This result highlights the issue of information content quality and the quality of relationships within networks because not only the social network structure but also the effectiveness of information links may affect the network performance (Lin 2015; Radosavljevic and Bennett 2012).

A summary of the significant correlations between social media metrics and KPIs is shown in Fig. 3. The links are shown with a 1 to represent positive, direct correlations or a -1 to show negative, inverse correlations between two variables. Direct correlations correspond to ideal relationships between the social network metrics and KPIs, as reported in the literature.

High densities and average degrees, as well as short diameters and path lengths, should correspond to better organization performance (Cherven 2015; Pentland 2014; Priven and Sacks 2015). Conversely, inverse correlations may indicate a reverse cause-effect relation or communication failure among organization members. Increased social network ties are not always beneficial to an organization's performance; rather, communication quality determines success, as documented by Krackhardt & Hanson (1993).

In Fig. 3, social networks (N) and project performance indexes (I) are represented by circular nodes. Larger nodes correspond to high degrees and have increased connectivity with other items in the diagram. The letters in the links represent social network metrics: AD is the average degree, DS is the density, DI is the diameter and PL is the average path length. A value of 1 or -1 is used to represent a direct or inverse correlation, respectively. In Fig. 3, some social network metrics are directly associated with better performance indicators, as in constraint release (median KPIs). In other cases, the correlations are inverse, such as those for the accident frequency, contract bid change, quality and planning effectiveness (median KPIs). The analysis of the correlation between social networks and the variability in the KPIs of the projects suggests that the high metrics of the social networks correspond to low variabilities in the KPIs. This finding may suggest that the conditions of the networks that favour communication are somehow positive for the control of the processes. Except in the cases of accidents and quality, this finding reinforces the concept that some project processes are beyond the reach of the stable social networks that manage the companies and correspond more to the scope of the organization in charge of the project.

DISCUSSION

The results in Table 5 show that corporate social networks with adequate metrics for information flow may produce contradictory results in their projects because they have some high KPIs, such as constraint release, but poor performance in planning, contract bid change, accidents and productivity. These corporate organizations may be prioritizing information flow to meet certain project requirements that help release constraints, whereas job-site and operative actions, such as production planning, labour productivity and safety, are out of their reach. Therefore, despite their well-configured informal organizations, they have little influence on these other aspects of a project. In addition, a negative or positive correlation does not necessarily imply a causal relationship. In this case, social network properties may be an adaptive response to project performance results, which is possible because social networks are complex systems influenced by the environment in which they operate, and, in turn, they influence that environment. Additionally, these properties are adaptive because networks mutate and self-organize in response to a triggering event or series of events, and, consequently, they control the number, type and duration of their interactions (Lymperopoulos and Lekakos 2013), as can be the case for organizations facing bad project results. In addition to having interconnected and related elements, social networks are adaptable and capable of learning (Page 2011). Moreover, since social networks evolve over time (Pryke 2012), the relationship between these two variables may also vary over time; therefore, the variables may display an inverse correlation during some periods and a positive correlation during others. Because the correlation exhibits two-way variability, the high density and average degree of the corporate social networks may result in negative project performance, especially for factors such as accidents, contract bid change and productivity reported to company offices. However, since the network metrics correspond to an instant in which the snapshot was taken, it is difficult to determine if these findings are a response to the conditions of their surroundings and the results obtained without performing a temporal analysis. However, these correlations would require extensive temporal analysis to establish the associated causality mechanisms because social network surveys offer only a snapshot and do not reflect the dynamics of social networks.

In Table 6, considering the close relationship between the density and the average degree of a social network (Cherven 2015), the correlation results suggest that the structure of the networks could be affected by a high concentration of connections for a few members, even if the other members have few connections, as shown in Fig. 3. In these structures, a few members act as hubs, concentrating connections and power and hindering the flow of information. This network structure can result in poor information flows and communication failures that may affect process results (Radosavljevic and Bennett 2012). The positive relation between full interaction networks with high metrics and corporate productivity was previously documented by Pentland (2014), who emphasized that good connectivity and information flow among members of an organization are key to improving productivity; however, this was not the case for the construction companies analysed in this study. In addition, some social network structures are better for certain KPIs and worse for others, suggesting that there is not a "one size fits all" type of corporate social network. This observation highlights the quality of information and the quality of communication within networks (Priven and Sacks 2015; Radosavljevic and Bennett 2012), as the network structure, number of ties and communication management are all important (Forcada et al. 2017; Krackhardt and Hanson 1993), especially for meeting health and safety goals. Even the communication mode can influence performance (Alsamadani et al. 2013), and this topic deserves further research.

CONCLUSIONS

This study examined the corporate organizational characteristics of construction companies through their social network metrics and the relationships between metrics and construction project performance. Based on data from five construction companies, this study performed a correlation analysis of four metrics from six social networks and nine KPIs. Significant correlations were found between the social network density, average degree, diameter and average path length and the median and standard deviation of KPIs.

The obtained results confirm the relation between high connectivity and short communication paths within the social networks of construction companies and good construction project performance. Additionally, high inverse correlations suggested that connectivity may be a consequence of poor project results, such as for the accident KPI or other factors not considered in this study. Consequently, high connectivity and closeness within corporate social networks are not directly related to good performance in construction projects. Therefore, corporate social networks do not possess an ideal condition that enables the best company performance in all areas; and several aspects of construction project performance are beyond the scope of corporate organization influences, instead depending on project organization conditions. Additionally, considering the small sample size studied, the results are not generalizable and should be cautiously considered.

Networks with high densities and short diameters are desirable because they facilitate information flow. However, the quality of communication and the relationships developed among team members should also be considered. Managers can leverage these exchanges to create quality interactions among members of the network and generate cooperative behaviour.

This paper is limited to portraying the conditions of the investigated companies. The results represent a temporal reality bounded by the study period. As the social structures of companies evolve during a project, timeline tracking should be performed to provide better information for management strategies. The relationships between the average degree and density of the social networks and the frequency of accidents should be tracked within a timeline to identify causal relationships.

Although this paper was based on a group case study, the procedures used here can be applied to other projects. The steps used to conduct SNA were thoroughly described and can be applied to other construction projects. The repeatability of these procedures will allow them to help project managers improve project performance based on information flow management.

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SUPPLEMENTAL DATA

Appendixes S1–S2 are available online in the ASCE Library (www.ascelibrary.org).

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Figure caption list

Table 1. Key performance indicators (KPIs)

Item	**KPI**	**Formula(s)**
Cost	Cost deviation	$\text{CD} = \frac{(\text{Real cost} - \text{Budget cost}) * 100}{\text{Budget cost}}$
Schedule	Scheduled deviation	$\text{SD} = \frac{(\text{Real advance} - \text{Scheduled advance}) * 100}{\text{Scheduled advance}}$
Safety	Accident frequency	$\text{FI} \frac{(\text{Disabling accidents}) * 10^6}{\text{Work hours}}$
	Accident gravity	$\text{GI} = \frac{(\text{Lost days}) * 10^6}{\text{Work hours}}$
Planning	Planning effectiveness	$\text{PPC} = \frac{\text{Fulfilled activities} * 100}{\text{Scheduled activities}}$
	Constraint release	$\text{CR} = \frac{\text{Released constrains} * 100}{\text{Total constrains}}$
Building	Quality	$\text{Qi} = \frac{(\text{Number of rework orders } * 10^6)}{\text{Work hours}})$
	Productivity	$\text{PT} = \frac{\text{Actual labour cost}}{\text{Budgeted labour cost}}$
Project scope	Contract bid change	$\text{CBC} = \frac{\text{Final projected sale contract}}{\text{Initial sale contract}}$

Table 2. Median KPIs by company

KPI	E1	E2	E3	E4	E5	E6	E7	E8	E9
Cost deviation	0.000008	-0.047700	-0.011600	0.120000	0.158704	-0.016150	-0.064000	0.464700	0.015000
Schedule deviation	0.035750	-0.090900	0.107600	0.169000	-0.211500	0.026610	-0.062300	-0.291500	0.276400
Accident frequency	8.615000	5.140000	5.000000	0.000000	0.000000	0.000000	0.000000	N/D	0.000000
Accident gravity	98.810000	74.000000	302.100000	162.800000	0.000000	0.000000	0.000000	N/D	76.340000
Planning effectiveness	0.770500	0.710000	0.810000	0.620000	0.530000	0.667950	0.783800	0.664000	0.909700
Constraint release	0.600000	0.780000	N/D	0.960000	0.363000	0.729100	0.789100	0.652000	0.214700
Quality	27.060000	75.723000	733.200000	22824.300000	N/D	31.740000	0.000000	N/D	N/D
Productivity	0.670000	1.414910	1.342323	1.013000	1.241350	1.117424	1.002640	1.258700	N/D
Contract bid change	1.000000	1.044000	0.985000	1.035000	1.000000	1.175000	1.010000	1.018000	1.040000

Note: N/D = No data were reported by the company.

Table 3. KPI standard deviations by company

KPI	E1	E2	E3	E4	E5	E6	E7	E8	E9
Cost deviation	0.040	0.020	0.135	0.534	0.037	0.023	0.128	0.100	0.000
Schedule deviation	0.069	0.082	0.155	0.211	0.042	0.206	0.098	0.179	0.066
Accident frequency	16.162	7.056	0.049	44.112	0.000	0.239	6773.916	N/D	22.037
Accident gravity	78.696	136.457	5.513	565.806	0.000	8.381	894.333	N/D	116.609
Planning effectiveness	0.091	0.114	0.130	0.126	0.010	0.050	0.081	0.099	0.029
Constraint release	0.196	0.056	N/D	0.162	0.032	0.104	0.133	0.193	0.080
Quality	89.972	16995.044	304.317	20820.181	N/D	29.211	4802.266	N/D	N/D
Productivity	0.074	0.557	0.295	0.276	0.079	0.244	0.611	0.790	N/D
Contract bid change	0.000	0.023	0.017	0.153	0.026	0.136	0.220	0.030	0.003

Note: N/D = No data were reported by the company.

Table 4. Outputs of the social network analysis for the five companies

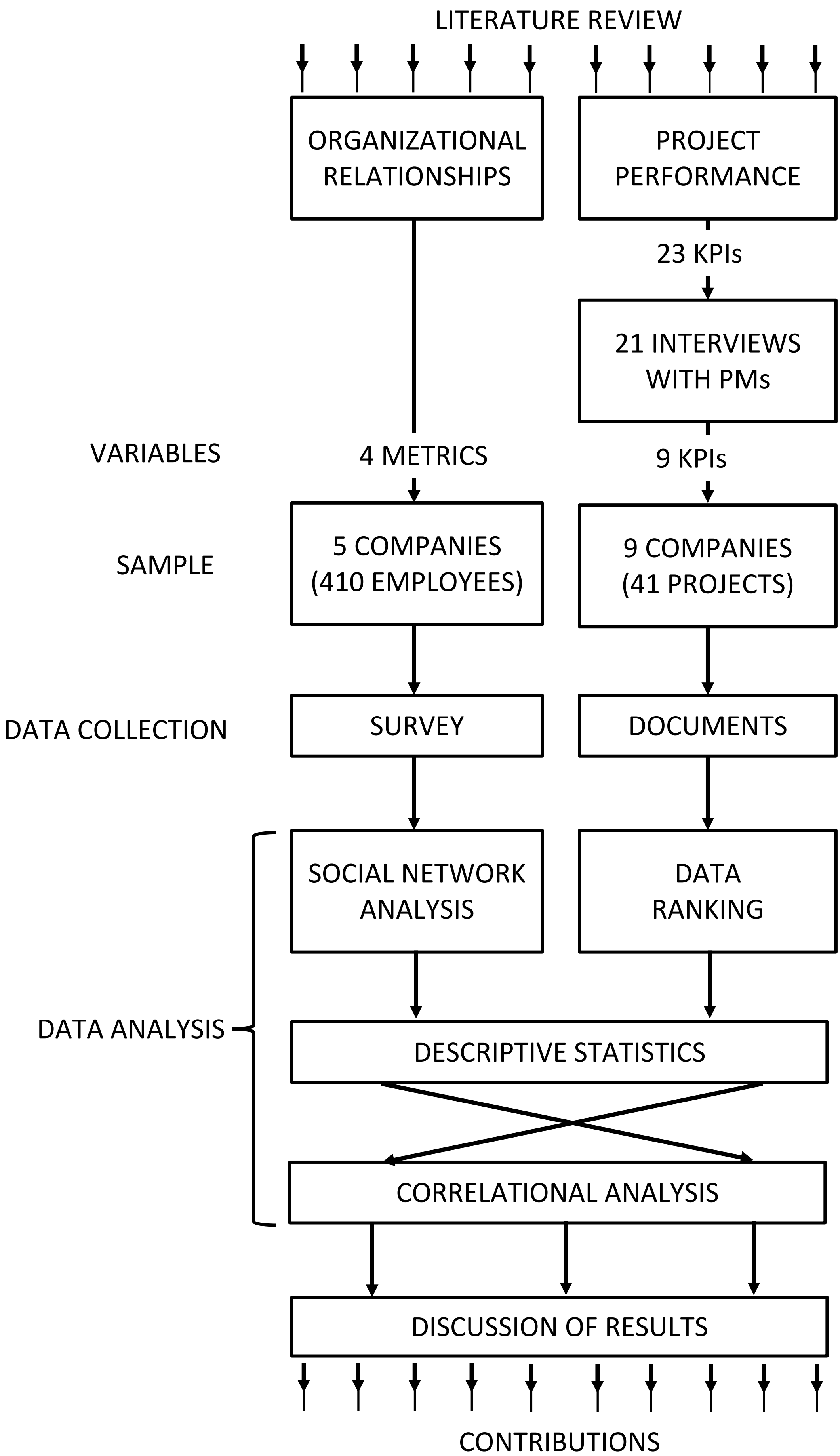
Social network metrics	E1	E2	E3	E4	E7
Average degree					
Personal Confidence	5.738	8.192	6.400	6.006	5.119
Innovation Development	4.167	5.064	4.500	4.449	4.090
Full Interaction	20.119	25.846	19.628	30.410	28.960
Frequent Interaction	11.476	13.538	11.300	13.747	13.119
Relevant Information Exchange	8.929	10.205	8.300	11.169	10.264
Planning and Problem Solving	8.167	9.282	7.872	9.382	9.055
Density					
Personal Confidence	0.140	0.106	0.080	0.034	0.026
Innovation Development	0.102	0.066	0.050	0.025	0.020
Full Interaction	0.491	0.336	0.231	0.172	0.145
Frequent Interaction	0.280	0.176	0.130	0.078	0.066
Relevant Information Exchange	0.218	0.133	0.100	0.063	0.051
Planning and Problem Solving	0.199	0.121	0.090	0.053	0.045
Diameter					
Personal Confidence	5	5	6	8	10
Innovation Development	9	8	7	9	12
Full Interaction	3	4	4	4	5
Frequent Interaction	4	5	4	5	6
Relevant Information Exchange	5	5	5	5	7
Planning and Problem Solving	5	6	5	6	7
Average path length					
Personal Confidence	2.308	2.332	2.600	3.481	4.116
Innovation Development	3.615	3.292	3.100	3.913	4.549
Full Interaction	1.500	1.697	1.839	1.929	2.166
Frequent Interaction	1.851	2.067	2.200	2.449	2.841
Relevant Information Exchange	2.107	2.233	2.500	2.653	3.012
Planning and Problem Solving	2.182	2.454	2.500	2.852	3.205

Table 5. Summary of correlations between social network metrics and median KPIs

Social network metrics	KPI median	Spearman r	p-value
Network average degree			
Full Interaction	Constraint release	1.000	0.000
Relevant Information Exchange	Constraint release	1.000	0.000
Frequent Interaction	Contract bid change	-0.900	0.037
Planning and Problem Solving	Contract bid change	-0.900	0.037
Frequent Interaction	Planning effectiveness	-0.900	0.037
Planning and Problem Solving	Planning effectiveness	-0.900	0.037
Innovation Development	Productivity	-0.900	0.037
Personal Confidence	Productivity	-0.900	0.037
Network density			
Frequent Interaction	Accident frequency	-0.975	0.005
Full Interaction	Accident frequency	-0.975	0.005
Innovation Development	Accident frequency	-0.975	0.005
Personal Confidence	Accident frequency	-0.975	0.005
Planning and Problem Solving	Accident frequency	-0.975	0.005
Relevant Information Exchange	Accident frequency	-0.975	0.005
Network diameter			
Personal Confidence	Accident frequency	-0.947	0.014
Network path length			
Frequent Interaction	Accident frequency	-0.975	0.005
Full Interaction	Accident frequency	-0.975	0.005
Personal Confidence	Accident frequency	-0.975	0.005
Planning and Problem Solving	Accident frequency	-0.975	0.005
Relevant Information Exchange	Accident frequency	-0.975	0.005

Table 6. Summary of correlations between social network metrics and KPI standard deviations

Social network metrics	KPI standard deviation	Spearman r	p-value
Network average degree			
Frequent Interaction	Quality	-0.900	0.037
Full Interaction	Accident gravity	-0.900	0.037
Planning and Problem Solving	Quality	-0.900	0.037
Relevant Information Exchange	Accident gravity	-0.900	0.037
Network density			
Frequent Interaction	Contract bid change	0.900	0.0374
Full Interaction	Contract bid change	0.900	0.0374
Innovation Development	Contract bid change	0.900	0.0374
Personal Confidence	Contract bid change	0.900	0.0374
Planning and Problem Solving	Contract bid change	0.900	0.0374
Relevant Information Exchange	Contract bid change	0.900	0.0374
Network diameter			
Innovation Development	Accident frequency	0.975	0.005
Frequent Interaction	Contract bid change	0.949	0.014
Frequent Interaction	Accident frequency	0.949	0.014
Planning and Problem Solving	Contract bid change	0.949	0.014
Planning and Problem Solving	Accident gravity	0.949	0.014
Full Interaction	Contract bid change	0.894	0.041
Full Interaction	Productivity	0.894	0.041
Network path length			
Frequent Interaction	Contract bid change	0.900	0.037
Full Interaction	Contract bid change	0.900	0.037
Personal Confidence	Contract bid change	0.900	0.037
Planning and Problem Solving	Contract bid change	0.900	0.037
Relevant Information Exchange	Contract bid change	0.900	0.037
Innovation Development	Accident gravity	0.900	0.037
Innovation Development	Accident frequency	0.999	0.000


LITERATURE REVIEW
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VARIABLES
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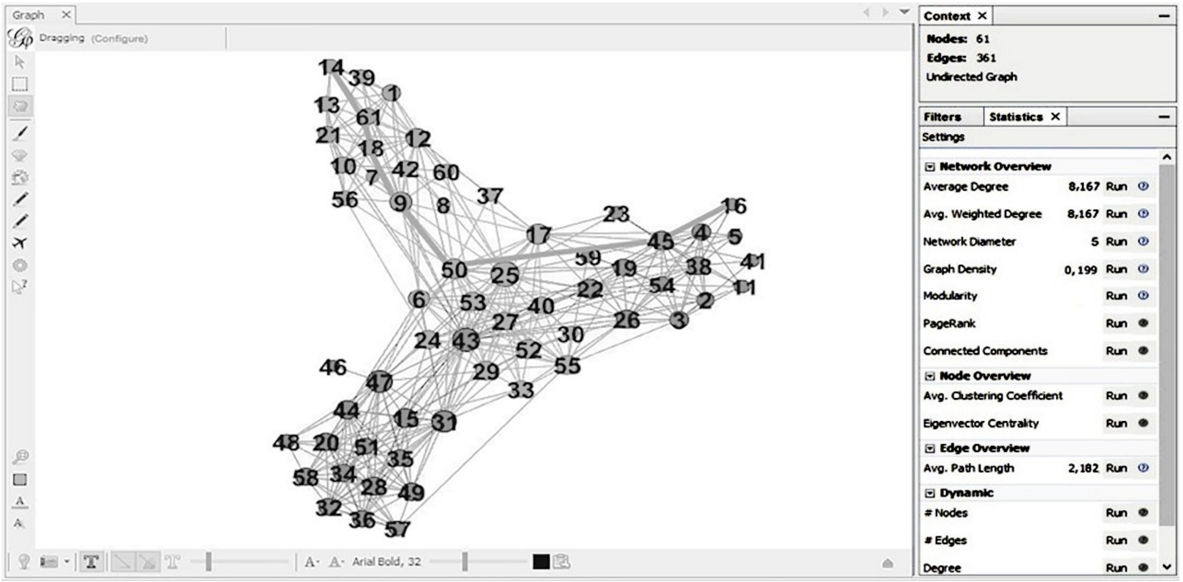
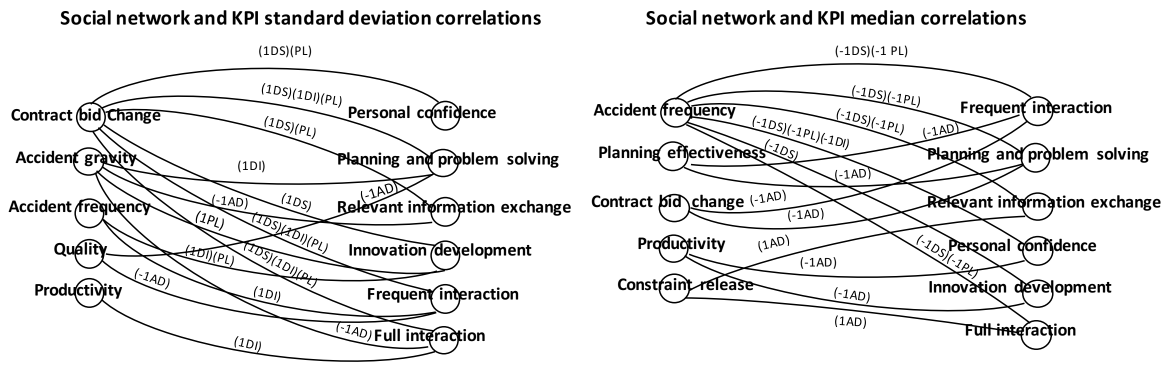
9 KPIs
SAMPLE
5 COMPANIES (410 EMPLOYEES)
9 COMPANIES (41 PROJECTS)
DATA COLLECTION
SURVEY
DOCUMENTS
SOCIAL NETWORK ANALYSIS
DATA RANKING
DATA ANALYSIS
DESCRIPTIVE STATISTICS
CORRELATIONAL ANALYSIS
DISCUSSION OF RESULTS
CONTRIBUTIONS

FIGURE 1



Graph
Dragging (Configure)
Context
Nodes: 61
Edges: 361
Undirected Graph
Filters
Statistics
Settings
Network Overview
Average Degree 8,167 Run
Avg. Weighted Degree 8,167 Run
Network Diameter 5 Run
Graph Density 0,199 Run
Modularity Run
PageRank Run
Connected Components Run
Node Overview
Avg. Clustering Coefficient Run
Eigenvector Centrality Run
Edge Overview
Avg. Path Length 2,182 Run
Dynamic
Nodes Run
Edges Run
Degree Run
Arial Bold, 32

FIGURE 2


Social network and KPI standard deviation correlations
Contract bid Change
Accident gravity
Accident frequency
Quality
Productivity
Personal confidence
Planning and problem solving
Relevant information exchange
Innovation development
Frequent interaction
Full interaction
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Social network and KPI median correlations
Accident frequency
Planning effectiveness
Contract bid change
Productivity
Constraint release
Frequent interaction
Planning and problem solving
Relevant information exchange
Personal confidence
Innovation development
Full interaction
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FIGURE 3