Social Network Analysis (SNA) for Construction Projects’ Team Communication Structure Optimization

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ABSTRACT

The construction industry is one of the most information dependent industries where effective communication greatly impacts the successful delivery of a project. While the best way to communicate is to involve project participants in all activities throughout the duration of project, lack of collaboration in projects’ early stages could result in a great deal of waste in the design, rework in construction, and delay or even failure to achieve initial goals. Although a considerable amount of research expanded the existing knowledge towards effective construction communication, studies show that there are still difficulties in controlling the spread of information during many projects. The objective of the presented research is to develop strategies for resolving early stage communication problems by focusing on team structure and information diffusion in construction projects. To address those issues, a team structure optimization framework through Social Network Analysis (SNA) is proposed. This paper first introduces SNA as a tool for understanding the spread of information in construction projects. A model is then developed to simulate project participants’ interaction and analyze potential communication problems. An illustrative example is finally presented to demonstrate how to optimize team structure for balancing communication in a construction project.

INTRODUCTION

The construction industry is one of the most information dependent industries (Tam 1999) where timely and effective communication on expectations, goals, and priorities should exist through a construction project’s life cycle. Adequate communication is important for improving team performance in a construction project due to the information exchange itself, the level of increased awareness of the availability of another project participant, the knowledge or special skills other participants possess, and the work currently undertaken by other participants (Ehrlich and Chang 2006). However, because of the construction industry’s high fragmentation and organizational disintegration nature, close collaboration and efficient information sharing are often prevented between individuals who have differing priorities, knowledge domains and professional skills. Decisions influencing project design and potential performance goals could not be communicated effectively from planning stages to construction and implementation. As a result, there is a lack of assimilation between design and construction that affects the final
project outcomes, and social aspects such as communication and interdisciplinary interaction have become critical success factors in the delivery of construction projects.

**LITERATURE REVIEW**

Social network analysis (SNA) has been a widely used tool for exploring the existence and strength of connections among groups of actors within an organization. It was originally introduced by Moreno in 1934 (Moreno 1960) and since then it has been deployed for researching a great variety of subjects. SNA has the ability to illustrate patterns of relationships within groups, outline the flow of information and generate what if scenarios (Garton et al. 1997). Thereafter, the total activity inside a network can be mapped on a graph format where actors (persons, organizations, concepts, etc.) and information exchange become nodes and arcs in it (Wasserman and Faust 1994). By having the above capabilities SNA has been useful in determining the type of the transferred information, as well as the parties involved and the delivery type (Pekericli et al. 2003). Furthermore, having the ability to apply mathematical analysis to network information exchange, SNA provides measurements for analyzing the effectiveness and weaknesses of the group being studied (Alba 1982). Through the use of network theory, analysis and related software a great variety of relationships could be depicted, able to mathematically and visually represent almost all kinds of differing relationships including knowledge transfer, learning, trust, and communication (Taylor and Levitt 2004).

Engineering scientists and scholars have started evaluating the use of SNA in construction management research proving that it can have important capabilities especially when dealing with the concepts of trust and communication between project participants (Katsanis 2006). The fact that people have key roles in nearly all aspects of construction additionally suggests that effective construction research requires the proper application of social science research methods (Toole 2006). Furthermore, the importance of combining social science with project management research practices has been illustrated by researchers (Chinowsky et al. 2008) who put great emphasis on SNA and on the building of Network Models for promoting organizational performance, project communications and their role in assisting coordination functions (Pryke 2004, Pryke and Smyth 2006). In addition, network analysis was used to examine modeling information dependencies in construction projects (Pekericli et al. 2003), organizationally modeling complex projects (Li et al. 2011) and to investigate knowledge sharing and integration (Javernick-Will 2011). Finally, the combination of SNA with Task Management has been used to analyze project schedules and identify potential communication disconnects between project stakeholders (Chinowsky et al. 2011).

**PROBLEM STATEMENT**

Communication for efficient knowledge sharing across an organization is considered a challenging topic of significant importance in the project-based engineering and construction industry (Javernick-Will 2011). SNA can be a helpful tool for studying the communication structure between all agents involved in a construction project by modeling information dependencies between them (Pekericli
et al. 2003). On the other hand, various studies show that there are still difficulties in controlling the spread of information during many construction projects even though the required tools are at hand (Adriaanse et al. 2010). The combination of SNA with construction communication research can be proved to have the ability to create frameworks for optimizing team structure, thus leading to an efficient organizational environment which promotes collaboration while balancing project-level communication. The presented research has the goal to illustrate the ability to detect and face early stage communication problems by focusing on team structure and information diffusion. The authors propose the use of network analysis in the early stages of projects (reception and design), focusing on small decision making teams. The research void aimed to be filled deals with the use of SNA as an input for designing more efficient communication networks. Unlike most of the related research that uses SNA for modeling purposes, here it is used as a diagnostic tool to find specific problems and propose solutions. By directly applying SNA to practical construction management problems, such as communication, specific measures could be proposed that will enable engineers adjust to the evolution of project networks.

RESEARCH HYPOTHESIS

Researchers made efforts to deal with information-knowledge sharing (Zhang et al. 2013), strategic management (Chinowsky and Byrd 2001) and other team management issues in different levels but still, very few research has been conducted on how effective early communication teams are. Most of the needed data for team management studies are collected long after that initial status of decision making has ended, when it is difficult for participants to recall even the formation of the original team assembled. In addition, when individuals are questioned about the sequence of events that took place back then, they face difficulties in remembering or they report events in an unreliable manner (Krackhardt 1987, Marsden 1990). Based on previous research the formed hypothesis is that in the early stages of a project, team management can be coordinated based on an analysis of the initial and often informal decision making chart. According to the above, if an early communications network could be depicted, its limitations could be detected based on an analysis of its dynamics. Later, its format should be manipulated to design an altered version that tackles information sharing problems, leading to better communication and decision making. By focusing on network performance measurements project managers can find communication bottlenecks and redesign the communication chart by involving the same participants more effectively.

RESEARCH MODEL FOR IMPROVING COMMUNICATION

In order to model the spread of information and communication barriers a network structure analysis should be performed, along with an evaluation of the relationships between its participants. The first step is to identify the major project individuals and detect the type and frequency of their communication during the project’s early stages. Furthermore, the meaning of each network measurement should be understood, in the context of construction communication, and the most appropriate ones should be selected to characterize team and individual communication performance. Measurements of networks are considered as the
presented method’s "independent variables". Their numerical values define the effectiveness of information diffusion in the team studied thus leading to a team communication overview. Different team structure can lead to different information diffusion making it a "dependent variable" defined by the network’s measurements. Based on the research context, the network measurements evaluated were:

- **Density**: indicates the amount of interaction between individuals. The largest the density, the greater the volume of communication in the network.
- **Centrality**: reveals the distribution of relationships through the network. In a high centralized network, a small percentage of its members will have a high percentage of relationships with its other members.
- **Betweenness**: measures the amount of information that passes through an individual. It could also reveal potential bottlenecks, meaning the existence of nodes that provide the only connection between different parts of the network.
- **Geodesic distance**: indicates either the distance between two nodes with the greatest separation or the distance between two specific nodes. Large distance between two nodes may reveal difficulties in their exchange of information.
- **Average shortest path**: the average of the shortest paths between all pairs of nodes. Networks with low shortest path values tend to transmit information more accurately and timely thus leading to better overall communication.
- **Modularity**: measures the strength of division of a network into modules. Networks with high modularity have dense connections between the nodes within modules but sparse connections between nodes in different modules.

Measurement analysis reveals network structure issues along with communication and information sharing problems. After evaluating the network recommendations for utilizing hidden power of individuals, altering network structure and identifying problematic network parts could serve as a proposal to the team management for communication optimization.

**ILLUSTRATIVE EXAMPLE**

The project studied is a 20,000 sq. ft. with a more than $2,000,000 initial estimated cost building renovation project in a University campus. The new building is completely re-planned and have its inner and outer spaces redesigned and rebuilt to be zero-energy and sustainable by acquiring a LEED Gold certificate. The delivery method is Construction Manager at Risk and at the time of research (project design phase) more than 30 participants were involved in the decision making process. Individuals who were established as nodes are University faculty members, students participating in project decision making meetings, staff from the University’s Facility Management and Office of Capital Planning, the general contractor, commissioning agent and design professionals who are going to design and materialize the project. Each participant was present in project meetings and had some type of decision making power. Various methods were used to collect communication data. Face to face discussions with participants that hold official decision making positions were conducted along with a careful studying of the communication and organizational chart of the project. Additionally, structured interviews with the University decision makers (faculty, student participants, facility managers, and capital planning staff) were held for identifying communication frequency and to have a view of the overall
team’s communication performance. Some project team meetings were also monitored. The data collection focused on acquiring information about communication frequency and decision making power. Communication frequency was considered to be the main variable for optimizing team structure based on the effects it has on information diffusion within a team and because it hints the strength of links between individuals in construction projects (Pekericli et al. 2003). The researchers define frequency as the number of communication instances between participants. The instances were face-to-face (conversations, meetings), paper means and electronic tools (email, phone calls, video etc.) communication happening at a daily, weekly or monthly basis.

An initial network was then created with its participants connected with weighted edges. The weights are based on the volume of communication frequency between individuals, the type of communication (formal-informal) and the relationship between them (formal-informal). For data visualization and SNA the Gephi 0.8.2 software was used. Gephi is an open-source network analysis and visualization software package that has been used in a number of research projects during the last years. It has capabilities of exploratory data analysis, link analysis and social network analysis providing real-time visualization and network metrics calculation (Bastian et al. 2009). The visualized data were analyzed and the findings were explained based on communications theory, sociology and project management foundations. Based on the project’s early stage the researchers believe that in the near future much more data is going to be available to validate the communications model and reveal the effects the identified communication obstacles have at project performance and utilization.

The network formation

Since the project is at a very early stage few participants are being involved and its network could be claimed to be relatively shallow. There are thirty different nodes in it, some of those being individuals and others being teams that act as a single participant-decision maker. After the participant selection their communication manners and decision making power were considered. They have different roles in the decision making process according to which their communication preferences and obligations are established. Furthermore, participants are connected in various ways. Formal meetings in daily, weekly and monthly basis take place in which decisions are made for project design, architecture team selection, funding options and many more. We should also have in mind that because of the project’s owner (academic unit) and of the decision makers (academics and other university personnel) a very large amount of informal communication takes place in a daily basis.

To form and analyze the network four additional characteristics of individuals were considered: formal and informal relationships-communication and formal and informal power. Formal communication is defined as any interaction between participants that deals exclusively with the specific construction project (meetings, decision team participation etc.). On the other hand, informal is considered the communication-relationship of any other type like friendship, advisor-student relationship, collaborations in School’s research projects, mutual organizational work and others. Formal power defines the ability of a participant to take decisions for the
progress of the renovation project, while informal power is the ability of an individual to affect others' decisions because of hierarchy in the University System, the possession of special knowledge that can be utilized for project purposes and others.

Three different networks were designed. The first network depicts formal and informal relationships, including contractors by the time they participate in meetings and have a word in decision making while working on the project’s design. The second one describes the formal and informal relationships between University participants only, while the third was made by accounting only their formal relationships. The three different networks are presented in Figure 1.

![Networks created](image)

**Figure 1. Networks created.** (a) Formal and informal relationships, contractors included, (b) Formal and informal relationships (without contractors), (c) Formal relationships (without contractors)

Communication frequency was used to create communication and decision making views of the project’s conceptual and design phases. Network nodes were connected based on the type and frequency of communication, formal meetings structure and decision team structure. Another goal was to calculate the geodetic distances between all nodes in the network to reveal possible isolated or unutilized participants, network’s decision teams (nodes with direct and frequent communication form a group-module) and the ability of a single individual to interact with others in the network.

**RESULTS ANALYSIS**

Three different network representations were designed in order to illustrate the change of its formation and metrics when informal relationships and interaction with contractors are added to the formal communication network. Measurements of the three networks are shown in Table 1. Their density was calculated along with their average degree, diameter, average path length and the centralities of each participant. Given the fact that a higher density reveals a higher level of communication, the network that includes formal and informal relationships, before the involvement of contractors, communicates significantly better than the other two (38%). On the contrary, when contractors start participating, density decreases to 28% revealing loose communication. Furthermore, in the plus-contractors network more communication groups are formed. While the network evolves, the formation of groups puts barriers to a holistic network communication (Figure 2). Individuals in those groups tend to communicate more between them, develop their own subcultures and have difficulties in reaching individuals belonging to other groups. The above is also supported by modularity measurement which is significantly larger in the
contractors network (46%) in comparison to the other two networks. Large modularity may imply the creation of isolated groups impervious to outside ideas and difficulties in communicating different opinions in the whole network. In addition, information has to travel longer to reach distant participants in the network depicting project communication between School members only. The other two networks have shorter average shortest paths (Table 1) but as the network becomes more complex its length gradually increases. Increasing of the average shortest path reveals a possible threat of future isolated populations to appear, thus leading to poor utilization of individual knowledge and experience. Such networks should be redesigned to decrease modularity and shortest paths and in the same time increase their density for a more efficient communication structure.

Table 1. Measurements for each of the three networks designed

<table>
<thead>
<tr>
<th>NETWORK</th>
<th>Avg. Degree</th>
<th>Diameter</th>
<th>Density</th>
<th>Modularity</th>
<th>Avg. Shortest Path</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formal and informal relationships, contractors included</td>
<td>8.2</td>
<td>4</td>
<td>0.283</td>
<td>0.456</td>
<td>1.989</td>
</tr>
<tr>
<td>Formal and informal relationships</td>
<td>8.667</td>
<td>4</td>
<td>0.377</td>
<td>0.347</td>
<td>1.775</td>
</tr>
<tr>
<td>Formal relationships only</td>
<td>4.583</td>
<td>3</td>
<td>0.199</td>
<td>0.407</td>
<td>2.167</td>
</tr>
</tbody>
</table>

Interesting issues related with individual performance of participants were also identified. In the formal-only communications network the coordinators of the project have the most central role. The Chair of the School for which the renovation project is done, along with the University’s Facilities Director have the highest centrality and are the individuals through whom the most pieces of information travel. Their ability to direct the project’s decision making team is enhanced by their central position making them the most important nodes in the network. In later stages of the project their communication ability and behavior should be closely monitored to enable them to efficiently manage project’s decisions. When the informal communication is added to the formal one other individuals also emerge. Two faculty members become the most central figures along with the Director of the University’s Capital Planning, a Design Services personnel, the School Chair and the Facilities Director. The two faculty members act as bridges (high betweenness centrality) that connect different participants giving them the ability to communicate their ideas in the network. It is obvious that when the informal communication is taken under consideration, more individuals obtain power by being in a position to acquire information and effect decision making. In that case, the two faculty members may not have the authority to take final decisions for the project but, by having close relations with multiple groups, they obtain informal and possibly unutilized power that needs to be taken under serious consideration. The decision team should be very
careful about the successful information deliverance from possible isolated parts of the network to the decision centers through the two faculty members.

Additionally, when contractors are added to the network two new individuals (one from Facilities and one from Capital Planning) become the most central nodes. Their direct connections with various contractors make them central communication figures. Their position becomes more central even from the Directors of the departments they work for, meaning that they override their defined function in the organizational structure and acquire more power. Furthermore, since they do not have official authorization to make final decisions their role is crucial for the effective communication and the utilization of the contractors’ expertise. This situation needs to be monitored in order to avoid bottlenecks caused by insufficient information deliverance. Organizational control should be applied to those two individuals in order to ensure their effective information deliverance to the decision centers.

![Network group formation](image)

Figure 2. Network group formation. (a) Formal and informal relationships with contractors (b) Formal and informal relationships, without contractors (c) Formal relationships only

On the other hand, some populations remain isolated from the rest of the network by having limited connections and by being in long distance from other nodes. The first isolated group, in all three networks, is the student representatives who participate in a number of project meetings. It can be claimed that those individuals do not need to have the power neither to take decisions nor to communicate with the most central decision makers. Nevertheless, they have needed knowledge and are also present in part of the decision making process. By representing a community that is going to constitute the majority of the renovated facility’s users they have access to that community’s will and requirements for the building’s efficiency. Their knowledge remains unutilized with their participation in meetings being extremely limited while their ability to efficiently communicate with others in the decision team is very thin. Isolated groups are a serious problem in decision teams because their skills remain untapped. It is important for the network structure to change giving students the ability to communicate their ideas and special knowledge as the project evolves. Finally, some individuals belonging to the department of Facilities Management are also isolated by having long geodetic
distances from many decision makers. Some of those are highly expert in mechanical and design matters and their involvement in the network needs to be monitored to make sure that their expertise could effectively be communicated. Three contractors also seem to experience communication inefficiencies but the project’s early stage does not leave room for safe conclusions on their situation. It is believed that those contractors are going to be more involved in the network during future project phases.

CONCLUSION

Social network theory could help construction management teams in mapping communication and in identifying information sharing problems in construction projects. The authors propose the use of a network analysis framework that starts from the conceptual stage of projects and focuses on small decision making teams. In that context SNA is used as a diagnostic tool that provides information for communication problems in an early stage project network and enables management teams propose efficient and well-grounded solutions. An example, based on an ongoing construction project, was presented to illustrate the important communication barriers existing in early project stages. The attribute of frequency was studied combining formal and informal communication. By analyzing network performance measurements project managers can detect phenomena leading to information sharing difficulties. Later, the communication chart can be redesigned to involve the same participants more effectively, utilizing their skills and leading to a better decision making and knowledge sharing environment. In order to reach to a more compete methodology for organizational and project management via SNA the proposed approach should be tested in projects with more complicated communication problems in a more layered decision making environment. Moreover, to efficiently incorporate informal communication a sociological approach must accompany the project management one used. In future research steps collaboration with sociologists will enable the researchers shed some light on the complex problem of the effect of informal and personal relationships to decision making. Finally, the theoretical recommendations made should be tested in practice and with the help of SNA lead to a more holistic approach for organizational management in construction.

REFERENCES


