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Communication networks of an integrated project delivery team for construction: relationships between formal and informal communication networks

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Abstract

The current study modeled formal and informal communication networks of an integrated project delivery (IPD) team and examined the interplay between the two networks. The IPD format as an alternative method of building construction relies on its multiple stakeholders' equal and active collaboration. Analyses of both endogenous and exogenous network variables found very distinctive tie formation dynamics between the formal and informal communication networks. While both networks were rather decentralized, a preferred structure for facilitating collaboration in IPD teams, reciprocal communication was identified only in formal (i.e., project-related information exchange), not in informal (i.e., social conversations) networks in valued exponential random graph modeling (VERGM). Ethnic heterophily, also a preferred structure for the IPD collaboration, was significant for formal, but not for informal communication networks. A small number of female members (4 out of 26) were more participating in formal, but less in informal conversations compared to males. Team members from designer and contractor organizations were active in project-related information exchange, but not as much in social conversations compared to the owner's representatives. While a multiplexity effect was identified between formal and informal communication networks in VERGM, MR-QAP regressions revealed the cyclicality of each network significantly predicted the other type of communication frequency above and beyond its own structural configuration.

Keywords
Communication networks, Integrated project delivery team, Valued exponential random graph modeling, Multiplexity, Cyclicality.

A building construction project is comparable to a dynamic social system with high uncertainty and interdependence of tasks, which requires flexible collaboration of many participants often coming from various organizational affiliations. Networks of individuals enacting project function-related roles design and deliver construction projects (Pryke, 2012, 2017). Central to the performance of this interorganizational project team is communication among its diverse members, which can facilitate the project members to accomplish their goal if properly done and managed. Communication here does not refer to a simple transfer of information among individuals but includes their opportunity to exchange questions and answers and clarify meanings to establish a shared understanding about the project, while building rapport and relationships with one another (Emmitt and Gorse, 2007). Development of such a common understanding and relational bonding can foster more interactions and future collaboration among team members, while lack of them may lead to an unsatisfactory project delivery.

As communication is an essential aspect of the construction project delivery (Dainty et al., 2006; Emmitt and Gorse, 1998, 2007), researchers have observed and analyzed the nature of interactions among construction project participants (Loosemore, 1996; Pietroforte, 1992; Pryke, 2004, 2005; Pryke and Badi, 2013; Pryke et al., 2015). Existing studies have highlighted the difficulties related to capturing interactions among construction team members in a naturally occurring context. Based on a rare opportunity to observe those interactions during project meetings, the current study examines how individual members' characteristics such as prior work experience and organizational affiliation, in addition to demographic and personality types, affected their communicative tie formation. This research particularly explores the interplay between formal (i.e., project-related) and informal (i.e., not directly related to the project, social in nature) structures of communication among members, consisting of a hospital construction project team, based on a social network perspective. The emphasis on actors and their connections in networks "classified by project function and quantified by actor prominence and their direction and value of flow" provides a useful framework to understand construction projects (Pryke, 2017, p. 19).

The construction project was located in the mountain states region of the USA and involved designing and constructing a four-storied fully functional hospital. The project was started in 2017 and took 20 months to finish. A delicate balance between technical requirements and stringent regulatory requirements makes healthcare facilities more complex to design and construct. The complexity of these projects demands more collaboration among the project stakeholders, contrary to the traditional procurement method in the construction industry. To promote collaboration and integration among the project stakeholders, an alternative procurement method was initiated in the construction industry early 2000s referred to as the integrated project delivery (IPD) (Bygballe et al., 2015; Mollaoglu-Korkmaz et al., 2014).

Within the IPD paradigm, the key stakeholders, contractually bound for the collaborative projects, take part in open exchange of information based on mutual trust and respect (AIA National and AIA California Council, 2007). Success of the IPD teams depends on the success of the entire project through shared risk and reward. IPD is a relatively new concept within the construction industry of the USA and is slowly getting its foothold on the market. The slow adoption of IPD may be due to complacency and resistance to change. After briefly discussing the relevant literature of IPDs in construction science and group and organizational dynamics through communication networks, we present our research questions.

Literature review

Integrated project team as transient self-organizing networks

Sir Michael Latham's (1994) report was the catalyst for the push in the construction industry to offer alternatives to the traditional procurement system. The key point of the alternative system is to increase the trust and cohesiveness among the project members (Lau and Rowlinson, 2011) and support for an alternative procurement system that provides more value to the client is growing. Integrated project delivery (IPD) is one representative of such alternative systems.

IPD adopts a systematic approach towards planning, designing, and building of any construction project that encompasses "strong team cooperation, early involvement of subcontractors, risk and benefit sharing models and joint responsibility for the success of the project" (Kent and Becerik-Gerber, 2010 cited in Bygballe et al., 2015, p. 23). The team includes not only the owner, designer, and general contractor, but also consultants in various areas such as construction management, engineering, or energy technology. The IPD team evaluates the project feasibility, identifies satisfactory conditions, and ascertains cost and time to build the project. The cost and time for construction and other goals are driven by collaborative efforts and determined iteratively by considering alternative layouts, materials, construction processes, and the performance of the building. The goal of an IPD team is to integrate all the necessary knowledge and expertise in the design and construction stage (Matthews and Howell, 2005).

Pryke (2017) argues that "project governance is a function of the network of relationships between role-holding actors in the project" (p. 14). Power and influence in these networks are acquired by actors rather than by official contracts and organizational protocols. Under the high levels of uncertainty, and the necessity to accommodate such uncertainty flexibly, project teams self-organize without necessarily following the hierarchy of authority relations. Earlier, Pryke (2012) demonstrated that contractual relationship networks have drastically different structures from the communication network structures in construction projects. He argues interdependencies between actors – and the ways networks respond dynamically to transient interdependencies – are key to the pursuit of more effective management of design and project delivery. Project actors are ultimately managing their own organizations, thus self-organizing, and the supply chains supporting them (Ruuska et al., 2011). Many companies engaging with project clients try to “respond to the environment for project delivery by organizing themselves into matrix structures” (Pryke, 2017, p. 14), the communication networks.

Based on social network analyses and interviews, Mollaoglu-Korkmaz et al. (2014) showed a “failed” IPD case in their study. An interorganizational team including an owner, designer, general contractor, and supplier organizations adopted an IPD format for constructing an environmentally sustainable office building for a small company. Notably, five months into the project and only two months after the kickoff of the IPD format, the owner decided to give up the IPD and return to construction management-at-risk style due to cost concerns. The network visualization of the team members’ communication over email illustrated dominance of the owner representatives and lesser involvement of the general contractor, which negatively affected their information sharing overall. Mollaoglu-Korkmaz et al. indicated lack of familiarity with and commitment to IPD, especially on the part of the owner, prevented self-organizing of the team.

Bygballe et al. (2015) investigated the interplay between formal and informal contracting in IPD. By informal contract, they meant a non-official, more social and relational mechanism was at work during a project delivery. From interviews with project team members involved in five different cases of IPD health-care construction projects in the USA and Norway, researchers found that projects relied heavily on the formal contracts and structures to stimulate collaborative problem solving among team members. At the same time, an informal mechanism of relational principles exerted just as much influence because the formal mechanisms of building trust and personal relationships between partners were created and recreated through informal practices. Coping with flexibility in the dynamic context and uncertainties in health care industry was less of an issue for an IPD team compared to “the complex interplay between formal and informal mechanisms, engendering commitment in joint problem-solving and responsibility” throughout the project period (Bygballe et al., 2015, p. 22).

As such, collaboration and trust among the team members are at the crux of any IPD project (Lau and Rowlinson, 2011). Effective communication among its members both in terms of project-related information exchange (Mollaoglu-Korkmaz et al., 2014) and relational bonding (Bygballe et al., 2015) can facilitate implementation of IPD with a flexible adaptation to environmental contingencies (e.g., changes in cost of building materials). Depending on how team members communicate and form relationships with one another, distinctive communities within a team can develop over time. Pryke (2017) notes based on his case studies that these subcommunities are not easily identified by the formal contract as they are self-organized by the project actors (i.e., emergent networks) based on the need to identify and obtain project-related information and to disseminate products such as design materials. Thus, the current study views an IPD team as transient self-organizing networks of individual participants from various organizations and examines both their formal and informal communication structures.

Relationships between formal and informal communication networks

Various theories and methods of social network analysis (SNA) have been applied to understanding small groups, intraorganizational, and interorganizational communication and collaborations. Groups and organizations can be viewed as emerging relational and communication networks among their consisting units, and their structures such as the extent of centralization and overall connectivity can be examined via SNA (Monge and Contractor, 2003). In fact, Breiger (1974) showed earlier how networks of interpersonal ties could represent networks of intergroup ties, and their duality and interpenetration could be analyzed using SNA.

The field of construction science started using SNA around early 2000 (Kereri and Harper, 2019; Pryke et al., 2017) and scholars have pointed out SNA’s potential to be a useful tool and framework for understanding construction team dynamics, interaction structures, and network roles that may lead to effective project governance (Pryke, 2012, 2017). Chinowsky et al.’s (2008) social network model of construction has three components: dynamics, mechanics, and performance. The component of dynamics involves team members’ value, trust, reliance, and experience, which influence the mechanics, such as knowledge, information exchange, and communication. These mechanics ultimately affect a construction teams’ performance that involves cost, schedule, and quality, and there are both social and strategic aspects of performance that need to be considered and evaluated.

Contrary to the earlier rational view of a construction team where members are chosen by factors like cost, skills, and knowledge, capturing the social and collaborative aspects of project organizing and the essence of interorganizational relations that comprise the construction project coalition has been emphasized by many scholars (e.g., Chinowsky et al., 2008; Pryke et al., 2017). This shift of emphasis on self-organizing relational aspects aligns with a long tradition of SNA focusing on informal relationships and communication networks (Krackhardt and Hanson, 1993). Organizational communication and management research also consider both task and social relationships among coworkers as influential constituents of employee and team performances (Johnson et al., 1994). Informal networks within or between companies are where critical information, knowledge, and insights are shared, decisions can be made, and social capital (i.e., resources embedded in social networks; Lin, 1999) is built (Methot et al., 2018).

A formal structure of an organization identifies members who are official sources of information and the information of their special concerns (Johnson et al., 1994). Traditionally, relationships were viewed as determined by organizational roles and organizational structure was viewed as a static entity conforming to a top-down configuration (Monge and Eisenberg, 1987). This configurational view emphasized the hierarchical coordination of work in achieving organizational goals from formal authority relationships (Dow, 1988; Jablin, 1987). On the contrary, informal approaches recognize varied social needs that underly communication in organizations, and consequently, actual communication relationships may be less rational than formal systems (Johnson, 1993). Informal networks function to simulate communication, while maintaining cohesiveness in the organization as a whole and a sense of personal integrity or autonomy for individual members (Johnson et al., 1994).

Employees valued informal communication that does not follow an organizational chart (e.g., calling friends in another work unit to discuss a work problem) (Johnson et al., 1994). Research showed employees believed the outcome of informal communication to be more effective; it was more culturally salient in achieving organizational goals and useful to them compared to formal channels (e.g., oral communication following an official hierarchy, or written communication of memoranda and departmental directives). However, formal communication channels were evaluated slightly higher in accuracy and credibility (Johnson et al.). These findings resonated with other research showing informal networks of an organization, from which members seek work-related advice and help, to perform tasks across divisional and functional boundaries, could be vastly different from the formal structure or chain-of-command in the workplace (Krachkardt and Hanson, 1993).

Against this background, the current study examines both formal and informal communication networks among IPD team members and describes how each type of communication network is structured and shaped by each other along with other factors such as members' attributes (e.g., demographics and project-relevant experiences). The following is an explanation of the major theoretical mechanisms, classified by endogenous and exogenous network variables (Monge and Contractor, 2003), known to be influential in network tie formation. Endogenous variables explain relations within the network and structural tendencies of those relations themselves (Monge and Contractor). Exogenous variables on the other hand explain structural characteristics of the network, other than the relations themselves, such as individual attributes, other nodes, or other relations within the network (Monge and Contractor).

Endogenous network mechanisms

First, individual actor-level network properties include various types of centralities, such as degree and betweenness, and actors with high number of incoming ties (i.e., high indegree centrality) can receive even more ties when newcomers join the network (i.e., indegree preferential attachment)[1]. Higher centrality in an IPD team's communication networks would indicate more active involvement in project meetings, and different members may emerge as central between formal and informal communication networks due to the distinctive nature of conversations. Whether certain members become more popular targets of formal and informal communication will also be examined in this study.

Second, dyadic-level reciprocity in formal and informal communication may impact how relationships are formed and structured in an IPD team's network. If an actor shares an idea about the project with another, the other person may naturally do the same

[1]Also known as the Matthew effect, preferential attachment in social networks indicates a mechanism that nodes (actors) with many existing ties tend to get even more ties when newcomers join the network; this principle has been found in many different types of natural and social networks including the internet, citation network, and other scale-free social networks with a heavily skewed distribution of degrees that follows a power law (Albert and Barabási, 2002).

(Pryke, 2005); if one inquires about the project progress to another, an answer as a reciprocation to that inquiry is expected, too. This reciprocal and interactive communication may facilitate mutual understanding and more frequent interactions between the same actors.

Third, transitive or cyclic communication ties may be formed in formal and informal networks. Transitivity in the triad-level, also known as tendency for closure in the network (Borgatti et al., 2018), can be understood as an actor A has a tie to B, B has a tie to C, which results in A's tie with C as well. Usually, friends of my friends should also be my friends because people typically like their friends (Monge and Contractor, 2003). When such transitive communication happens frequently, the network is likely to become more closed, cliquish, and locally dense (Halgin et al., 2015). Higher transitivity could indicate having more localized conversations within the IPD team meetings, which can potentially increase the information flow and trust among the sub-group members (Lau and Rowlinson, 2011).

Cyclicality occurs when there is a link from actor A to B, a link from B to C, and a link from C to A, completing the cycle in one direction (Monge and Contractor, 2003). Cyclicality is based on the logic of generalized exchange that a favor, resource, or benefit you provide to an alter may not directly return to you but eventually through other alters who are connected to your initial alter, which contributes to the overall solidarity of a community (Bearman, 1997; Ekeh, 1974). When the communication tie indicates a flow of resources such as project-related information exchange within an IPD team, cyclicality can happen like the following scenario; actor A inquires an information to B, and B, rather than answering the inquiry directly to A, asks C who may have the relevant information for A. While transitivity may more likely happen in informal communication networks due to the friendly sentiment of social conversations, cyclicality may occur more in formal communication based on actors' project-related functions and roles.

Contrary to the local closure of the network, centralization at the whole network level considers "the extent a network is dominated by a single node" (Borgatti et al., 2018, p. 184). If a few members of a team form communication ties with many other members, and most other members do not, the network would become more centralized like a wheel-structure. Centralized networks have benefits of efficiency for central actors as they may easily control communication and task flow. A traditional construction team may have had a centralized communication structure where the owner and a few general contractors gave orders to subcontractors and subcontractors did not necessarily participate in sharing ideas from the beginning of the project as an IPD team would (Mollaoglu-Korkmaz et al., 2014). However, such an unequal structure was pointed out as the major culprit for less involvement of subcontractors, which over time reduced effectiveness and quality of the project outcome due to a low level of trust and cohesiveness within the team (Latham, 1994; Lau and Rowlinson, 2011).

According to the Bavelas-Leavitt experiment (cited in Borgatti et al., 2018), a highly complex task is better achieved by a decentralized network structure with the least amount of time and errors and the highest level of satisfaction among team members. Thus, for an IPD team to retain its collaborative nature and accomplish a complex task such as a hospital building construction, less centralization of communication structure is preferred. Pryke (2017) also notes a 'democratic network' is better than an 'autocratic network' to establish and maintain a high level of trust in construction teams, which would be represented by low levels of standard deviations in team members' eigenvector and betweenness centralities.

Exogenous network mechanisms

After accounting for the endogenous variables in individual (i.e., degree centrality), dyadic (i.e., reciprocity), triadic (i.e., transitivity, cyclicality), and global (i.e., centralization) levels, a series of dyadic homophily can be considered along with individual attributes' effects on communicative tie formation. Although SNA usually focuses on structural configuration and dynamics, individual actors' networking choices based on such attributes (i.e., human agency; Halgin et al., 2015) can also be influential in tie formation.

Homophily reflects how people are more likely to form ties with similar others (McPherson et al., 2001). Various types of similarities can shape tie formation including demographics (e.g., gender, age, ethnicity) and socio-psychological factors (e.g., personality). Members of an IPD team may communicate with other members of similar work backgrounds (e.g., IPD experience, organizational affiliation, tenure) because communication with homophilous others can be easier based on common understanding and knowledge between actors who share similar jargon and past experiences, such as working in an IPD-format project.

However, if members communicate only with similar others, for example, who have the same jobs, the IPD team may face challenges as many people who have different job titles and obligations, such as engineers, architects, and foremen, need to collaborate with one another in the team. For the same reason, if members tend to communicate frequently with those who share demographic backgrounds (e.g., gender, race), a social division may happen based on homophily, which can hurt the trust and performance of the zero-history team (Mollica et al., 2003). We know IPD is a collaborative form, but such a procurement system does not automatically guarantee members' collaboration and improved performances (Cicmil and Marshall, 2005). Therefore, maintaining a good balance between homophily and heterophily would be important for communication and joint work coordination in diverse interorganizational teams.

Members with certain characteristics can become prominent, receiving many ties from others in the network, or they may strategically initiate ties with popular others. In a directed network where ties are not always reciprocated and symmetrical, there could also be sender (e.g., information disseminator; Pryke, 2017) and/or receiver (e.g., gatekeeper hoarder; Pryke, 2017) effects. Actors could have a certain number of outgoing or incoming ties due to various reasons. For example, IPD team members more experienced in IPD-format projects may disseminate more information during project meetings to share their knowledge (Matthews and Howell, 2005), which is about an attribute activity effect, and they could have a certain number of outgoing ties that are higher than others', a sender effect (Lushner et al., 2012). Gatekeeper hoarders would collect information, but would not share with others (Pryke, 2017); so high indegree centrality, but low in outdegree.

Furthermore, members' personality types can influence their prominence in communication networks (Pryke, 2017; Sasovova et al., 2010). When discussing various network roles and their relationships to personality traits, Pryke (2017) argued prominent information disseminators for a construction project team may not necessarily have to be an extrovert, as many would think at first. Construction projects might be better served by conscientious introverts who are obsessive about details and try to be perfectionists. Sociable and agreeable extroverts might show 'highly iterative' behaviors, which can be unhelpful in terms of achieving accurate and timely project delivery (Pryke, 2012, 2017).

Presence of one type of tie can increase the probability of another type of tie being present (Monge and Contractor, 2003). If team members exchange both project-related information and social conversations, rather than just focusing on one type of communication, such multiplexity may strengthen their bonds and collaboration (Bliemel et al., 2014; Methot et al., 2018). Applied to the interaction within an IPD team, a significant multiplexity overall could indicate more frequent and richer conversations that would enhance relationship building and trust among team members.

In order to examine the structure of communication networks of an IPD team and how various individual attributes and their dyadic homophily influence communication tie formation, in the context of both informal and formal conversations during project meetings, we first model each network separately by asking the following question:

RQ1. What are structural mechanisms, dyadic homophily factors, and individual attributes that shape tie formation of (a) formal and (b) informal communication networks of an IPD team?

Given the mutually constitutive and complementary relationships between formal and informal communication networks (Bygballe et al., 2015; Johnson et al., 1994; Krackhardt and Hanson, 1993; Methot et al., 2018), we also examine how they interplay with each other in terms of structural configurations while controlling for the effects of dyadic homophily and individual attributes. To do so, we propose the following:

RQ2. How are formal and informal communication networks of an IPD team related and compared to each other in their structures?

Methods

Construction project

The construction project for this study was a new addition to an existing healthcare facility located in the Mountain States Region of the USA. The 168,000 SF addition was structurally tied to the existing building and would cost approximately $71 million. The owner of the project did not have prior experience with IPD and hired the designer, general contractor, and one major trade partner to conduct the project validation and conceptual design. With the general contractor and the major trade partner having prior experiences with IPD, the owner adopted IPD as the preferred delivery method for the construction project. The other trade partners were collectively hired as the project advanced from the conceptual design to design development phase. There was a mix of project participants who had prior IPD experience ($n = 4$) and those who did not ($n = 22$).

Data collection

Communication data from the construction project meetings were collected using direct observations. Three different types of project meetings were observed by the second author: (1) Big room, (2) core team, and (3) make ready planning meetings.[2] The second author has led and been part of similar construction meetings for more than 10 years, which has made him familiar with the topics typically discussed and the common jargon used. A total of 11 meetings were held weekly or biweekly between June 22 and July 20, 2017; each meeting lasted from 40 min and up to 2 hr. As the use of audio or video recording was not allowed, the researcher recorded written notes of the interaction during the meetings.

After obtaining the participants' consent, the researcher started observing communication in each meeting and coded the conversations based on who initiated a conversation with whom (i.e., direction), and whether the topic was specifically about project-related information exchange (i.e., formal)[3] or social in nature such as a friendly banter or exchanging jokes (i.e., informal). Being well aware of the ongoing project, the second author could understand and relate to the content of the discussion in the observed meetings. This was critical in differentiating formal and informal communication as sometimes the participants passed informal remarks in a rather subtle way rather than being blatant. Having detailed knowledge of the project also helped in capturing, documenting, and coding the conversations. Notes taken during the meetings were later corroborated with the participants where the observer was doubtful about the content. With one person observing as well as coding, it is possible some of the conversations could have been inadvertently omitted or summarized (rather than transcribed verbatim).

Identifying the direction of the conversations was guided by the content of the conversation. If a participant spoke about a topic that pertained to all the attendees and glanced around the room, the author coded that as addressing the entire group. When a participant uttered something specific to a trade or asked a trade specific question, it was coded as dyadic communication. Below is an excerpt from the notes taken during one of the meetings (for reference, letter O indicates the whole group and other letters are individual actors)[4]:

[M-O] I do want to go through the garage and the B schedule, then the site-work and skin packages real quick (referring to the items in the agenda).

[H-O] Fire proofing at stair 2 is taking place today and tomorrow.

[H-FC] Where are you with framing for stair 1?

[FC-H] It's going on …

[M-H] You will have to work around the glazing. We are not going to hold off ….

A tie from actor i to j was indicated when i talked to j. If an actor addressed the whole group, ties were noted between that actor and all others. Coded data were later aggregated across the three different types of meetings held over a month period and the frequency of conversations between participants

[2]Big room meetings support cross functional team environment and expand a traditional owner-architect-contractor to be more inclusive of the entire team. The agenda includes updating on the progress of the project and upcoming tasks and constraints. Make ready meetings support pull planning from phase scheduling. These meetings are attended by the foreman of the trade contractors for identifying tasks that are ready to be completed, related constraints of the tasks (if any), and how to resolve the constraints. Core team meetings are attended by the decision-makers of the project where complex situations are broken into an environment conducive to rapid learning and analyzing solutions. In these meeting, decisions can be made faster within these groups due to distributed leadership and having the right people in the group to make appropriate decisions.

[3]A wide gamut of topics were discussed during project-related information exchange starting from updating the progress, to what is coming up, who all will be affected in the upcoming works, how one trade is holding up another trade, if there is any delays, what are the reasons of delays, if there is any cost overruns, what are the reasons of that, etc.

[4]The example provided in the main text represents a case of formal communication (i.e., project-related information exchange). Here is an example for informal communication (e.g., social conversations). It starts from N joking to H:

[H-0] I got an email during the weekend that the frame doesn't fit us. So, I will follow it up today. Even though there is a guy out here who fixed it.

[N-H] So the guy fixed the door that doesn't fit the frame?

[N-0] It was like Halloween! Everything falling off from the building.

[N-J] Last year, my son dressed up like a builder in Halloween. I know it was a bad idea…and he tore up lot of stuff around the house…it was a mess. I spanked that ******** hard and you know…I think he learned his lesson.

[J-N] Your son must be cussing you N for that.

was preserved for communication ties' values. This process generated a total of 349 cases of formal utterances (i.e., communicative ties) with frequency values (i.e., tie strength) ranging between 1 and 160, and another total of 159 cases of informal utterances with frequency ranging between 1 and 33. All meetings were held in the jobsite trailer shared by the team members. Participants' and their organizations' names have been kept confidential for identity protection.

Sample

Overall, a total of 26 members participated in the three types of meetings, with four females and 22 males. Participant's age was categorized into four groups: 25 to 34 years ($n=6$), 35 to 44 years ($n=7$), 45 to 54 years ($n=6$), and 55 to 65 years old ($n=7$). There were three Hispanic/Latinx members, and all remaining were Caucasian. Participants' education level ranged from some high school or high school diploma ($n=4$), some college ($n=5$), college degree ($n=12$), to graduate degree ($n=5$). Project team members came from 10 different organizations: three members represented the owner organization, five members were either architects or engineers (designer), and the rest were either general contractors ($n=8$) or subcontractors ($n=10$). Their current position in their own firm was categorized into six groups: Engineer ($n=5$), project manager ($n=7$), superintendent ($n=3$), principal director ($n=3$), general foreman ($n=4$), and others ($n=4$). Others included project architect, coordinator, facilities manager, and project executive. Individuals' personality types were surveyed based on the Myer-Briggs Type Indicator (MBTI; see Capraro and Capraro, 2002; Randall et al., 2017 for validity and reliability assessment) and four types of personality indicator were used to split the sample into two opposite groups: Extrovert ($n=18$) vs. introvert ($n=8$); intuitive ($n=13$) vs. observant ($n=13$); thinking ($n=22$) vs. feeling ($n=4$); and perceptive ($n=12$) vs. judging ($n=14$).

Analytical strategy

In order to answer RQ1 about the structural mechanisms and homophily effects in formal and informal communication networks of an IPD team, valued exponential random graph modeling (ERGM, also known as p^* models; Krivitsky, 2012) via *statnet* in R (Goodreau et al., 2008) was used to estimate various endogenous and exogenous parameters in each network first. Monge and Contractor (2003) introduced ERGM to the field of organizational communication, and it has been used widely as an inferential statistical tool, particularly geared towards social network data. Based on the Markov Chain Monte Carlo algorithm, ERGM explores initial values of parameters and searches for reliable parameters by simulating networks based on those initial values and comparing them with the observed network. What ERGM does eventually is to show whether the observed network's configuration is statistically significant or not. The impact of different parameter values is examined one tie at a time and continually refined until the parameters look like the observed network's (Pilny and Atouba, 2017).

Until valued ERGM became possible, traditional ERGM could only estimate the binary presence of a tie. Thus, the strength of ties such as frequency of communication or level of intimacy between actors was not considered, which certainly underrepresented the complexity of a phenomenon (Pilny and Atouba, 2017). Valued ERGM requires specifying a reference distribution indicating what the tie distribution might look like in the absence of any model terms. For binary networks, the reference is simply a baseline Bernoulli distribution of a 0.5 probability of a tie existence. However, in valued ERGMs, the sample space (i.e., the set of possible networks given the size and density of the observed network) must be defined for all the possible values in which relationships can occur (i.e., range of values between any two nodes). The setting of a sample space via the reference distribution thus determines "the support and the basic shape of the ERGM distribution" (Krivitsky, 2012, pp. 7-8). Among the four common reference distributions (i.e., Poisson, geometric, binomial, and discrete uniform), the current study used the Poisson distribution as the reference as there was no upper bound limit (i.e., maximum value) to the valued connection (i.e., frequency) between any two nodes in the communication networks (Krivitsky and Butts, 2017). Poisson distribution is useful when the average tie value ($M=12.82$ in our sample) does not significantly differ from the variance ($SD=16.06$ in our sample; Pilny and Atouba, 2017), which is the case in this study.

The comparison between informal and formal communication networks of the IPD team (RQ2) was performed by utilizing QAP (quadratic assignment procedure) multiple regression available in UCINET, 6.0 (Borgatti et al., 2002). QAP is based on the idea of randomization/permutation, and its technique correlates the two matrices (i.e., informal and formal networks) by reshaping them into two long columns and calculating an ordinary measure of statistical association such as Pearson's *r* (Borgatti et al., 2018). To calculate the significance of the observed correlation, QAP compares the observed correlations to a reference set of thousands of correlations between thousands of pairs of matrices that are exactly like the data matrices, but independent of each other. The method counts the proportion of these correlations among independent matrices that were as large as the observed correlations to construct a p value (Borgatti et al., 2018). A QAP regression allows modeling the values of a dyadic dependent variable (such as formal communication ties) using multiple independent variables (such as formal and informal communication ties' endogenous and exogenous network factors).[5]

Results

Descriptions of communication networks based on actor centralities

Among 26 members who participated in a series of IPD project meetings, the average direct connection of informal communication (i.e., degree, which means the number of conversations) was 14.46 (Outdegree SD = 20.64, Indegree SD = 9.57), whereas it was 172.89 (Outdegree SD = 287.76, Indegree SD = 107.43) for formal communication. Thus, the team members engaged much more often in formal, project-related information exchange during these meetings. Density (i.e., the average tie strength for a valued network) of informal communication was 0.58, and 6.92 for formal communication networks, which also reflects the high frequency of project-related information exchange among team members. When dichotomized based on the correlation between the original networks and the dichotomized ones (Borgatti and Quintane, 2019), there were 20 components (i.e., a maximal set of actors in which everyone can reach everyone else by some path of connection; Borgatti et al., 2018) in informal communication networks (cutoff value = 3), whereas we found 17 components in formal communication networks (cutoff value = 36). This suggests that informal

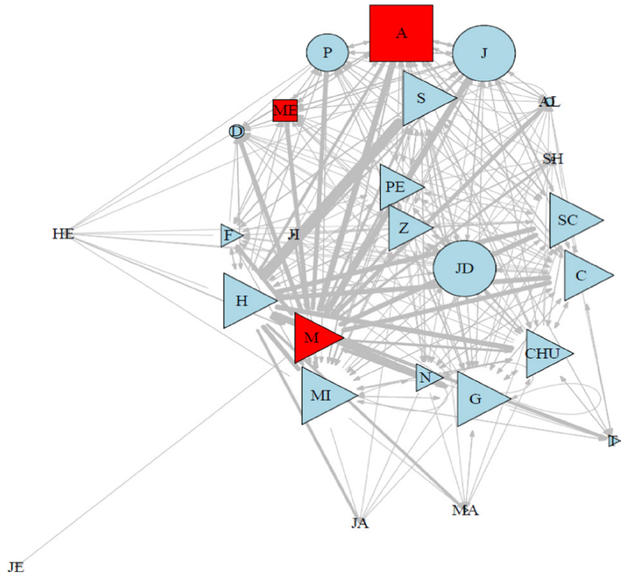


Figure 1: The formal communication networks by gender, organizational affiliation, and outdegree centrality. Node size represents outdegree centrality with larger nodes having higher outdegree and node color gender [red = female, light blue = male]. Node shapes represent organizational affiliation [square = owner, circle = architect/engineer, triangle = general- or sub-contractor]. Edge thickness represents communication frequency. Layout algorithm is Kamada-Kawai.

conversations were more fragmented (fragmentation score[6] = 0.87; connectedness = 0.12) and formal conversations were more connected (fragmentation score = 0.35; connectedness = 0.65) across the network. In fact, one member who participated in formal conversations was an isolate in the informal network (see Figs 1 and 2, node JE), which means he did not engage in any social conversation during the meetings. The average distance between actors in the

[5]Although ERGM can also be used to evaluate the association between two networks, just like QAP, ERGM cannot specify a multivariate linear model of matrices of the form $Y = b0 + b1X + b2X2 + , \ldots,$ as QAP can (Borgatti et al., 2018). The key difference between the two analysis methods is that QAP considers the myriad dependencies among ties in the network as nuisances to be controlled away by randomization, whereas ERGM explicitly models and interprets them. UCINET's "transform" function allows creating structural effects (e.g., preferential attachment, transitivity) for MR-QAP regressions.

[6]Fragmentation score was calculated as the proportion of pairs of nodes that cannot reach each other in the network using UCINET's cohesion measure. Distance weighted fragmentation is one minus the average reciprocal distance between all pairs of nodes; thus, if all nodes are reachable from all others, which is one component, then fragmentation score would be zero (Borgatti et al., 2018).

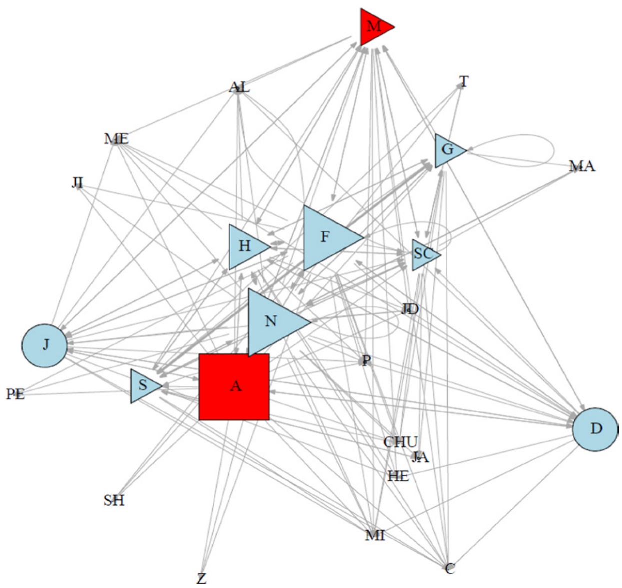


Figure 2: The informal communication networks by gender, organizational affiliation, and outdegree centrality. Node size represents outdegree centrality with larger nodes having higher outdegree and node color represents actors' gender [red = female, light blue = male]. Node shapes represent organizational affiliation [square = owner, circle = architect/engineer, triangle = general or sub-contractor]. Edge thickness represents communication frequency. Layout algorithm is Kamada-Kawai.

informal communication was 1.32 (SD = 0.47), and 2.12 (SD = 0.68) in the formal communication networks.

Various types of centralities were examined per network and actor. In the informal communication network, actors like J (65), G (59), N (44), M (41), and F (40) were central in outdegree indicating they initiated social conversations more frequently than other members. For the indegree, actors S (46), SC (24), H (23), MI (23), and M (22) were more central than other members, meaning they were frequent recipients of social conversations more so than others. For betweenness centrality, indicating the shortest path between actors in the dichotomized network, members like J (10), M (10), G (4.5), and N (2.5) were higher than all the others (0).

For the formal communication networks, actors like M (1144), H (1041), A (353), J (330), and SC (311) were more central in terms of outdegree, which means they initiated more project-related information exchange than others. Actors like H (534), M (301), S (282), SC (248), and MI (247) were more central in terms of indegree, suggesting they received project-related information exchange more often than others did. For the betweenness centrality in the dichotomized network, actors like H (144.5) and M (113.5) were more central than others.

Comparing the two types of communication networks, it becomes clear that those who were central in informal communication were not necessarily central in formal communication. The QAP correlation between the two networks was 0.27 ($p = 0.004$). Actor N, who was one of the most central in terms of informal communication initiation (i.e., outdegree), did not show up as a larger node in the formal communication (compare Figs 1 and 2).

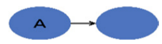
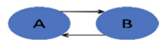
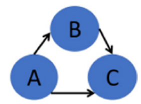
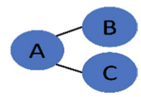
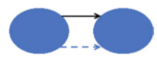
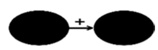
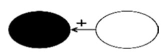
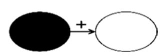
In the meantime, actors H, M, and J were quite central in both formal and informal communication networks. Actor J represents the architect organization whereas H and M were general contractors; among the three central actors, M had a previous IPD experience. Calculating eigenvector and betweenness centrality of both formal and informal communication networks revealed both networks were relatively low in centralization as standard deviation values were less than the two times of average centrality scores for each case (Pryke, 2017).

Results of valued ERGM for RQ1a

To identify the structural mechanisms and individual attributes associated with the formal communication tie formation of the IPD team, valued ERGM was performed with a series of parameters: sum, mutual, nodesqrtcovar, nodematch, nodefactor, nodecov, transitiveweight, and edgecov. The summary of analysis results is provided in Table 1 along with dimensions and images of each parameter.

A non-significant and negative parameter estimate of sum (MLE = –0.45, SE = 0.28) means the network is not necessarily dense or sparse considering the number of actors and their formal communication frequencies. The significant positive estimate of the parameter, mutual (MLE = 0.22, SE = 0.05) indicates the formal communication ties in their frequencies were reciprocated more likely than by chance (If A shared project-related information with B frequently, then B also did the same with A), which also suggests that work-related conversations in the project meetings were interactive. The formal communication network did not show a strong tendency toward transitivity or closure, as its parameter was negative and insignificant (MLE = –0.01, SE = 0.02). A negative and significant parameter estimate of degree

Table 1. Valued ERGM predicting formal communication tie strength.

Parameter	Dimension	Images	MLE estimate (SE)
Sum	Tie-dependencies		–0.45 (0.28)
Reciprocity			0.22 (0.05)***
Transitivity			–0.01 (0.02)
Degree centralization			–2.61 (0.03)***
Informal communication network	Multiplexity		0.50 (0.04)***
Same ethnicity	Homophily		–0.79 (0.05)***
Same current positions	Homophily		–0.03(0.02)
Female indegree	Attribute popularity		0.14 (0.06)*
Female outdegree	Attribute activity		0.81 (0.07)***
Some college indegree	Attribute popularity by education		–0.71 (0.08)***
College degree indegree			0.28 (0.05)***
Graduate degree indegree			0.63 (0.06)***
Some college outdegree	Attribute activity by education		–0.88 (0.11)***
College degree outdegree			0.82 (0.07)***
Graduate degree outdegree			1.65 (0.08)***
Hispanic/Latin indegree	Attribute popularity by ethnicity		–0.97 (0.32)**
Hispanic/Latin outdegree	Attribute activity		0.47 (0.15)**
Architect/Engineer indegree	Attribute popularity by organizational affiliation (base = owner)		0.05 (0.08)
GC/SC indegree			0.30 (0.07)***
Architect/Engineer outdegree	Attribute activity by organizational affiliation		0.44 (0.08)
GC/SC outdegree			1.32 (0.08)***
Non-IPD indegree	Attribute popularity		0.09 (0.04)*
Non-IPD outdegree	Attribute activity		0.73 (0.07)***
Years in organization indegree	Continuous attribute popularity		–0.25 (0.02)***
Years in organization outdegree	Continuous attribute activity		–0.36 (0.03)***
Years in position indegree	Continuous attribute popularity		0.39 (0.08)***
Years in position outdegree	Continuous attribute activity		0.75 (0.03)***

Notes: GC, General contractor; SC, Subcontractor.*$p<0.05$; **$p<0.01$; ***$p<0.001$.

centralization (MLE = −2.61, SE = 0.03) suggests the formal communication network was not necessarily centralized by a few members dominating the conversation.

The frequency of informal communication was considered as an edge covariate and the significant positive parameter estimation (MLE = 0.50, SE = 0.04) suggested a multiplexity effect. If two members frequently conversed socially, they also communicated about the project frequently. Various aspects of homophily were considered in modeling the formal communication networks such as team members' gender, education, ethnicity, current position, organizational affiliation, IPD experience, and personality types. According to the final valued ERGM results[7], team members did not necessarily communicate more often with the same ethnicity members. This is potentially due to the sheer difference in number of white (*n* = 23) and non-white (*n* = 3) members. Participants with college or graduate degrees received or initiated project-related information exchange more frequently than members with high school degree or less.

Members representing general- or sub-contractor organizations (MLE = 0.30, SE = 0.07) were more frequently a recipient of project-related information compared to those representing the owner organization. Members representing designer organizations (MLE = 0.44, SE = 0.08) and general/subcontractors (MLE = 1.32, SE = 0.08) initiated more project-related information exchange compared to those from the owner organization. It is possible that designers asked general- or sub-contractors about the project progress frequently and contractors reported the progress or checked with one another about it. Also, members with no previous IPD experience were actively involved in project-related information exchange compared to those who had previous experiences. This may have been the case because there were only four members who had previous experience of IPD format construction.

Team members with longer years of experiences in their current positions were more likely to receive (MLE = 0.39, SE = 0.08) and share (MLE = 0.75, SE = 0.03) project-related information than members with fewer years of experience. One year of longer experience in the current position brought almost twice the level of information sharing [exp (0.75) = 2.12]. Participants who had longer tenure in their organizations, however, were less likely to receive (MLE = −0.25, SE = 0.02) or initiate (MLE = −0.36, SE = 0.03) project-related information exchange during meetings than less experienced members. Figure 1 visualizes the formal communication networks based on the members' gender, organizational affiliation, and outdegree centralities.

Results of valued ERGM for RQ1b

A similar valued ERGM was performed for examining informal communication networks of the IPD team. The final model[8] that converged looked rather different from the case of formal communication networks in terms of which parameters being significant in explaining the frequency (i.e., strength) of ties. The summary of valued ERGM results for informal communication networks is provided in Table 2.

A significant and positive parameter estimate of sum (MLE = 13.01, SE = 3.29) means the network is relatively dense considering the number of actors and their informal communication ties. Participants' social conversation during the project meetings tended to be transitive (MLE = 0.67, SE = 0.13), meaning conversational partners were locally clustered. In line with the local clustering, the overall informal communication was not centralized by a few members dominating the social conversations. The frequency

[7]After identifying a model that explains the network configuration reasonably, a goodness-of-fit (GOF) test needs to be performed to examine how well the original parameters produce networks that resemble the observed network. As of now, an official GOF test is not implemented for valued ERGM in statnet (Krivitsky, 2012). Pilny and Atouba (2017) suggested an alternative method to test a potential GOF. For example, even if cyclicality (the opposite of transitivity) was not entered in the model, it is still expected that the model would explain cyclicality relatively well. In this alternative GOF test, thousands of networks are simulated using the final ERGM formula and then compared with the observed network. If the networks created by the formula look very much like the observed network, it is possible that there is a good fit. In 1,000 simulations of the final valued ERGM, we get an average count of 2,527.06 cyclical triads. Because there were 2,521 observed cyclical triads, the difference between the two were not statistically significant (*p* = 0.94), suggesting a potential good fit for explaining cyclical triads.

[8]The same procedure of testing goodness-of-fit for the informal communication networks' valued ERGM was adopted as the one for formal communication networks. In 1,000 simulations of the final valued ERGM, we get an average count of 158.76 cyclical triads. Because there were 147 observed cyclical triads, the difference between the two were not statistically significant (*p* = 0.50), suggesting a potential good fit for explaining cyclical triads.

Table 2. Valued ERGM predicting informal communication tie strength.

Parameter	Dimension	MLE (SE)
Sum	Tie-dependencies	13.01 (3.29)***
Transitivity		0.67 (0.13)***
Degree centralization		–1.64 (0.02)***
Formal communication ties	Multiplexity	1.56 (0.17)***
Same ethnicity	Homophily by ethnicity	–0.38 (0.67)
Hispanic/Latin indegree	Attribute popularity by ethnicity	0.12 (0.71)
Hispanic/Latin outdegree	Attribute activity by ethnicity	5.71 (1.39)***
Female indegree	Attribute popularity by gender (base = male)	–1.81 (0.34)***
Female outdegree	Attribute activity by gender	–16.36 (2.04)***
Some college indegree	Attribute popularity by education (base = high school graduate or less)	–2.10 (0.58)***
College degree indegree		–0.12 (0.37)
Graduate degree indegree		0.73 (0.33)*
Some college outdegree	Attribute activity by education	–32.79 (4.40)***
College degree outdegree		–4.39 (1.29)***
Graduate degree outdegree		5.06 (1.02)***
Age group indegree	Attribute popularity by age groups	0.34 (0.08)***
Age group outdegree	Attribute activity by age groups	4.27 (0.52)***
Architect/Engineer indegree	Attribute popularity by organizational affiliation (base = owner)	–1.12 (0.38)**
GC/SC indegree		–0.76 (0.33)*
Architect/Engineer outdegree	Attribute activity by organizational affiliation	–8.11 (1.18)***
GC/SC outdegree		–5.09 (0.88)***
Introvert indegree	Popularity by extrovert vs. introvert	–0.68 (0.20)***
Introvert outdegree	Activity by extrovert vs. introvert	–5.43 (0.77)***
Observant indegree	Popularity by intuitive vs. observant	–0.54 (0.15)***
Observant outdegree	Activity by intuitive vs. observant	–2.37 (0.80)**
Feeling indegree	Popularity by thinking vs. feeling	0.70 (0.21)***
Feeling outdegree	Activity by thinking vs. feeling	11.47 (1.44)***
Judging indegree	Popularity by perceptive vs. judging	0.28 (0.26)
Judging outdegree	Activity by perceptive vs. judging	0.63 (0.68)
Years in organization indegree	Continuous attribute popularity by organizational tenure	–0.80 (0.17)***
Years in organization outdegree	Continuous attribute activity by organizational tenure	–8.96 (1.34)***
Years in position indegree	Continuous attribute popularity by career experiences	0.46 (0.12)***
Years in position outdegree	Continuous attribute activity by career experiences	5.81 (0.82)***
Non-IPD indegree	Attribute popularity (base = IPD experience)	–0.05 (0.22)
Non-IPD outdegree	Attribute activity	0.03 (0.60)

Notes: GC, General contractor; SC, Subcontractor. *$p<0.05$; **$p<0.01$; ***$p<0.001$.

of formal communication was considered as an edge covariate, which was significant (MLE = 1.56, SE = 0.17) and suggested multiplexity of ties.

Similar to the case of formal communication networks, except for the ethnicity heterophily, there was no significant homophily effect identified in the informal communication networks. Female members were less likely to initiate social conversations than males. This was different from the case of formal communication for which females were more likely to initiate project-related information exchange. Perhaps due to their smaller number, female members were less active in making social conversations. Older team members were more likely to be engaged in social conversations than younger members. Those who had graduate degrees tended to exchange social conversations more frequently compared to members with high school degree or less; however, those with some college experience or college degrees were less likely to initiate social conversations than high school graduates or less.

In terms of participants' personality type effect, those who were introverted were less likely to receive (MLE = –0.68, SE = 0.20) and initiate social conversations compared to extroverted members (MLE = –5.43, SE = 0.77). Those who were more observant were less likely to have made social conversations (MLE = –0.54, SE = 0.15) compared to intuitive members, and members with the 'feeling' personality type were more likely to be involved in social conversation exchange than the 'thinking' type.

Contrary to the formal communication networks' case, team members who represented architect/engineer and general- or sub-contractor organizations were less active in exchanging social conversations compared to those from the owner organization. Team members with longer years of experience in their current organizations were less likely to be involved in social conversations frequently, but longer tenure in their current positions was associated with higher likelihood of exchanging social conversations during the project meetings. Figure 2 visualizes the informal communication networks by the same nodal attributes used in Figure 1.

Results of multiple regression QAP for RQ2

Two multiple regressions QAP (MR-QAP) were performed: one for each type of communication network as the dependent variable and the other network's and its own structural configurations as predictors. Dyadic homophily and individual sender/receiver effects were considered in this case as controls in the regressions. First, for the case of informal communication networks, controlling for the effect of structural mechanisms of their own such as preferential attachment, reciprocity, transitivity, and cyclicality along with various homophily and sender/receiver effects, formal communication networks' cyclicality predicted the informal communication networks' tie strength significantly ($p = 0.04$). This means the tendency of exchanging project-related information in circles (a→b, b→c, and c→a) is positively related with frequency of social conversations between the team members. This result was based on 650 observations and 2,000 permutations, and all the parameters together explained about 39.1% of variance in informal communication networks' tie strength ($p < 0.001$).

The results had both similarities and differences for the case of formal communication networks' MR-QAP. While controlling for the significant effects of various structural parameters of formal communication networks (see Table 3 for the details), indegree preferential attachment ($p = 0.02$), reciprocity ($p = 0.03$), and cyclicality ($p = 0.01$) effects of informal communication networks significantly predicted the tie strength of formal communication networks.

This result means that if IPD team members showed a tendency to informally chat with those who frequently became targets of social conversations during project meetings, they were more likely to exchange project-related information frequently as well. Reciprocity in informal communication networks was negatively related to formal communication frequency, which means if two members reciprocated social chats frequently, they did not exchange project-related information frequently. Additionally, the tendency to chat informally in circles seemed to bring more project-related information exchange among the same triad. The significant parameters explained about 76.8% of variance in formal communication ($p < 0.001$), which was based on 650 observations and 2,000 permutations.

In sum, the results of the two MR-QAP seemed to suggest that the structure of informal communication networks, especially in their indegree preferential attachment and cyclical conversation among triads, was significantly associated with the frequency of dyadic formal communication of the IPD team members. The cyclical structure of formal communication networks at the triad-level also had a meaningful impact on the dyadic informal communication frequency above and beyond its own structural configuration. More implications of these findings will be discussed in the following section.

Table 3. MR-QAP predicting formal communication (FC) tie strength.

	Standardized coefficient	*p* value	As Large	As Small	SE
FC-Indegree preferential attachment	−0.11	0.03*	0.97	0.03	0.01
FC-Transitivity	0.64	0.00***	0.00	1.00	0.00
FC-Reciprocity	0.73	0.00***	0.00	1.00	0.05
FC-Cyclicality	−0.44	0.00***	1.00	0.00	0.00
Same Organization	−0.01	0.28	0.72	0.28	0.40
Receiver Organization	−0.05	0.03*	0.97	0.03	0.54
Sender Organization	0.12	0.01*	0.01	0.99	1.36
Same Sex	0.03	0.07	0.07	0.93	0.92
Sender Judging vs. Perceptive	0.01	0.42	0.42	0.58	2.99
Sender Feeling vs. Thinking	0.08	0.04*	0.04	0.96	3.00
Sender Observant vs. Intuitive	−0.04	0.14	0.86	0.14	2.32
Sender Introvert vs. Extrovert	0.13	0.00***	0.00	1.00	2.77
Sender previous non-IPD experience	−0.03	0.23	0.77	0.23	3.32
Sender Years in Current Position	0.03	0.26	0.26	0.74	1.16
Sender Years in Organization	−0.01	0.41	0.59	0.41	1.00
Sender Education	0.17	0.00***	0.00	1.00	1.97
Same Ethnicity	−0.06	0.02*	0.98	0.02	1.31
Sender Age	0.02	0.29	0.29	0.71	1.06
IC	0.02	0.20	0.20	0.81	0.24
IC-Indegree Preferential Attachment	0.09	0.02*	0.02	0.98	0.09
IC-Transitivity	−0.03	0.15	0.85	0.15	0.03
IC-Reciprocity	−0.05	0.03*	0.97	0.03	0.24
IC-Cyclicality	0.07	0.01*	0.01	0.99	0.02
Intercept	0.00	0.00***	0.00	0.00	0.00

Notes: IC indicates informal communication networks. *$p<0.05$; **$p<0.01$; ***$p<0.001$

Discussion

Based on a social network perspective, the current study analyzed an IPD team's communication networks constructed through a series of project meetings that occurred over a month period. Who talked to whom in which context about what (i.e., formal, project-related information vs. informal, social conversation) among 26 team members were directly observed and coded as dyadic communication ties. Survey data of demographic and other individual attributes (e.g., personality, current position, organizational affiliation) were also collected to test various homophily and sender/receiver effects in communication network dynamics. The focus of exploration was to model both endogenous and exogenous network variables in formal and informal communication networks by using an advanced technique of valued ERGM (Krivitsky, 2012; Pilny and Atouba, 2017) that considers not only the presence/absence of ties, but also the value of ties. The analysis revealed a few notable differences between the two types of networks. The results from two MR-QAP examining the interplay between formal and informal networks in detail (Bygballe et al., 2015; Methot et al., 2018) highlighted distinctive relationships between the two communication networks of an IPD team in shaping tie strength of each network (Halgin et al., 2015; Krackhardt and Hanson, 1993).

The combined results of our study seemed to suggest the structure of communication networks of the IPD team was rather closer to what would be expected from an ideal type of IPD team dynamics. Both formal and informal communication were not dominated by a few, and team members from minority demographics (e.g., female, Hispanic/Latinx) participated in the conversation as equally as, if not more, than majority members. More importantly, there was an active and equal amount of participation from the subcontractors and general contractors in the project-related information exchange compared to the architect/designer group and the owner's representatives. This really achieves the true purpose of an IPD team, creating decentralized and democratic communication structures so the members can exchange ideas freely and participate in important decision-making from the start of a construction project.

Having a relatively decentralized structure, team members tended to reciprocate each other's talk when sharing project information with one another in formal communication networks. This represents the collaborative (Bygballe et al., 2015) and democratic (Pryke, 2017) nature of IPD teams. However, informal conversations during the project meetings tended to happen more locally, so relational bonding might have happened in sub-groups within the team. If one member exchanged project-related information frequently with another, they also often exchanged social conversations and vice versa, such multiplexity effect (Bliemel et al., 2014; Methot et al., 2018) was commonly identified in both types of communication networks.

The stark difference between the two types of communication networks of the IPD team was female members' participating level, measured by outdegree. In formal communication, the four female members spoke significantly more compared to males; however, in the informal communication, their participation level was significantly lower than males. This finding is different from the existing notion of gendered communication styles that women are community-oriented, and men are status-oriented (Coates, 2016). However, since there were only four female members out of 26, it might have been just the issue of conversation distribution and lack of opportunity for female members to chat informally, which could have also contributed to the non-significant gender homophily in both types of networks. Female members lacked a significant number of other females to communicate with; thus, to a certain extent, they were forced to converse with males during the meetings. It is still noteworthy that the two out of four females happened to occupy core positions (i.e., owner A and general contractor M), which related to female members having significantly more project-related information exchange compared to the remaining male members.

Dyadic homophily effects were not identified as major parameters in either formal or informal communication networks' valued ERGM except for the formal networks' heterophily in ethnicity. This finding indicated that IPD team members did not communicate more frequently with those from the same ethnic background, which could be positive for sharing diverse perspectives especially related to the project-related information exchange. This result contrasts with research findings about persistent racial homophily in newcomers' social networks (Mollica et al., 2003). In a zero-history group, people tend to feel more comfortable and supportive interacting with those from the same racial/ethnic background. Nevertheless, this segregation created by racial/ethnic homophily could limit ethnic minorities' access to information and resources in organizations (Mollica et al., 2003). In the IPD team we studied, Hispanic/Latinx members received or inquired about project-related information less frequently overall, but they initiated more information exchange compared to non-Hispanic members. Whether this suggests more effort of information sharing from the ethnic minority members, but not being reciprocated by the white members, or the three Hispanic/Latinx members happened to be more prominent information disseminators (Pryke, 2017) will need to be further examined.

Members with higher education were more active in project-related information exchange both in terms of initiating and receiving it. Considering the possibility of this result having to do with an implicit hierarchy among the team members, we cross-checked members' education levels with their organizational affiliations (e.g., owner, general contractor, and subcontractor). In a typical construction project, there is a hierarchy where the owner is at the top of the chain followed by the general contractor (GC) and then the other subcontractors. However, in an IPD project, the GC and the subcontractors who are part of the core team are considered at the same level of the hierarchical chain (Bygballe et al., 2015). Nevertheless, due to years of working within the traditional procurement system, the subcontractors still often look up to the GC for directives and even GCs may stay less involved when the owner's representative is too dominant and giving orders (Mollaoglu-Korkmaz et al., 2014). In our sample, the owner and GC organizations' representatives tended to have higher level of education than subcontractors, but not always. One GC and four subcontractors had high school diplomas and two subcontractors were quite active in project-related information exchange. Thus, the potential relationship between education level and hierarchy within the team seemed inconclusive.

Unlike the traditional procurement system, all the stakeholders should have the same level of interest for the successful completion of the IPD project (Mollaoglu-Korkmaz et al., 2014). However, it has always been seen that the subcontractors are not as interested in the overall success of the project, but more focused on their part of the contract. One of the major reasons IPD evolved as an alternative delivery method is to reduce this disposition of the subcontractors to work in their silos (AIA National and AIA California Council, 2007). In our study, members from the various subcontractor organizations were actively involved in project-related information exchange compared to the owner representatives, which was close to an IPD team's ideal situation. Some architects and engineers were more actively participating than others and one out of three owner representatives was more involved in both formal and informal conversations; however, other subcontractors also emerged as central communicators during project meetings. Due to the contractual agreement of IPD among the core members, their overall profit margins are dependent on achieving the performance goal(s) of the entire project, not just their part of the contract. Thus, active participation from members from all organizational affiliation is desirable.

This equal participation across different organizational affiliations, however, was not apparent in the informal communication network. Members representing designer and general/subcontractor organizations made social conversations much less frequently compared to the three owner representatives. Even with a collaborative nature of the IPD format, owners of the construction project probably have the most power as they pay for the project cost. Thus, members from the owner organization might have been more relaxed in these project meetings and made more friendly social conversations and jokes with other team members.

There were only four members who had previous IPD experience in this team, and our analysis showed those who did not have previous experiences still engaged in project-related information exchange as frequently, if not more, as those with previous experiences. In a traditional project delivery, construction project participants were used to getting directives from the GC or the owner. In contrast, IPD provides a collaborative platform where all the team members contribute to the progress of the project by sharing information related to tasks, constraints, or resources (Mollaoglu-Korkmaz et al., 2014). Findings of this study showing non-IPD experienced members participating as equally active in project-related information exchange resonated with Bygballe et al.'s (2015) explanation on how IPD models based on collaborative interaction rely on "relational contracting principles, defined as the simultaneous use of formal contracts and informal relational mechanisms to govern relationships between partners" (p. 22). A lack of a clear centralization in the formal communication networks of the team may also reflect the collaborative nature of an IPD team's dynamics.

Members' individual personality effects were identified only in informal communication networks' valued ERGM, which partially supports network literature on the impact of agent-level attributes on network structure (Pryke, 2017; Sasovova et al., 2010). Considering this IPD team was an ad hoc group, we can safely assume members' personality traits, a preceding exogenous factor, may have influenced their communication networks structure, not vice versa. Those who were introverted, or observant, were less active in social conversations; this trend however might not be necessarily beneficial to an IPD team dynamics considering Pryke's (2017) discussion about how introverts and detail-oriented persons could serve as more effective leaders for a construction project. In our sample, introverts did not emerge as a prominent information disseminator or social conversation starters.

The multiplexity effect between formal and informal communication networks was significant in both cases of valued ERGM; but, when the two networks' relationships were examined with MR-QAP, the results were different. When controlling for its own structural mechanism, the formal communication frequency (i.e., tie strength) was significantly predicted by the informal communication networks' structural parameters such as indegree preferential attachment, reciprocity, and cyclicality. In the meantime, cyclicality of formal communication networks also significantly predicted informal communication frequency, which may suggest mutually constituting relationships between formal and informal communication within the team.

Interplay between formal and informal communication networks

Many scholars emphasize the importance of understanding the self-organizing, emergent informal networks dynamics in an organization behind or in tandem with its official hierarchical structure (Bygballe et al., 2015; Johnson et al., 1994; Krackhardt and Hanson, 1993). Without necessarily following the formal relationships such as 'who reports to whom,' organizational members form multiple types of relationships and seek advice and help from them, which may ultimately impact their formal decision making. Those who provide work-related or non-work-related support to many other members, thus well connected in the network, are more powerful or influential in the organization, and many tasks get accomplished by those prominent actors (Krackhardt and Hanson, 1993). Therefore, examining the structural configuration of informal networks and identifying central and peripheral actors located there can provide crucial insights and practical guidelines for creating interventions, if necessary, in the formal networks' configuration.

The findings of this exploratory study highlight the distinctive nature between formal and informal communication networks in their structural configurations yet demonstrate how the two networks are related to each other. Many project-related attributes (e.g., organizational affiliation, positional tenure) and individual demographics (e.g., gender, education, ethnicity) were at play in how the IPD team members communicated about the project itself; but the same demographic factors seemed to have influenced the members' informal communication differently and the personality effects were more pronounced informally. Notably, both types of communication networks' cyclicality seemed to affect the other type of communication frequency. Cyclicality is a particular type of transitive triad where content of the tie flows in one direction among actors (Borgatti et al., 2018) based on the logic of generalized exchange (Bearman, 1997; Ekeh, 1974). Cyclical project-related information can be thought of as member A asking member B for information about project progress, and B then asking for the relevant information from another member, C. Then, C can provide the answer directly to A without going through B. This can be done rather easily among co-located project meeting participants. If this type of circular conversation happens frequently, during project-related information exchange, members can also insert social chats during the same sequence of conversations. This type of social exchange based on a cyclical structure may also increase the overall cohesion of the IPD team.

It is also worth noting that the informal communication networks' indegree preferential attachment was positively related to formal communication frequency. The tendency to initiate social conversations with popular actors who also receive many friendly chats from other members seemed to be related to frequent project-related information exchange with them. Compared to the findings from individual centrality analysis and valued ERGM, it might be the case IPD team members who initiated social conversations frequently with the owner's representatives who became popular targets of social conversations also exchanged project-related information frequently with them. Through this multiplex communication between formal and informal networks, the team members' collaboration might become more effective. Such findings demonstrate mutually constituting and enabling relationships between formal and informal communication networks of an IPD team (Bygballe et al., 2015; Pryke, 2017).

The current study also made a significant improvement in applying social network analysis to understanding IPD team dynamics by utilizing a recently developed technique such as valued ERGM as previous studies in construction science mainly utilized descriptive level analyses (Pryke et al., 2017). Valued ERGM provides a more detailed and distinctive characterization of the network dynamics as it considers not only presence/absence of ties, which is the case of binary ERGM, but also the value of ties (Krivitsky, 2012; Pilny and Atouba, 2017). In this way, the classical concept of tie strength (Granovetter, 1973) can be incorporated and examined directly in the network analyses. Relationships between two actors who just talked once or twice during the whole project period and those who talked to each other very frequently, perhaps over 100 times, would certainly be different in their intensity; but, binary ERGM cannot consider those differences in tie values in the same way as valued ERGM can.

Limitations and future directions

Due to the limited access and resources, data on informal communication of this study was collected only during project meetings. Thus, social conversations exchanged between IPD team members were still situated within a formal work-related setting. Since all team members shared a jobsite trailer during the project period, they also had ample opportunities to interact with one another outside of official meetings. The second author, who directly observed all meetings, could not capture other randomly occurring conversations among team members. An alternative way of data collection using a network survey may have captured participants' perceptions of their network ties both formal and informal; however, the focus of our study was to observe naturally occurring communication behaviors, not relying on self-reported data to construct the networks.

A future study can benefit from connecting these results to a possible assessment of team members' satisfaction with the project outcome. Whether the decentralized, not so cohesive, overall structure of formal communication networks made it easier for them to achieve the project outcome or not would be worthwhile to examine (Pryke, 2017). Also, depending on each actor's structural position (e.g., centrality, brokerage), their evaluation of the project outcome may also vary. In addition, since the communication data of this study was collected over a month for three different types of meetings, a longitudinal analysis per each type of meeting may reveal distinctive communication dynamics and more refined and novel descriptions of the network changes.

References

AIA National and AIA California Council 2007. *Integrated Project Delivery: A Guide* AIA National and AIA California Council, Sacramento, CA, 1–62.

Albert, R. and Barabási, A. -L. 2002. Statistical mechanics of complex networks. *Reviews of Modern Physics* 74: 47–97, doi: 10.1103/RevModPhys.74.47.

Bearman, P. 1997. Generalized exchange. *American Journal of Sociology* 102: 1383–1415.

Bliemel, M. J., McCarthy, I. P. and Maine, E. 2014. An integrated approach to studying multiplexity in entrepreneurial networks. *Entrepreneurship Research Journal* 4: 367–402.

Borgatti, S. P. and Quintane, E. 2019. Techniques: dichotomizing a network. *Connections* 38: 1–11, doi: 10.21307/connections-2018-002.

Borgatti, S. P., Everett, M. G. and Freeman, L. C. 2002. *Ucinet 6 for Windows: Software for Social Network Analysis* Analytic Technologies, Harvard, MA.

Borgatti, S. P., Everett, M. G. and Johnson, J. C. 2018. *Analyzing Social Networks*, 2nd ed., Sage, London.

Breiger, R. 1974. The duality of persons and groups. *Social Forces* 53: 181–190.

Bygballe, L. E., Dewulf, G. and Levitt, R. E. 2015. The interplay between formal and informal contracting in integrated project delivery. *The Engineering Project Organization Journal* 5: 22–35, doi: 10.1080/21573727.2014.992014.

Chinowsky, S. P., Diekmann, J. and Galotti, V. 2008. Social network model of construction. *Journal of Construction Engineering Management* 134: 804–812, doi: 10.1061/(ASCE)0733-9364(2008)134:10(804).

Capraro, R. M. and Capraro, M. M. 2002. Myers-Briggs type indicator score reliability across studies: a meta-analytic reliability generalization study. *Educational and Psychological Measurement* 62: 590–602, doi: 10.1177/0013164402062004004.

Cicmil, S. and Marshall, D. 2005. Insights into collaboration at the project level: complexity, social interaction and procurement mechanisms. *Building Research & Information* 33: 523–535, doi: 10.1080/09613210500288886.

Coates, J. 2016. *Women, Men and Language: A Sociolinguistic Account of Gender Differences in Language* 3rd ed, Routledge, Milton Park, Abingdon, Oxon New York, NY.

Dainty, A., Moore, D. and Murray, M. 2006. *Communication in Construction: Theory and Practice* Taylor and Francis, New York, NY.

Dow, G. K. 1988. Configurational and coactivational views of organizational structure. *Academy of Management Review* 13: 53–64.

Ekeh, P. P. 1974. *Social Exchange Theory: The Two Traditions* Harvard University Press, Cambridge.

Emmitt, S. and Gorse, C. A. 1998. Information management the heart of the design agenda. *The International Journal of Architectural Management, Practice and Research* 14: 112–120.

Emmitt, S. and Gorse, C. A. 2007. *Communication in Construction Teams* Taylor & Francis, Oxford.

Goodreau, S. M., Handcock, M. S., Hunter, D. R., Butts, C. T. and Morris, M. 2008. A statnet tutorial. *Journal of Statistical Software* 24: 1–26.

Granovetter, M. 1973. The strength of weak ties. *The American Journal of Sociology* 78: 1360–1380.

Halgin, D. S., Gopalakrishnan, G. M. and Borgatti, S. P. 2015. Structure and agency in networked, distributed work: the role of work engagement. *American Behavioral Scientist* 59: 457–474, doi: 10.1177/0002764214556807.

Jablin, F. M. 1987. "Formal organization structure", In Jablin, F. M., Putnam, L. L., Roberts, K. H. and Porter, L. W. (Eds), *Handbook of Organizational Communication: an Interdisciplinary Perspective* Sage, Newbury Park, CA, 389–419.

Johnson, J. D. 1993. *Organizational Communication Structure* Ablex, Norwood, NJ.

Johnson, J. D., Donohue, W. A., Atkin, C. K. and Johnson, S. 1994. Differences between formal and informal communication channels. *Journal of Business Communication* 31: 111–122, doi: 10.1177/002194369403100202.

Kent, D. C. and Becerik-Gerber, B. 2010. Understanding construction industry experience and attitudes toward integrated project delivery. *Journal of Construction Engineering and Management* 136: 815–825.

Kereri, J. O. and Harper, C. M. 2019. Social networks and construction teams: literature Review. *Journal of Construction Engineering Management* 145: 03119001, doi: 10.1061/(ASCE)CO.1943-7862.0001628.

Krachkardt, D. and Hanson, J. R. 1993. Informal networks: the company behind the chart. *Harvard*

Business Review 71: 104–111, available at: https://hbr.org/1993/07/informal-networks-the-company-behind-the-chart.

Krivitsky, P. N. 2012. Exponential-family random graph models for valued networks. *Electronic Journal of Statistics* 6: 1100–1128, available at: https://doi.org/10.1214/12-EJS696.

Krivitsky, P. N. and Butts, C. T. 2017. Exponential-family random graph models for rank-order relational data. Sociological Methodology, 47:68–112, doi: 10.1177/0081175017692623.

Latham, S. M. 1994. Constructing the team. Final report of the Government/Industry review of procurement and contractual arrangements in the UK construction industry.

Lau, E. and Rowlinson, S. 2011. The implications of trust in relationships in managing construction projects. *International Journal of Managing Projects in Business* 4: 633–659, doi: 10.1108/17538371111164056.

Lin, N. 1999. Building a network theory of social capital. *Connections* 22: 28–51.

Loosemore, M. 1996. Crisis management in building projects: a longitudinal investigation of communication behavior and patterns within a grounded framework (PhD Dissertation). University of Reading, Reading.

Lushner, D., Koskinen, J. and Robins, G. 2012. *Exponential Model for Random Graph Models: Theory, Methods, and Applications* Cambridge University Press, Cambridge.

McPherson, M., Smith-Lovin, L. and Cook, J. M. 2001. Birds of a feather: homophily in social networks. *Annual Review of Sociology* 27: 415–444, doi: 10.1146/annurev.soc.27.1.415.

Matthews, O. and Howell, G. A. 2005. Integrated project delivery: an example of relational contracting. *Lean Construction Journal* 2: 46–61.

Methot, J. R., Rosado-Solomon, E. H. and Allen, D. G. 2018. The network architecture of human capital: a relational identity perspective. *Academy of Management Review* 43: 723–749, doi: 10.5465/amr.2016.0338.

Mollaoglu-Korkmaz, S., Miller, V. D. and Sun, W. 2014. Assessing key dimensions to effective innovation implementation in interorganizational project teams: an integrated project delivery case. *Engineering Project Organization Journal* 4: 17–30.

Mollica, K. A., Gray, B. and Treviño, L. K. 2003. Racial homophily and its persistence in newcomers' social networks. *Organization Science* 14: 123–136, doi: 10.1287/orsc.14.2.123.14994.

Monge, P. R. and Contractor, N. 2003. *Theories of Communication Networks* Oxford University Press, New York.

Monge, P. R. and Eisenberg, E. 1987. "Emergent communication networks", In Jablin, F. M., Putnam, L. L., Roberts, K. H. and Porter, L. W. (Eds), *Handbook of Organizational Communication: An Interdisciplinary Perspective* Sage, Newbury Park, CA, 304–342.

Pietroforte, R. 1992. *Communication and Information in the Building Delivery Process (PhD Dissertation)* Massachusetts Institute of Technology, Cambridge, MA.

Pilny, A. and Atouba, Y. 2017. Modeling valued organizational communication networks using exponential random graph models: *Management Communication Quarterly*, available at: https://doi.org/10.1177/0893318917737179.

Pryke, S. D. 2004. Analysing construction project coalitions: exploring the application of social network analysis. *Construction Management and Economics* 22: 787–797.

Pryke, S. D. 2005. Towards a social network theory of project governance. *Construction Management and Economics* 23: 927–939.

Pryke, S. D. 2012. *Social Network Analysis in Construction* Wiley-Blackwell, Oxford.

Pryke, S. D. 2017. *Managing Networks in Project-Based Organizations* Wiley-Blackwell, Oxford.

Pryke, S. D. and Badi, S. M. 2013. Identifying optimal business network configurations in construction project supply chains. Proceedings of Sunbelt XXXIII. Annual research conference of the International Network of Social Network Analysis, Hamburg, Germany.

Pryke, S. D., Badi, S. M. and Bygballe, L. E. 2017. Editorial for the special issue on social networks in construction. *Construction Management and Economics* 35: 445–454, doi: 10.1080/01446193.2017.1341052.

Pryke, S. D., Badi, S. M., Soundararaj, B., Watson, E. and Addyman, S. 2015. Self-organising networks in complex projects. Proceedings of COBRA 2015. Annual conference of the Royal Institute of Chartered Surveyors, Sydney.

Randall, K., Isaacson, M. and Ciro, C. 2017. Validity and reliability of the Myers-Briggs personality type indicator: a systematic review and meta-analysis. *Journal of Best Practices in Health Professions Diversity* 10: 1–27, doi: 10.2307/26554264.

Ruuska, I., Ahola, T., Artto, K., Locatelli, G. and Mancini, M. 2011. A new governance approach for multi-firm projects: lessons from Olkiluoto 3 and Flamanville 3 nuclear power plant projects. *International Journal of Project Management* 29: 647–660.

Sasovova, Z., Mehra, A., Borgatti, S. P. and Schippers, M. C. 2010. Network churn: the effects of self-monitoring personality on brokerage dynamics. *Administrative Science Quarterly* 55: 639–670, doi: 10.2189/asqu.2010.55.4.639.