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ORIGINAL RESEARCH

Unveiling the Impact of Communication Network on Engineering Project Team Performance: The Interplay of Centralization and Tie Strength

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Purpose: Recent research has focused on the impact of communication networks on the performance of construction project teams, attempting empirical exploration from various social network analysis perspectives. However, there is still a significant gap in understanding the variations in performance and the mechanisms for teams using different communication networks. Drawing from organizational learning theory and social network theory, this study, based on the Input-Mediator-Output (IMO) model, explores the effects of the interaction between centralization and tie strength in communication networks on team performance, as well as the mediating mechanisms of knowledge sharing behavior and team resilience performance in engineering project teams.

Methods: Drawing on classic group communication experiment, we design an online communication and collaboration platform to simulate the execution of a construction engineering project. Finally, data was collected through the communication experiment with 720 participants, and hypotheses were tested using ANOVA and *PROCESS.*

Results: The results indicate that under conditions of weak tie strength, centralized communication networks yield higher performance. Conversely, under conditions of strong tie strength, decentralized communication networks demonstrate superior performance. Furthermore, this study also verifies the mediating role of knowledge sharing behavior and team resilience performance when tie strength is strong.

Conclusion: This study focuses on engineering project team, exploring the evolutionary development of knowledge sharing behavior and team resilience performance from the perspective of the interaction of communication network structural characteristics, as well as the paths to enhancing team performance. Our research results highlight the interactive effects of structural indicators and relational indicators of communication networks, revealing the mechanism by which the structure of communication networks impacts team performance. Additionally, from the perspectives of forming and timely adjusting team communication models, and motivating and supporting employee communication behavior, our study provides practical insights for project managers and relevant administrators.

Keywords: engineering project team, communication network, knowledge sharing behavior, team resilience performance, team performance

Introduction

An engineering project team is comprised of various experts including owners, designers, general contractors, subcontractors, and consultants, all of whom join forces to bring a unique engineering project to fruition. The caliber of this collaborative endeavor significantly influences the project's outcome. Thus, it's absolutely vital to bolster the performance of the project team in order to ensure the successful completion of the project.[1] Nevertheless, issues such as communication delay and information omission among team members may lead to cost escalation and schedule overruns, thereby undermining overall team performance.[2,3] In response to these challenges, an increasing number of studies have explored the adoption of digital technologies to improve communication efficiency and performance.[4] It is worth noting that recent research has highlighted the significance of creating communication networks that enable knowledge transfer,

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contributing to both team and project performance.[5–7] And knowledge sharing within a team is defined as the process of transferring knowledge within a team in such a way that team members can learn and apply the knowledge.[8,9]

Team resilience is conceptualized as the collective capacity of a team to rebound and recuperate from procedural setbacks triggered by challenging circumstances.[10] Currently, engineering projects often confront challenges such as volatility, uncertainty, and complexity. Enhancing the resilience of engineering project teams is a crucial pathway to improve team performance.[11,12] A recent study investigates the impact of social interaction patterns on team resilience under conditions of turbulence and complexity,[13] and it is well-established that social interaction patterns serve as the foundation for shaping communication network structures.[14,15] In this way, we propose that optimizing communication network emerges as an indispensable strategy for fostering effective knowledge sharing and enhancing team resilience, ultimately leading to the improvement of team performance. Nonetheless, further exploration of the relevant research is warranted.

Network centralization is defined as the degree to which communication flows disproportionately through one or more members of the team, rather than being more equally distributed.[16] Drawing upon the existing research on communication networks of engineering project teams, as featured in mainstream peer-reviewed papers and case studies,[7,17,18] this study summarizes three communication network structures from the perspective of differences in network centralization. These structures include the fully connected structure, the community structure, and the core-periphery structure. The first two structures are distinguished by their low centralization, whereas the latter structure exhibits a high degree of centralization. Moreover, tie strength is confirmed to be associated with communication network structure, influencing various outcomes such as knowledge transfer[19] and project performance.[20] In this paper, tie strength refers to the measure of the intensity of connections formed among project team members in their communication and collaboration from a relational perspective.[21,22] Even though some research suggests that the communication structure itself could influence the strength of the connections, this paper mainly focuses on how the tie strength within the network changes due to external factors. A variety of external factors can impact the strength of the communication network connections. For instance, the different stages of project progress, the varying levels of familiarity among team members,[23] or the complexity of the engineering project and the size of the team.[24] Previous studies have shown that strong tie strength can boost the transfer of knowledge in engineering project communication networks.[23] More recent research also suggests that strong tie strength and fully connected networks can lead to better project performance.[6] However, the related discussions are far from being concluded.

It is worth noting that several studies have compared the performance differences of teams utilizing communication networks with varying degrees of centralization from the perspective of external influences, such as environmental shifting[16] and member turnover.[25] Furthermore, the Input-Mediator-Output (IMO) model also provides a theoretical foundation, suggesting that structure characteristics and environmental stress can jointly drive team interactions, subsequently influencing team performance.[26] All these streams on peer-reviewed papers have generated important insights. For engineering project teams, from the perspective of changes in tie strength, the exploration of the impact of communication networks with different centralization on team performance is worthy of further investigation. The objective of this study is to explore the following three questions with respect to engineering project teams: (1) Does the interplay of centralization and tie strength for communication networks influence team performance? (2) Which level of communication network centralization leads to superior team performance, with both strong tie strength and weak tie strength? (3) In the context of strong tie strength, do knowledge sharing behavior and team resilience performance mediate the impact of the interplay between centralization and tie strength of communication networks on team performance?

This study addresses these questions by drawing upon the IMO model and utilizing the methodology of social network analysis. A theoretical framework, inclusive of several hypotheses, was developed. Data were subsequently collected through communication network experiments to validate the proposed framework. Our paper contributes to engineering project management literature in the following three ways. First, this study validates the impact of communication networks on team performance by examining the interplay between network structural attributes (centralization) and network relational attributes (tie strength). Second, strong tie strength is identified as the driving factor that leads to knowledge sharing behavior and team resilience performance within communication networks of different centralization. Third, from the unified perspective of knowledge sharing behavior and team resilience performance, this study underscores the influence of team interaction on team performance.

Literature Foundation and Hypotheses Development

Theoretical Foundation: The IMO Model

The IMO model has been served as an important research foundation for exploring how inputs are transformed into outcomes by team interactions.[27] Inputs are described as antecedents that inspire team interactions, including individual-level factors, team-level factors and organizational-level factors. Specifically, the inputs at the team level include structure, cohesiveness, and external leader influences, etc. It is suggested that different inputs can combine to drive team interactions toward multiple team outcomes. Mediators employed to assess team interactions primarily fall into two categories: team processes and emergent states. Within the realm of action processes, researchers primarily investigate team collaboration and knowledge management issues, such as the effects of various horizontal or vertical collaboration methods,[28] as well as how to enhance team creativity through team learning, knowledge sharing, and knowledge acquisition, etc.[29,30] In recent years, the study of emergent states has mainly concentrated on aspects such as team confidence, cohesiveness, and team atmosphere. Notably, team confidence, which comprises both team efficacy and potency, has been found to exert a positive influence on team performance by enhancing team resilience. With regard to performance evaluation, it is advisable to utilize a composite set of criteria that correspond with both the team's functional objectives and task-oriented goals.[1,26]

Communication Network and Centralization

Human communication networks, defined as the patterns of contact created by the flow of information among individuals, can substantially improve the execution of teamwork and increase the overall efficiency.[31,32] In engineering project team, members should make efforts to share and distribute unique knowledge to others for achieving project goal. Communication networks build bridges for knowledge sharing whereas the complex interrelations among team members are emerging.[33] Social network analysis is described as a tool for analyzing the complex interrelations through network structure whereas network attributes related to roles, interactions, linkages, and metrics are discussed.[34] Based on representative social network models (such as the random network, the small-world network, and the scale-free network), the fully connected structure, the community structure, and the core-periphery structure have been proposed to depict the communication patterns within engineering project teams.[34,35] Among them, the fully connected structure and the community structure are considered centralized structures, while the core-periphery structure is considered a decentralized structure.

The fully connected structure is maximally decentralized structure. It is similar to the random networks, wherein individuals can freely interact with others. Team members can access any one another within the network for resources, skills, or knowledge, where each member contributes to maximize the collective benefits. There is no clustering, and the average path length between members is quite short because the connection ties are direct.[34,36] The community structure, which is a less-decentralized structure, consists of interconnected subgroups. Each subgroup attends to specific aspect of the project. Interactions (eg, knowledge and resources transfer) are concentrated within the boundaries of subgroups and relatively sparse between them. This resembles a small-world network, where the clustering coefficient is high and the average path length is low within clusters, while long-distance ties exist between different clusters.[18,34]

The core-periphery structure is a commonly observed centralized structure in empirical studies. It consists of an internally fully connected core subnetwork and peripheral individuals connected to the core but not each other. Members within the core subnetwork exert significant influence over the operation of the overall network, while peripheral members contribute to the creation of project goals by providing necessary resources to the core. Similar to the scale-free network, the core-periphery structure exhibits a higher clustering coefficient and shorter average path length compared with random networks.[18,37]

Communication Network and Tie Strength

In the study of communication network, the strength of ties, whether weak or strong, can be explored from both structural and relational perspectives. From a structural perspective, tie strength is considered a structural property of networks.[38] For instance, strong ties involve all members within a team being interconnected, wherein various relationships among members facilitate communication and cooperation, ultimately mitigating conflict and enhancing project performance.[19,39] The structural property of weak ties is defined by bridging ties in a network, which could build bridges between different members to fill in "structural holes".[40] The openness of weak ties in a network can bring new and heterogeneous knowledge to the team, promote the mobilization of knowledge, and thus be more conducive to improving project performance.[41] From a relational perspective, tie strength mainly reflects the degree of close connection, the frequency of mutual interaction, and the consistency of common objectives.[42] Empirical research has demonstrated that frequent contact between members is valuable for mobilizing resources[43] or sharing knowledge.[44]

It is worth noting that network structure determines the availability of knowledge, while communication frequency determines the extent of knowledge accessibility.[20,45] Within the scope of communication networks addressed in this study, network centralization is investigated through a structural lens, while tie strength is examined from a relational standpoint. Generally, it is believed that during the early stages of project development, team members may be unfamiliar with each other. As collaboration time increases, the frequency of communication interaction gradually rises, the degree of intimacy deepens, and the strength of the network connection transitions from weak to strong.[46] Compared to the view that strong ties enhance trust and communication performance,[47] recent studies have also proposed the advantages of weak ties in promoting continuous information flow and improving project performance.[48] Currently, comparative studies on strong tie and weak tie within organizations continue to be conducted.

Centralization, Tie Strength and Team Performance

In recent years, a consensus has emerged from numerous studies indicating that decentralized structures are more conducive to enhancing team performance compared to centralized structures. This is because, in centralized structures, individuals on the periphery are unable to directly share ideas, information, or solutions to problems with others, which can impede task completion. Furthermore, due to the disproportionately large influence of central nodes compared to peripheral nodes, the adoption of suboptimal solutions or the manifestation of optimistic biases can lead the entire network astray. Central nodes also face the bottleneck of processing large amounts of information, resulting in reduced team performance.[17,49,50] In contrast, decentralized structures possess more communication pathways, which are beneficial for adapting to faster information flows and the increase of knowledge-based work, where ideas and information must come from different experts within the team.[51,52] However, the increased number of communication pathways also demands more of members' time, consequently reducing the communication frequency along any single pathway. Conversely, in centralized structures, the fewer available communication channels increase individuals' reliance on each pathway, enhancing the communication frequency on available paths. Thus, new research suggests that centralized structures have advantages in uncertain and complex external environments. For example, when turnover occurs, new members may have difficulty quickly understanding and engaging in team communication within a decentralized structure, potentially harming team performance. In centralized structures, new members can swiftly identify limited communication pathways and prescribed coordination logic, actively contributing new information and perspectives to the core nodes, assisting with task completion.[25] A recent experimental study also supports this conclusion, suggesting that in centralized structures, the relatively independent peripheral nodes are maintained separately by the core nodes, who do not exert conformity pressure from other members. This encourages the generation of diverse solutions and connectivity, allowing the dissemination of effective ideas and adaptability to a constantly changing environment.[16]

These progressively refined insights embody the notion that evaluating the performance of communication networks based solely on their structural attributes may be inadequate. Furthermore, we propose that tie strength, when considered from a relational perspective, is likely to serve as a stimulating factor that moderates the performance of communication network centralization as a structural feature. This is because, under conditions of weak tie strength, centralized structures inherently possess a higher average frequency of communication along available paths, leading to superior team performance. By reinforcing the tie strength, decentralized structures can achieve a higher communication frequency in individual channels, building upon the existing broad communication pathways, ultimately leading to improved team performance. Consequently, the following hypothesis is suggested:

H1: Centralization and tie strength for communication network interact to affect team performance.

H1a: Communication network with centralized structure perform better when tie strength is weak.

H1b: Communication network with decentralized structure perform better when tie strength is strong.

Mediating Effect Hypotheses

In recent years, the implementation of engineering projects has been confronted with constantly changing environments and complex task challenges. Project teams are required to integrate various types of knowledge and enhance team resilience in order to reduce errors, improve work efficiency, and mitigate the risk of failure.[11,30] Communication, as the primary form of interpersonal interaction, promotes knowledge sharing by integrating dispersed individual knowledge.[53,54] In other words, increasing the frequency of interaction among team members can foster the generation of more valuable ideas and strengthen the team's ability to execute complex and dynamic tasks, thereby serving as an effective approach to enhance team performance.[55,56] Prior studies have explored the impact of communication patterns on aspects such as knowledge sharing[53,57] and team resilience[13,58] through the lens of social network analysis, examining elements like network centralization, tie strength, and cohesion.

Knowledge sharing behavior, as a component of knowledge sharing, refer to the activities of individuals transmitting their knowledge to other team members,[59] and are typically measured by the quantity of shared knowledge.[60] Based on organizational learning theory,[61] strengthening the ties within a decentralized communication network can increase the frequency of communication across multiple channels. This facilitates the integration of various knowledge and contributes to a rapid improvement in team performance. In centralized communication networks, increased knowledge sharing behavior can also mitigate biases introduced by the cores, thereby enhancing performance. In other words, knowledge sharing behavior may occur in communication networks with different centralizations, and the closeness between members in the network is the key factor that triggers its effect. Therefore, we propose the following hypothesis:

H2: Knowledge sharing behavior mediates the impact of communication network centralization (centralized vs decentralized) on team performance when tie strength is strong.

Existing studies have substantiated that the interactional patterns within project teams significantly influence team resilience.[13] Moreover, in environments characterized by adversity and stress, team resilience has been empirically observed to uphold team performance.[62] Team resilience is conceived as a systemic emergence within team interaction and coordination processes,[63] a consequence of participants' actions intertwined with their complex interplay.[64] In the implementation of engineering projects, intimate connections can enhance interpersonal trust,[65] and interpersonal trust can promote resilient performance.[11] Therefore, we propose that, even under different conditions of communication centralization, strengthening the tie strength between team members and promoting the formation of closeness is important. A centralized structure can reach a state characterized by a limited number of connections between members, but increased tie strength. Meanwhile, a decentralized structure may experience enhanced tie strength through multiple channels. These factors are expected to facilitate effective interaction between team members and, by boosting team resilience, achieve optimal team performance. Therefore, the following hypothesis is formulated:

H3: Team resilience performance mediates the impact of communication network centralization (centralized vs decentralized) on team performance when tie strength is strong.

The theoretical model with hypotheses is shown in Figure 1.

Method

Overall Research Design

Due to the influence of factors such as the scale and various external environments pertaining to each engineering project team, it presents a formidable challenge to accurately discern the mechanism of how the interplay between centralization and tie strength for communication networks on team performance through surveys. Therefore, we draw on existing research that uses game experiments to simulate real-world scenarios in engineering project management, collect data,

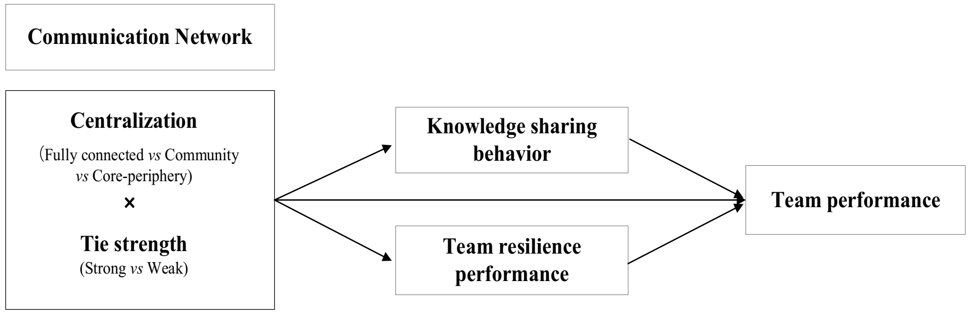

Figure 1 The Theoretical Model.

and conduct research.[25,66] In this experiment, participants are required to put themselves in these specific situations, make genuine responses, complete designated tasks, and analyze their behavioral characteristics.[33,67]

Building upon the framework of classical communication experiments[68] and recent network research,[16] this paper utilizes an innovative online communication and collaboration laboratory platform to simulate the execution of a construction engineering project. By measuring the performance of participants under specified communication rules, we aim to verify our hypotheses. According to the fundamental model of engineering project teams—wherein diverse professionals work together through communication and collaboration to achieve project objectives—our experimental tasks consist of the following: within a span of 30 minutes, groups of 12 participants are required to perform task analysis, retrieve key information, share information pairwise, and integrate three pieces of key information to complete a single procedure. These participants are expected to sequentially complete up to 40 procedures, in line with their specific numbering The details on experimental settings are shown in the Appendix A. An example of the experimental interface is shown in Figure 2.

Prior to the main experimentation, a pilot study was conducted to validate the experimental design and ensure appropriate measurements of the variables of interest. In the experiment, we manipulated two variables:

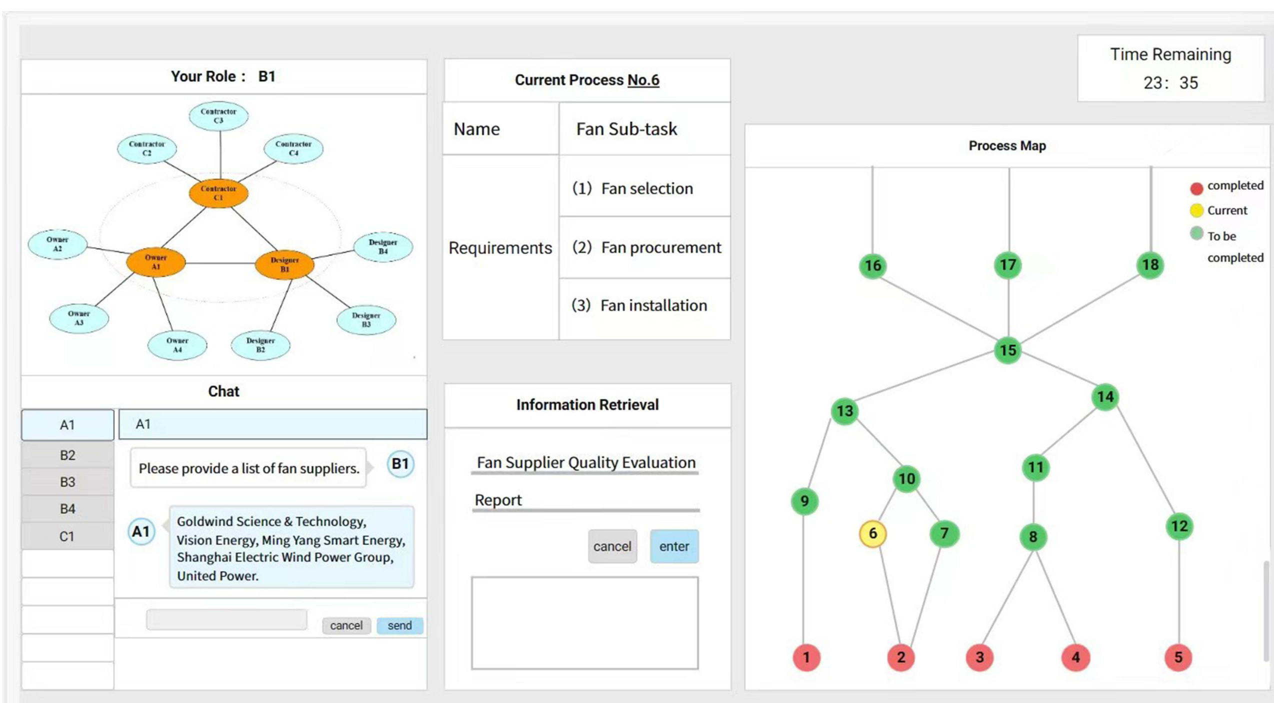

Figure 2 Screenshot of The Experimental Interface.

centralization and tie strength for the communication network. Control over who can communicate with whom was exerted through a communication client, allowing us to manipulate the communication network. Each network consists of 12 nodes, corresponding to the 12 members who assume three types of roles, each holding similar types of information with different meanings. We tested three types of network structures: (A) fully connected, where all members can communicate with each other; (B) community, where subgroups can communicate internally with some members connected externally; (C) core-periphery, where core members are interconnected and peripheral members are connected to only one core member, as depicted in Figure 3. Each instance of a team member sending a message to another is counted as one communication. Tie strength is regulated by the frequency of allowed communication, with a threshold of three times per minute differentiating between strong tie strength and weak tie strength. In essence, this study employed a 3 (network centralization: fully connected, community, core-periphery) × 2 (tie strength: weak, strong) between-subjects design.

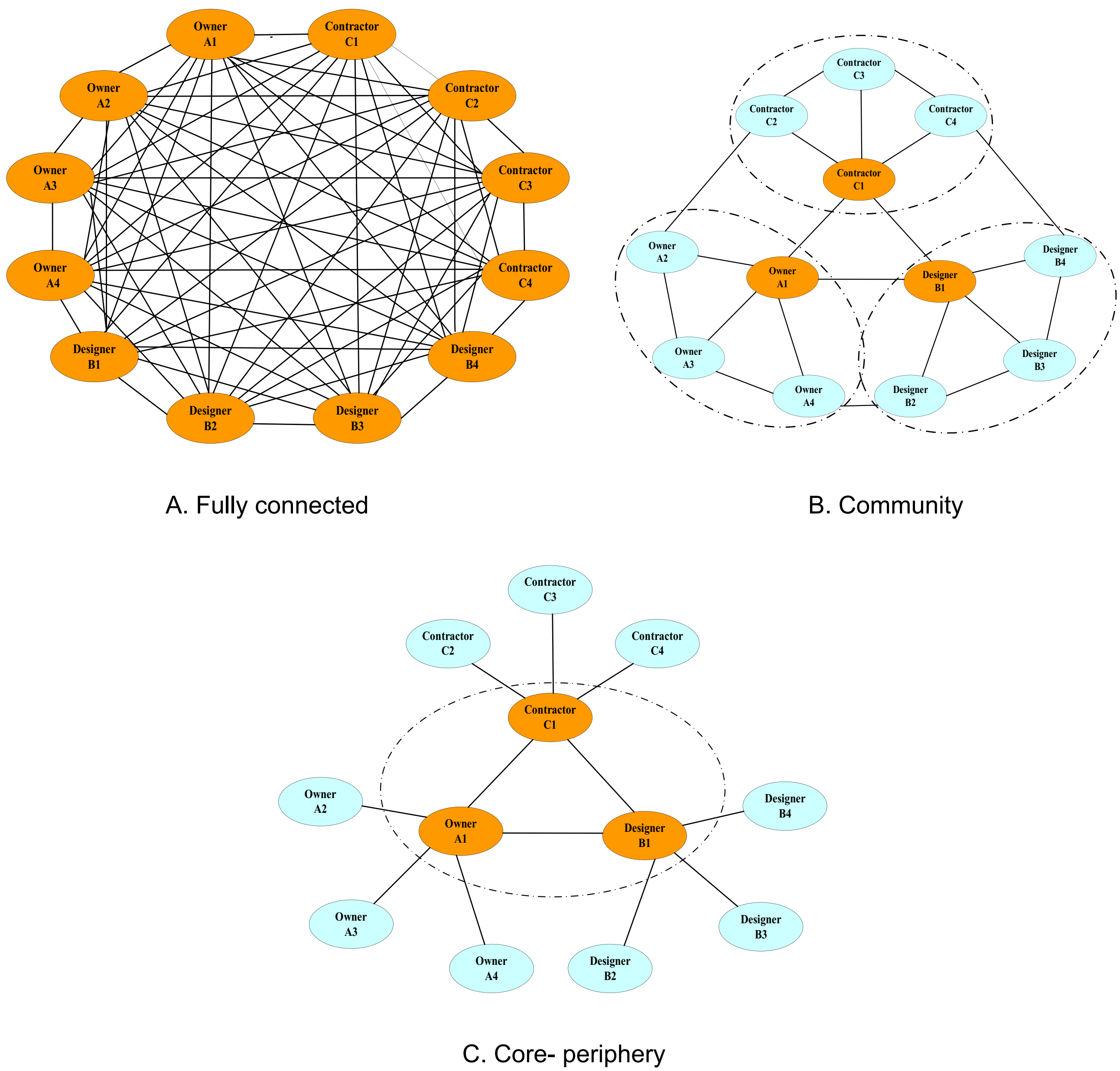

Figure 3 Network Visualizations.

Sample and Procedure

In an effort to recruit participants for our experiment, we enlisted 878 individuals from the MBA and Master's in Engineering Management programs at the School of Economics and Management, Tongji University. All participants possessed prior work experience in the construction or related industries. In other words, they were familiar with the basic processes of project management and had the ability to simulate the formation of an engineering project management team in a short time, and to collaborate to complete tasks. As an incentive, those who completed the experiment were awarded practical course credits. Additionally, the best-performing team member in each scenario was given an extra reward of a 100-yuan shopping card per person. Following the recommendations of Meade, Craig[69] and Shore, Bernstein, Jang,[16] we established a four-stage participant pipeline.

Stage 1: Rule learning and testing. Upon entering the laboratory, each participant was seated at a computer in a private booth and watched a video explaining the communication rules and operating interface. After viewing the video, participants answered five questions about the experimental rules based on a given scenario, shown in the Appendix B. Participants who did not pass the test were allowed up to four additional attempts. Stage 2: Main Experiment I. Participants who successfully passed the preceding test proceeded to the first main experiment. They were randomly assigned to groups and roles. Within specified communication conditions (partners and communication frequency) and role permissions (sharing and integration of the information), they had 30 minutes to complete the task. This stage did not involve any task changes. Finally, participants completed a survey on basic personal information, such as gender, age, and work experience. Recognizing that these factors could potentially influence their cognition and behavior in both communication and collaborative contexts, we accounted for them as control variables.[67,70] Stage 3: Main Experiment II. Building upon the recommendations of Shore, Bernstein, Jang,[16] participants were randomly regrouped and tasked to repeat the experiment. The only difference from Stage 2 was that their teams received reorganized task cards at the 10-minute and 20-minute marks, unbeknownst to the participants beforehand. Stage 4: Experiment process data check. Individual participants' information delivering frequency was examined to identify those who sent significantly fewer messages than the team average or sent repetitive or invalid messages more than three times. Participants exhibiting inadequate engagement were excluded from their respective team's data. The implementation of Stages 1 and 4 aimed to identify and eliminate participants who failed to follow instructions, lacked concentration, or were unable to complete the task correctly. To mitigate potential confounding factors such as unequal practice or fatigue effects, each participant was only allowed to participate in one main experiment.[71]

In alignment with previous studies,[16] our analysis focused on team-level outcomes, necessitating the formation of groups beginning the experiment with twelve independent observations. Consequently, we often had to tolerate situations where experiments could not be commenced due to the lack of twelve participants per group. We facilitated those participants, who remained ungrouped but were willing to continue, in waiting for entry into the next experimental group. To achieve balance in our samples, we repeated the aforementioned four-stage procedure until the point when the recruitment of additional participants, to maintain group equilibrium, was no longer feasible, and data collection was thus halted. Eventually, 29 individuals did not pass the first-stage testing, and nine others could not participate due to unsuccessful group formation. This resulted in a total of 840 individuals participating in the main experiment. After discarding the invalid data from six groups filtered out during the Stage 4 and four groups that exceeded the balance of the sample, we obtained effective data from 120 groups, comprising a total of 720 participants. Among these, each of the three structures under both strong tie strength and weak tie strength, with and without interference, had ten groups. The demographic representation demonstrated that the participants' average age was 31 years, with 56.9% male and 43.1% female participants. Furthermore, 23.2% of the participants had less than three years of experience, 25.1% had three to five years of experience, 29.2% had five to ten years of experience, and 22.5% had over ten years of experience. These participants were found to have a substantial experience in their respective fields.

Measures

In this investigation, centralization and tie strength of the communication network were manipulated as independent variables through experiments, and both the mediating and dependent variables were ascertained via behavioral measures. Following the approach proposed by Guetzkow, Simon[68] and Lu, Wang, Ni, Shapiro, Zheng,[72] the task completion degree was measured as team performance, which was operationalized as the number of processes completed by the team within a 30-minute duration. In this experiment, knowledge sharing behavior was manifested through the exchange of information among team members. In accordance with the recommendations,[70] we utilized the count of information units shared per minute among all team members as the data source for knowledge sharing behavior. In referencing the recent study Massari, Giannoccaro, Carbone,[13] this research employed the ratio of the performance mean under intermittent interference to the performance value in a static environment (V/V_{static}) to quantify team resilience performance.

Results

Manipulation Check

In this study, according to Argote, Aven, Kush,[25] we performed a manipulation check on centralization and tie strength in the communication network through the analysis of experimental process data. Initially, by examining the usage of available communication paths among team members, we found that under both strong tie strength and weak tie strength, there were no significant differences in the usage rates among members in fully connected structure and community structure ($p>0.1$). However, in the core-periphery structure, the usage rate of available communication paths by core points was slightly higher than that of other members ($p<0.1$), suggesting that the manipulation of network centralization was effective. On the other hand, statistical analysis of the communication frequency of members under the three communication network structures revealed that under the strong tie strength condition, the average communication frequency was significantly higher than under the weak tie strength condition ($p<0.001$). This result indicates that the manipulation of tie strength was effective.

Testing of Main Effect

We adopted analysis of variance (ANOVA) to test the effectiveness of our hypotheses. Initially, a two-way ANOVA was conducted for network structure and tie strength, using team performance as predictors. The results indicated a significant interaction between network centralization and tie strength ($F(1114)=52.644$, $p=0.000$, $\eta^2_p=0.661$). Subsequently, a one-way ANOVA was applied to perform a simple effect analysis. As shown in Figure 4, the results of which revealed that under weak tie strength, the team performance of core-periphery structure ($M=20.20$, $SD=3.225$) was significantly higher than that of the fully connected structure ($M=7.50$, $SD=3.951$; $F(1,38)=62.008$, $p=0.000$, $\eta^2_p=0.775$) and community structure ($M=9.50$, $SD=4.249$; $F(1,38)=40.235$, $p=0.000$, $\eta^2_p=0.691$). Thus, Hypothesis 1a was supported. On the other hand, under strong tie strength, the team performance of the core-periphery structure ($M=28.40$, $SD=2.797$) was significantly lower than that of the fully connected structure ($M=35.90$, $SD=2.644$; $F(1,38)=37.978$, $p=0.000$, $\eta^2_p=0.678$) and the community structure ($M=33.90$, $SD=2.514$; $F(1,38)=2.386$, $p=0.000$, $\eta^2_p=0.543$). Thus, Hypothesis 1b was supported. Therefore, Hypothesis 1 was validated.

Testing of Mediating Effect

Following, we use *PROCESS* to test the mediating effect. We selected Model 4 with a sample size of 5000, and the confidence interval was set at 95%. When the tie strength was weak, the indirect effect of knowledge sharing behavior yielded the following results: $\text{Effect}_{(fully\ connected\ vs\ core\text{-}periphery)}=0.7383$, 95% CI=[−1.4699, 1.3338]; $\text{Effect}_{(community\ vs\ core\text{-}periphery)}=0.3989$, 95% CI=[−0.9428, 0.7112]. The range in both cases included 0, indicating that the mediational effect of knowledge sharing at this juncture was not significant. However, under strong tie strength, the indirect effect of knowledge sharing behavior came out as $\text{Effect}_{(fully\ connected\ vs\ core\text{-}periphery)}=1.0597$, 95% CI=[−5.4136, −1.4201]; $\text{Effect}_{(community\ vs\ core\text{-}periphery)}=1.9931$, 95% CI=[−10.7276, −2.9614], with the range not including 0, denoting that the mediational effect of knowledge sharing at this point was significant. Therefore, Hypothesis 2 was supported.

In the scenario of weak tie strength, the indirect effect results for team resilience performance were: $\text{Effect}_{(fully\ connected\ vs\ core\text{-}periphery)}=1.0213$, 95% CI=[−3.4908, 0.6424]; $\text{Effect}_{(Community\ vs\ core\text{-}periphery)}=1.6797$, 95% CI=[−3.9583, 2.8136]. Since these ranges included 0, it indicates that the mediational effect of team resilience performance was not significant at this point. However, when tie strength was strong, the indirect effect of team resilience performance was

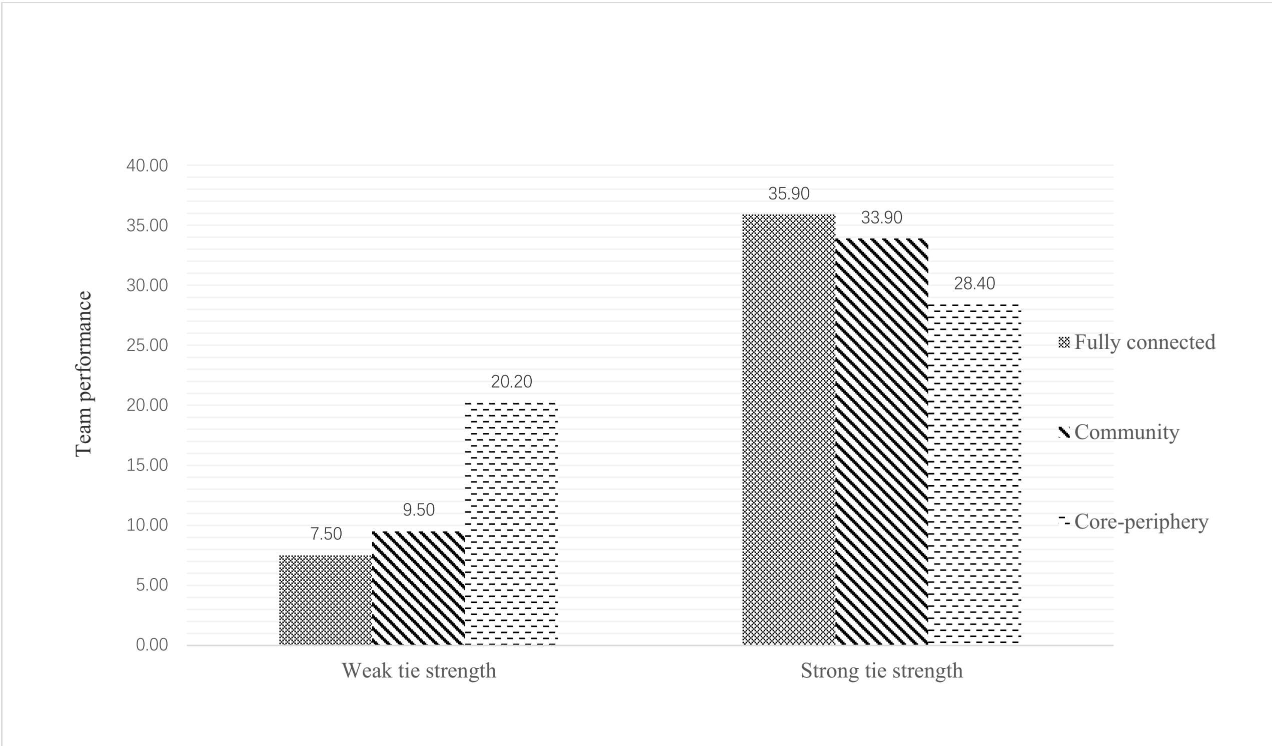

Figure 4 Team Performance of Interaction Between Network Centralization and Tie Strength.

determined as $\text{Effect}_{(fully\ connected\ vs\ core\text{-}periphery)}$=0.6358, 95% CI=[0.1030, 2.5658]; $\text{Effect}_{(community\ vs\ core\text{-}periphery)}$ =1.2431, 95% CI=[2.1025, 6.9350]. As these ranges did not include 0, it signified that the mediational effect of team resilience performance was significant at this stage. Thus, Hypothesis 3 was supported.

Discussion

Main Findings

This study dissects the real-world communication scenarios of engineering project management teams by analyzing the behavioral experimental data from 120 groups, and explores the impact mechanism of communication networks on team performance. Based on the IMO model, the interplay between centralization and the tie strength of communication networks significantly impacts team performance, and the mediating effects of knowledge sharing behavior and team resilience performance have been tested. The main conclusions of this study are as follows.

First, this study finds that the team performance of communication networks with different centralization is influenced by the tie strength. More specifically, when the tie strength is weak, the team performance of centralized structure exceeds that of decentralized ones. When the tie strength is strong, the team performance of decentralized structures surpasses centralized one. Due to the existence of structural holes in the centralized structure, they can promote the effective flow of unique information among members.[73] That is, when the tie strength is weak, human and material resources are difficult to concentrate, centralized communication networks can quickly coordinate various resources to enhance collective productivity. For example, the case of the 2010 Shanghai World Expo showed that the establishment of a headquarters composed of management personnel from relevant government agencies could expedite project progress and improve the quality of completion through integrated communication coordination mechanisms.[74] There are plenty of available paths in decentralized communication networks, but when the tie strength is weak, their collaboration integration mechanism has not been fully established,[57] which could be the reason for low task performance. This predicament can be resolved as the intimacy of cooperation among members increases and the strength of communication ties becomes stronger. Enhancing tie strength of a decentralized structure helps form Simmelian ties with super strength and high stickiness, which restrict group polarization and opportunism.[6] At this time, the established cooperative integration model facilitates knowledge sharing among members, stimulates team management efforts, and improves team performance and project returns.[75] At this time, central members in the centralized structure may use the information advantage and special power brought by their strategic position to advance their own interests, which affects the rapid improvement of team performance.[6,76] According to the above discussion, we have summarized the transformative characteristics of the impact of communication networks on team performance, which is consistent with previous research.[18,25] Such characteristics can also be explained by the theory of complex network evolution, as changes in connections between network participants may stimulate the renewal and change of network structure.[77]

Second, this study explores how knowledge sharing behavior mediates the impact of communication network centralization on team performance, and under what conditions this mediation occurs. The findings indicate that the mediating effect of knowledge sharing behavior is not significant when the tie strength is weak. However, when the tie strength is strong, the mediating effect of knowledge sharing behavior is significant. This finding also supports earlier views and confirms that communication networks could build bridges for knowledge sharing, while the complex interrelations among project team members are emerging.[78] Moreover, knowledge sharing behavior can break down barriers between knowledge owners, promote the free flow of knowledge within a certain scope, and further enhance organizational learning, knowledge integration, and innovation capabilities, thus improving overall performance.[79,80] However, the occurrence of knowledge sharing behavior depends on intimate interactions and internal collaboration.[81,82] The close connection is beneficial in avoiding resource waste caused by duplicated knowledge production and, thus, improving the quality of knowledge sharing. The quality of knowledge sharing is crucial for the quality of collective decision-making,[70,83] which will impact the performance of engineering project management teams.[33] This is not entirely consistent with existing study that mention when team members have a wider range of communication channels, they can transfer knowledge more easily.[84] This is because in a decentralized structure, with dispersed positions and shared pressure among members, fully connected communication paths and close interactions can quickly improve the quantity and quality of knowledge sharing, thereby enhancing team performance. However, in a centralized structure, increasing the frequency of interactions among members may bring excessive information processing pressure to core members, leading to negative effects of information overload.[25] It is worth noting that when the team is sufficiently staffed, decision-making information is directly passed to the responsible engineers according to the decision-making hierarchy and is promptly processed. On the other hand, when communication tie strength is weak, the frequency of hidden information may increase, which could hinder the process of knowledge sharing and potentially lead to biases in collective decision-making, ultimately resulting in decreased overall performance.[85,86] For example, in multidisciplinary engineering projects, critical information may reside with peripheral subcontractors, and when interaction relationships are not close, information omission or distortion may occur.

Third, research indicates that when the tie strength is high, team resilience performance plays a significant mediating role between communication network centralization and team performance. However, this mediating effect does not hold under conditions of weak tie strength. This finding corroborates prior studies asserting that in the typically high-pressure environment of engineering project teams, resilience serves as a crucial conduit for maintaining and even enhancing performance.[11,87] Moreover, resilience interactions (the patterns, scale, and connections of communication structure) are drivers for improving resilience performance.[88,89] Therefore, under strong tie strength, decentralized network structure can stimulate more symmetrical and autonomous interactions,[13] leading to an increase in trust among team members,[90] fostering improved cooperation, and facilitating an uplift in resilience performance and task completion. Within centralized communication networks, there exist heightened opportunities for peripheral nodes to interact with connectable central nodes. In real-world applications, such interactions facilitate the execution of team plans under leadership guidance,[91] and allow for exploratory attempts in swiftly altering unfavorable situations.[92] Furthermore, through the reconciliation of team conflicts, the alignment of differing perspectives among team members, and the intensification of team introspection,[93] team resilience performance can be improved and task goals can be reached.[94] This conclusion stands in contrast to the view by Massari, Giannoccaro, Carbone,[13] which suggests that centralized structures exhibit lower resilience. The primary reason for this discrepancy lies in the fact that this study considers the tie strength for communication networks as a vital situational factor, demonstrating its crucial role in the formation and manifestation of team resilience.

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Theoretical Contributions

This research makes three significant contributions to the literature on construction project team management. First, it demonstrates the mechanism of the impact of the evolutionary interaction between the centralization and tie strength of communication networks on team performance. Existing research, based on case scenarios, has explored the impact of internal interactions and communication relationships within engineering project management teams on team performance or project performance.[57,95–97] These studies have shown specific communication patterns in engineering project management teams in real-world, but have also sparked controversy regarding different communication patterns and performance outcomes.[98] Based on this foundation, the study combines the classic communication networks and summarizes the typical communication networks of engineering project teams. Using the IMO model and classic communication experiments, it analyzes from an innovative perspective the interaction between network structural attributes and network relational attributes. The study examines how the centralization of communication networks influences team performance through tie strength. The research results highlight a high level of abstraction, making them applicable to a broader range of scenarios and providing theoretical guidance for resolving disputes. Additionally, the study introduces the effect of relational indicator of communication networks on structural indicator, thereby enriching the literature on team management predicated on social network analysis.

Second, focusing on engineering project teams, this study expands upon research on the antecedents and consequences of team knowledge sharing behavior and team resilience performance. As prior research has noted, team knowledge sharing and team resilience will enhance team performance.[99] Moreover, team interactions and trust play a facilitating role in on knowledge sharing[30,100,101] and enhancing team resilience.[11,56] However, research on the triggering mechanisms and behavioral pathways of knowledge sharing behavior and team resilience performance is still insufficient. This study draws on organizational learning theory and social network theory to clarify the mediating role and occurrence conditions of team knowledge sharing behavior and team resilience performance under the influence of the interaction between centralization and tie strength of communication networks on team performance. The results supplement the motivating factors regarding knowledge sharing behavior and team resilience performance, underscoring the pivotal role of organizational learning in team processes and emergent states.

Third, this study enriches research on the unified framework of team processes and emergent states specifically in the context of engineering project teams. Based on the IMO model, team interactions are a critical factor influencing team effectiveness.[26] Although recent research has discussed the impact of team processes on team performance based on project progression stages,[91] research that combines team processes and emergent states is still limited. Starting from the two dimensions of knowledge sharing behavior and team resilience performance, this paper combines team processes and emergent states to explore the impact of team interaction on team performance. It is an application and extension of the classic IMO model and contributes to the literature on project management behavior.

Managerial Implications

This study provides several managerial implications for practice. Firstly, communication structures are built on organizational structures but evolve with the progression stages of a project.[18] Optimizing the communication structure is of great significance for improving the performance of project management teams and responding to organizational changes. Project managers can evaluate the communication pattern adopted according to the project's characteristics, development stage, and organizational environment factors, referring to the communication structure proposed in this paper and its applicable conditions, and optimize it timely. Secondly, managers should realize that even under certain communication structure, there are task-based interdependencies among team members, but interaction may not effectively occur. Managers should pay attention to the interdependence among team members, investigate and recognize the actual needs and difficulties of effective interaction among members, adjust the communication structure timely, encourage knowledge contributions among members, and enhance team resilience. Lastly, appropriate digital technologies should be employed to improve the positivity and convenience of team member interactions, enhance team communication efficiency, and thereby improve team performance.

In addition, we believe that the findings of this study also provide guidance for project organizations, the construction engineering industry, and community practices in the context of the constantly changing era. In project organizations, establishing flexible communication structures and open communication cultures, encouraging knowledge sharing and cross-departmental collaboration, are key to enhancing organizational adaptability and innovation. Furthermore, engineering management industry associations can promote knowledge delivery and technological innovation within the industry by setting communication standards and sharing best practices, thereby improving the overall communication efficiency and competitiveness of the industry. At the community level, establishing effective communication platforms and participation mechanisms can enhance the interaction between construction projects and community residents, improve the social acceptance of projects, and strengthen the cohesion and responsiveness of the community. By adopting appropriate digital technologies and communication strategies, collaboration and innovation can be promoted at a broader organizational, industry, and community level, thereby enhancing the overall performance and social value of engineering projects.

Conclusion

In recent years, the viewpoint that an appropriate communication network structure can improve team performance has been validated. Based on the IMO model, this study constructs a theoretical framework and uses classic team communication experiments to explore the interplay of centralization and tie strength for communication networks and its impact on team performance. The experimental scenarios, task design, and measurement methods of target variables are based on previous research. The results reveal that the impact of the communication network centralization on team performance is moderated by the tie strength. In the process of increasing tie strength, decentralized communication networks will replace the centralized communication networks in terms of performance advantages. Enhanced tie strength can prompt communication networks with varying centralization to generate superior knowledge sharing behavior and team resilience performance, thereby improving team performance. This study advances our understanding of the structural relationships in engineering project teams from a two-dimensional perspective that combines structural indicator and relational indicator for communication network, clarifying key pathways to improving teams.

There are several limitations to this study that warrant further work to deepen and make more practical insights on this issue. Firstly, the three network structures derived from the perspective of network centralization cannot fully demonstrate all team communication structures, such as the hybrid structures found in large-scale projects. Therefore, future studies should integrate field experiments with laboratory experiments to delve into the performance of communication structures under varying scales, types, and environmental volatility. Secondly, this study uses task completion numbers as the measure of team performance in the experiment, but we also recognize that the dimensions for evaluating team performance in reality are broader. Future research could include other indices, such as error frequency, for multi-indicator measurement. Moreover, our experiments were conducted in China without considering the effects of regional cultural differences on team members. Future research can expand the boundary of the study subjects.

Ethics Approval and Informed Consent

All procedures conducted in this research strictly adhered to the laws and guidelines concerning human subject research, involving both human participants and/or tissue, for scientific purposes. This study protocol was reviewed and approved by Tongji University. The data collected in this research has been gathered and analyzed anonymously. We assured the participants that the laboratory behavioral experiment was conducted solely for academic purposes and did not involve any personal identification. Participants' data was gathered with their written consent. This consent is included in the supporting information uploaded to the system.

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Disclosure

The authors report no conflicts of interest in this work.

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