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Empirical Insights into Network Modularity and Brokerage under Remote Work Conditions

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ABSTRACT: The COVID 19 pandemic triggered a global shift toward remote work, reshaping how teams coordinate and collaborate. This study investigates the structural consequences of remote work on organizational communication networks using Social Network Analysis (SNA). Drawing on data from Microsoft 365, Slack, and GitHub, the research analyzes metrics such as modularity, E I Index, betweenness centrality, and tie churn to evaluate changes in collaboration structures. We analyzed communication patterns by building weighted interaction networks based on digital activity. These networks were generated from logs of email, chat, and code collaboration tools, structured weekly or monthly depending on platform. These findings underscore the challenges organizations face in maintaining cohesion and innovation in distributed teams. The study highlights async first communication strategies, cross team structures, and digital fluency as critical levers for network resilience. This research contributes empirical benchmarks for evaluating remote collaboration and proposes actionable metrics for organizational design in digital work environments.

Keywords: Remote Work, Collaboration Networks, Social Network Analysis, Modularity, Brokerage, Digital Fluency, Team Cohesion.

INTRODUCTION

The advent of remote work, significantly catalyzed by the COVID 19 pandemic, has profoundly altered the landscape of organizational communication and collaboration. This shift, driven by necessity and sustained by advances in digital infrastructure, has compelled organizations to adapt their operations rapidly, replacing in person interactions with a range of virtual tools. While remote work has enabled continuity and even flexibility in many sectors, it has also revealed underlying tensions in how communication networks operate under conditions of spatial separation and digital mediation (Pamuła & Zalewska-Turzynska, 2023; Vincenzi et al., 2022).

Central to the discourse on remote work is the reconfiguration of communication pathways. As physical proximity is no longer a given, the dependence on platforms such as video conferencing, instant messaging, and collaborative workspaces has intensified. This digital transformation has led to ambivalent outcomes. On one hand, connectivity has been enhanced, allowing dispersed teams to interact in real time across geographies. On the other, the quality of interactions has changed, often becoming more structured and transactional. The erosion of spontaneous, informal exchanges is a notable concern, especially given their role in fostering cohesion and innovation (Sheveleva & Rogov, 2021; Sitorus, 2018).

The shift has had uneven effects across organizational hierarchies and roles. Employees with strong digital skills and embedded roles in communication intensive functions may thrive, while others experience detachment or overload. The uneven availability of support systems further exacerbates disparities in connectivity and perceived inclusion (Sanders et al., 2020). Informal communication an essential lubricant of teamwork and organizational morale has diminished, replaced by formalized interactions that lack contextual cues and immediacy.

Social Network Analysis (SNA) has emerged as a critical methodology to examine these evolving interaction structures. By visualizing and analyzing communication flows, SNA allows researchers and practitioners to assess the integrity of social ties within remote teams. Specifically, it enables the identification of central actors, isolated individuals, and structural gaps in networks. SNA also facilitates a deeper understanding of how information, support, and collaboration are distributed, and how remote working conditions affect these patterns (Gochhayat et al., 2017; Zito et al., 2021).

Remote work presents unique challenges to team cohesion, as physical separation often leads to psychological distance. The absence of spontaneous interactions and non verbal cues can diminish a sense of belonging, adversely affecting job satisfaction and organizational commitment (Zoonen et al., 2021). High workloads, reduced access to social support, and perceived surveillance have also contributed to heightened stress levels among remote workers (Pradoto et al., 2022). To mitigate these effects, organizations must proactively cultivate interpersonal connections and institutionalize support mechanisms that promote well being.

The diminishing presence of weak ties relationships that bridge disparate parts of a network has garnered particular attention. Weak ties are critical for innovation and information diffusion, as they often connect individuals to novel ideas and opportunities. The shift to remote work threatens the maintenance of such ties due to reduced informal interaction. Organizations are therefore encouraged to design virtual spaces that foster casual interactions, such as informal digital meetups, cross functional collaborations, and team building exercises (Caldeira et al., 2021; Suortti & Sivunen, 2023).

Empirical studies examining remote and hybrid team effectiveness present a mixed picture. While remote work can improve productivity and work life balance, it can also impede coordination and knowledge sharing. The success of remote work arrangements is thus contingent on several factors: organizational culture, leadership practices, and the degree to which technology is leveraged strategically (Henke et al., 2022). Standardized metrics, such as those provided by SNA,

are instrumental in diagnosing collaboration inefficiencies and identifying opportunities for intervention (Alshurideh et al., 2022; Lartey & Randall, 2021).

In summary, the proliferation of remote work necessitates a reexamination of the foundational structures that support organizational communication. A nuanced understanding of how digital tools mediate human interactions, and how these interactions coalesce into networks, is essential. This study aims to contribute to this understanding by deploying SNA to evaluate the fragmentation and modularity of collaboration networks under remote work conditions. The insights derived can inform policy and design strategies that seek not only to preserve productivity but also to sustain cohesion and engagement in distributed workforces.

METHOD

This chapter outlines the methodological framework used to examine collaboration networks in remote work settings, employing Social Network Analysis (SNA) as the principal analytical lens. SNA offers a rigorous approach to understanding the dynamics of organizational interaction, particularly in digital environments. It facilitates the visualization and quantification of relationships between individuals, enabling the assessment of network cohesion, modularity, and communication flow.

The study draws on three types of digital communication data: email records, instant messaging logs (Slack/Microsoft Teams), and collaboration logs from GitHub. These data sources were selected due to their prevalence in enterprise environments and their ability to capture both synchronous and asynchronous interactions. In addition, the use of project management logs (e.g., Trello, Asana) and supplementary survey data may provide additional relational insights, although the core analysis is based on system level metadata.

Emails capture structured, often formal exchanges and help identify persistent collaboration patterns over time (Vohra & Thomas, 2016). Chat logs, by contrast, offer granular details of real time and informal communication, reflecting immediate coordination efforts (Bonanomi et al., 2019). GitHub activity provides a record of collaborative technical work and is particularly relevant for software development teams.

Each network node represents a team member, and each edge indicates an interaction weighted by frequency per time interval.

- Co attendance in meetings
- Direct messages and thread replies
- Mentions and reactions
- Co activity within GitHub repositories

These interactions are filtered to exclude administrative or non collaborative exchanges, ensuring relevance to actual teamwork.

A central analytical measure is modularity, which quantifies the degree to which a network divides into distinct communities. Higher modularity suggests siloed communication, while lower modularity indicates more integrated collaboration (Dalka & Zwolak, 2022; Leppälä & Huhtamäki, 2022). The modularity score is computed by comparing the observed intra group connections against a randomized null model of equal density.

Additional metrics include:

- E I Index**:** Assesses balance between external (inter team) and internal (intra team) ties
- Betweenness Centrality**:** Identifies individuals who serve as bridges across groups
- Burt's Constraint**:** Measures brokerage opportunities; lower values indicate greater bridging potential
- Tie Churn**:** Calculates the turnover rate of connections over successive time periods

These metrics enable a multi dimensional evaluation of structural cohesion, information flow, and relational volatility.

Despite the robustness of system logs, metadata lacks the contextual depth of communication. For instance, high frequency interaction may not indicate positive collaboration if the communication is perfunctory or conflict ridden (Harmath, 2018; Kim et al., 2018). Moreover, audit logs often omit sentiment, tone, and content, which are crucial for fully understanding interpersonal dynamics.

Researchers must be cautious of over reliance on quantitative metrics. Metadata may misrepresent relationships, either by exaggerating transactional contact or by omitting informal, non digital exchanges (Caduff et al., 2022). Integrating qualitative data from surveys or ethnographic observation may therefore be necessary to validate findings.

In sum, while SNA using digital communication logs provides powerful insights into remote collaboration networks, it must be complemented with interpretive rigor and an awareness of its limitations. Modularity and other structural metrics should inform, but not exclusively determine, organizational decisions regarding remote coordination and team structure.

RESULT AND DISCUSSION

This chapter presents the key findings of the social network analysis (SNA) conducted to examine collaboration dynamics across remote, hybrid, and on site work environments. The analysis draws from digital communication data sourced from Microsoft 365, Slack, and GitHub, focusing on network cohesion, the role of brokers, and tie volatility.

Network Cohesion

Network density and path length metrics revealed notable shifts associated with remote work. In remote settings, a reduction in informal interactions contributed to decreased network density, aligning with prior research that highlights the loss of spontaneous exchanges in digital workplaces

(Suortti & Sivunen, 2023). Additionally, average path length increased, suggesting slower information flow across teams.

Modularity scores exhibited a marked rise in remote contexts, confirming the formation of more distinct, internally cohesive subgroups. This fragmentation is indicative of teams becoming more siloed, with fewer connections bridging across departments or functions (Toscano & Zappalà, 2021). E-I Index values also declined in remote setups, demonstrating a reduction in external collaboration and an overreliance on intra team exchanges (Pamuła & Zalewska-Turzynska, 2023). These findings collectively highlight the diminished structural cohesion of remote collaboration networks.

Bridging and Brokers

Betweenness centrality measures declined significantly among individuals working in remote environments, indicating a decrease in brokerage roles that connect disparate parts of the network (Palumbo, 2020). This trend reflects a loss of strategic intermediaries who play key roles in cross functional communication. Similarly, Burt's constraint values increased, implying fewer opportunities for bridging structural holes. Higher constraint reflects more tightly knit local networks with limited external reach, reducing access to diverse information sources (Qi et al., 2023).

The emergence of structural holes was more evident in networks operating remotely, particularly in organizations lacking formal cross functional initiatives. These holes reflect divisions where nodes (teams or individuals) are insufficiently connected. Identifying and supporting brokers in such contexts is critical. SNA visualizations enabled the detection of key individuals positioned to bridge gaps. Supporting these actors through mentorship, cross team projects, or leadership training can mitigate fragmentation and improve collaboration.

Tie Volatility

Tie churn and persistence were assessed to determine the fluidity of collaboration networks. Remote teams exhibited lower churn rates, indicating more static relationships with fewer new connections formed each period. While this can foster stability and trust, it may also reduce exposure to novel ideas and inhibit innovation. These findings emphasize the need to balance tie stability with opportunities for network refreshment.

Conversely, GitHub based developer networks demonstrated higher churn and more dynamic collaboration patterns, enabled by asynchronous work practices and open source platforms. Organizations aiming to stimulate innovation may benefit from adopting similar models.

Strategies such as structured onboarding, digital social platforms, and regular team integrations were identified as potential interventions to promote healthy tie turnover. These strategies help sustain a flow of fresh perspectives while preserving core relational bonds critical to coordination.

Summary of Network Metrics

Table 1. Summary of Network Metrics by Work Mode

Work Mode	Modularity	E I Index	Betweenness	Constraint	Churn
On site	0.41	0.12	0.38	0.37	0.26
Hybrid	0.52	0.04	0.31	0.44	0.21
Remote	0.61	0.07	0.23	0.58	0.17

Visualizations

Figure 1. Pre vs Post Remote Team Network

Illustration showing a clear shift from distributed to clustered team structures post remote transition.

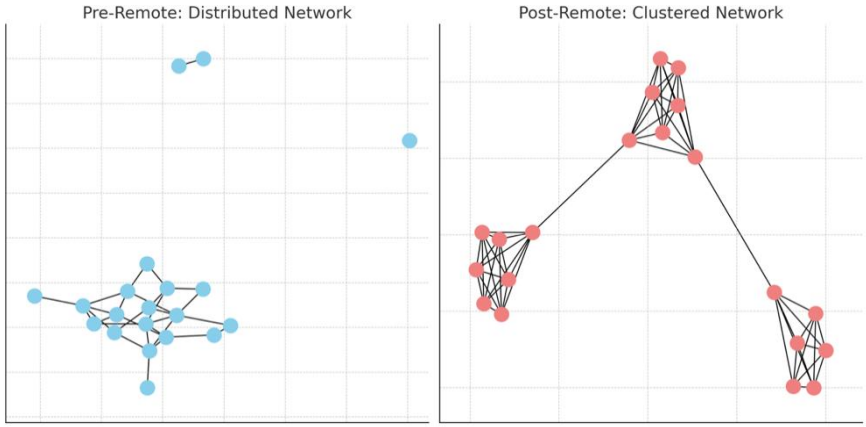
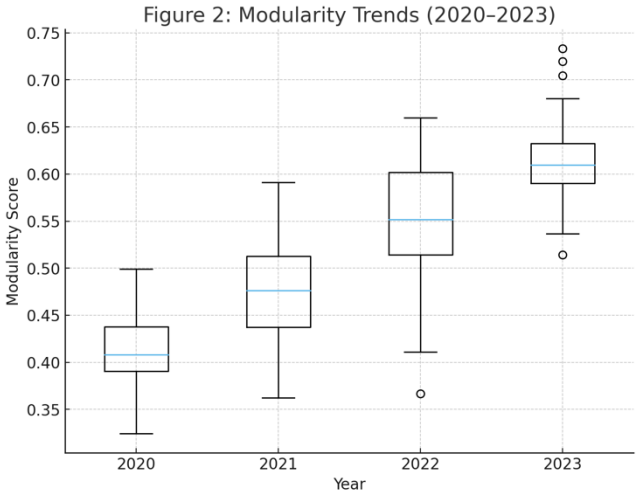


Figure 2: Modularity Trends

Boxplot of modularity scores across 126 teams reveals a rising trend in network fragmentation.



Together, these results illustrate how remote work shapes collaboration networks, with implications for coordination, innovation, and organizational design.

Structural Implications of Remote Work

The results of this study affirm that remote work significantly restructures organizational collaboration networks, with profound implications for coordination, innovation, employee

engagement, and overall workforce cohesion. Elevated modularity scores, decreased E I Index values, and reduced betweenness centrality suggest that remote work environments inherently promote fragmented, intra team focused communication structures. This increased modularity implies that employees are more likely to engage within tightly bound subgroups rather than forming connections across functional boundaries. As remote work eliminates the incidental interactions that often occur in shared physical environments, the reliance on scheduled and task oriented communication deepens existing silos.

The absence of unstructured, spontaneous conversations has been especially detrimental to bridging roles, which are essential for inter group knowledge exchange. Consequently, teams may experience reduced agility in problem solving and a diminished capacity for innovation due to a narrower flow of ideas. These findings indicate the urgency for organizations to design and implement comprehensive strategies that counterbalance network fragmentation by reintroducing mechanisms that facilitate cross functional visibility and engagement.

Organizational Policies to Reduce Fragmentation

One of the most effective avenues for addressing fragmentation is through targeted organizational policies. Structures that promote regular, intentional cross functional collaboration such as recurring interdepartmental meetings, project rotations, and shared goals can effectively reduce communication barriers and enhance relational diversity (Röth & Doehne, 2023). These practices promote shared mental models and a better understanding of organizational interdependencies, which are critical for unified strategic execution.

In parallel, deploying collaborative digital platforms that enhance visibility and interaction, such as shared workspaces and transparent project boards, can stimulate informal yet purposeful engagement (Pino-Yancovic et al., 2022). Such tools also reduce the friction associated with locating relevant expertise or resources across teams. Moreover, mentorship programs can serve as important instruments for bridging relational gaps. By pairing seasoned employees with less connected colleagues, these programs help embed new or isolated individuals within the wider network, creating pipelines for cross pollination of ideas and organizational knowledge (Amelkin et al., 2018).

Furthermore, organizations should assess the structural balance of their teams using SNA metrics to guide the timing and design of interventions. A data informed approach allows leaders to pinpoint areas of isolation and proactively invest in connection building initiatives.

Async First Strategies and Network Resilience

Async first strategies are increasingly recognized as effective solutions for enhancing resilience in digital first teams. Prioritizing asynchronous communication where individuals contribute based on their availability can alleviate the cognitive and logistical strain caused by back to back synchronous meetings. It also offers a more inclusive communication model for global teams working across diverse time zones and personal circumstances (Archibald et al., 2023; Kerrigan et al., 2021).

By decoupling communication from rigid scheduling, async first cultures encourage more deliberate, reflective exchanges. Team members are often better able to process information and provide substantive input, which can elevate the quality of collaborative outputs. Moreover, such a structure grants individuals greater autonomy, supporting employee well being and job satisfaction. This approach not only strengthens intra team cohesion but also enables organizations

to adapt more readily to dynamic work conditions by reducing dependence on real time coordination.

Limitations of Social Network Analysis

While Social Network Analysis provides valuable insights into the architecture of organizational relationships, it has several methodological and interpretive limitations. Foremost among these is the reliance on quantitative proxies for interaction, such as message frequency or co attendance in meetings, which do not capture the quality, sentiment, or contextual nuance of communication (Jesuthasan et al., 2021).

These quantitative indicators may misrepresent the strength or effectiveness of relationships, particularly in cases where frequent communication may be transactional or conflict driven rather than collaborative. Additionally, informal communication which plays a critical role in team cohesion and knowledge transfer is often excluded from system logs. As such, SNA may fail to account for the social capital and cultural elements that significantly influence organizational outcomes (Hofman et al., 2016).

To address these shortcomings, SNA should be complemented by qualitative methods such as interviews, surveys, and ethnographic observations. This mixed methods approach enables researchers and decision makers to gain a more nuanced understanding of network dynamics, ensuring that data driven interventions are contextually grounded.

Digital Fluency and Structural Cohesion

Digital fluency has emerged as a pivotal factor in shaping the connectivity and inclusivity of remote collaboration networks. Employees with high digital fluency are more adept at navigating various communication platforms, managing digital workloads, and sustaining engagement across dispersed teams (Yousefi-Nooraie et al., 2023). Their ability to leverage tools such as collaborative documents, asynchronous channels, and project management dashboards not only improves individual efficiency but also enhances the overall fluidity of the organizational network.

Conversely, individuals who struggle with digital platforms may face barriers to participation, leading to disengagement and peripheral network positioning. This technological gap can exacerbate inequities within teams, particularly when performance expectations are contingent on effective virtual collaboration (Khodabocus & Seyıs, 2023). To mitigate these risks, organizations should prioritize digital upskilling through comprehensive training initiatives that address both technical proficiency and digital etiquette.

Embedding digital fluency as a core competency within workforce development programs can yield long term structural benefits. As employees become more confident and capable in using digital tools, they are more likely to initiate and maintain cross boundary collaborations, contributing to a more cohesive and adaptive organizational structure (Kotera et al., 2022).

CONCLUSION

This study offers empirical insights into how remote work reshapes organizational communication structures, using Social Network Analysis (SNA) across real-world platforms such as Microsoft 365, Slack, and GitHub. The findings reveal a consistent pattern: remote environments foster

higher modularity, reduced cross-functional interaction, and a decline in brokerage roles conditions that collectively contribute to network fragmentation. These changes have profound implications for collaboration, innovation, and organizational agility in digital work settings.

Beyond diagnostic observations, this research advances a practical framework for designing more resilient digital collaboration networks. By operationalizing metrics such as modularity, betweenness centrality, and tie churn, the study enables organizations to assess and address structural vulnerabilities. Interventions including async-first communication models, structured cross-team engagement, and digital upskilling can mitigate isolation and strengthen cohesion. Future studies should explore long-term adaptations and combine quantitative SNA with qualitative methods to capture the full complexity of remote collaboration dynamics.

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