Temporal Distance, Communication Patterns, and Task Performance in Teams

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ABSTRACT: Drawing on theories on dispersed teamwork, computer-mediated communications, and organizations, we examine the direct associations between temporal distance and team performance as well as the mediating role of team interaction. We tested our research model in a laboratory experiment with four temporal distance conditions. Results show that the direct associations between temporal distance and team performance are substantially diminished when we enter the intervening team communication variables (communication frequency and turn-taking) into the analysis model. We find that communication frequency and turn-taking have differentiated effects on conveyance of information and convergence on its meaning. Conveyance is positively associated with production speed, whereas convergence is positively associated with higher product quality (i.e., accuracy). These findings speak to the theoretical significance of communication patterns and information exchange behaviors in dispersed team research. They also transcend the common wisdom that temporal distance is good for speed and bad for quality.

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Technology keeps making our work time more malleable (e.g., [74, 75]). But when workers collaborate across time zones the temporal distance between them becomes a key factor affecting how they interact and perform, presenting challenges that are not so easily bridged with technology. Temporal distance refers to the work schedule difference between two people, due primarily but not exclusively to their time-zone separation [70].[1] On one hand, temporal distance reduces the time window that team members have to interact synchronously, leading one to expect a negative effect on team performance. On the other hand, temporal distance offers the opportunity to work without interruption and around the clock in a "follow-the-sun" fashion, which helps in attaining calendar efficiencies and can reduce task completion time [11]. Our literature review,[2] summarized in Table 1 reveals that these equally plausible yet seemingly contradictory perspectives have not been formally modeled and tested to date. Our study attempts to fill this knowledge gap.

Prior dispersed team research has taken either a nominal or a simplified view of temporal distance. In the nominal view, temporal distance is mentioned in the research background but omitted from the research model (e.g., [1, 16]). This view acknowledges the relevance of temporal distance in dispersed teamwork, but it does not inform how temporal distance affects team process and performance. In the simplified view, temporal distance is represented with simplistic measures, such as a binary value depending on whether a temporal boundary exists or not [18, 92]. This approach has provided some evidence on the impact of temporal distance on team performance [18, 92], but it has helped us to gain only a partial understanding of how various gradations of temporal distance influence team process and performance. For example, how team members interact may be a key factor affecting how well they work together across temporal distance, but this perspective has not been investigated in the research literature.

Motivated by this knowledge gap, the present study seeks to untangle the composite relation between temporal and spatial distance and dispersed teamwork. Prior research has established that member interaction is an important component of geographically distributed collaboration [26]. Therefore, to develop deeper insights into how temporal distance affects performance, we refer to the principle of interactivity [8, 9] as a key aspect of our study framework. Burgoon and colleagues reduced the seemingly complicated human communication processes and outcomes into a simple principle of interactivity positing that "human communication processes and outcomes vary systematically with the degree of interactivity that is afforded and/or experienced" [9, p. 659] in the exchange of interdependent messages in a human communication process [80]. The principle of interactivity suggests two causal paths between temporal distance and team performance: (1) structural factors (e.g., temporal distance) may exert some direct effect on task performance; and (2)

Table 1. Global Team Boundary Literature Review Summary

Global Team Boundary Literature Review Summary			
Study	Boundary	Theoretical argument	Empirical finding
DeSanctis and Gallupe (1987) [27]	• Spatial	Group decision support systems design can vary as a function of group task, physical proximity of group members, and group size.	NA
Fritz, Narasimhan, and Hyeun-Suk (1998) [35]	• Spatial	Effects of job characteristics, information technology uses, and coordination methods on individual satisfaction with office communication vary between telecommuters and nontelecommuters.	Telecommuters report higher satisfaction with office communication than nontelecommuters. Job characteristics, information technology uses, and coordination methods have similar effects on telecommuters and nontelecommuters.
Van den Bulte and Moenaert (1998) [99]	• Spatial	Reducing the physical distance among collaborators results in more frequent communication, and hence higher product development performance	Communication among R&D teams was enhanced with co-location, but not between R&D and marketing, suggesting that the effect of co-location depends on the content and medium of the communication flows.
Jarvenpaa and Leidner (1999) [46]	• Spatial • Cultural	Trust is important in a global virtual team. Interpersonal relationships, cross-cultural communications, and organizational role systems are possible foundations of trust in virtual teams.	Trust in global virtual teams takes the form of swift, depersonalized, action-based trust. It is more likely to be created at the beginning stage of a virtual team.
Majchrzak et al. (2000) [57]	• Spatial • Disciplinary • Organizational	A collaborative technology and virtual team members mutually adapt to each other during work processes.	Misalignments among the organizational environment, team, and technology structures triggered sporadic mutual adaptations between team members and technology.

(continues)

Table 1. Continued

Global Team Boundary Literature Review Summary

Study	Boundary	Theoretical argument	Empirical finding
Maznevski and Chudoba (2000) [62]	• Spatial • Cultural • Organizational	Adaptive structuration theory provides strong guidance for examining technology and group dynamics across space and over time.	Global virtual team interactions comprise a series of communication incidents. A fit among a communication incident's form, task characteristics, and decision process is conductive to effective outcomes.
Cramton (2001) [16]	• Spatial	Spatial distance impairs the establishment of mutual knowledge among dispersed team members. Less mutual knowledge leads to lower team performance.	Geographically dispersed teams experienced problems caused by a lack of mutual knowledge. These problems were exacerbated by task interdependencies.
Kiesler and Cummings (2002) [50]	• Spatial	Close proximity is beneficial to relationships and group interaction.	NA. The authors propose that communication technology helps bridge geographic distance when groups are cohesive or with structured management.
Watson-Manheim, Chudoba, and Crowston (2002) [103]	• All boundaries in general	Global boundaries create discontinuities, which need to be bridged to collaborate, creating coordination costs.	NA, but theoretical claims are based on a study of seventy-five published articles on virtual teams.
Espinosa et al. (2003) [30]	• Spatial • Functional • Temporal • Identity • Organizational	There are multiple boundaries in global teams. Their effects on team process and performance may commingle.	Effects of team boundaries can be nonlinear and can change over time. They require methods that can effectively measure and control the effect of specific boundaries.

Hinds and Bailey (2003) [44]	• Spatial	Spatial distance and technology mediation lead to task, affective, and process conflicts, which in turn affects dispersed team performance.	NA
Massey, Montoya-Weiss, and Hung (2003) [61]	• Spatial • Temporal	Temporal coordination can benefit dispersed team performance by influencing team interaction patterns.	Temporal coordination behaviors influence teamwork process and interactions, which in turn shape team's performance.
Griffith, Sawyer, and Neale (2003) [39]	• Spatial	The authors develop the concept of "virtualness" based on three orthogonal factors: physical distance; percentage of time apart on task; and level of technology support. They propose that more virtualness hinders the formation of collective knowledge.	NA
Herbsleb and Mockus (2003) [42]	• Spatial	Geographical distance introduces delay in software teams.	Software tasks take considerably longer across sites compared to within site, but this was due primarily to the fact that cross-site teams are generally larger than co-located teams.
Cummings (2004) [17]	• Spatial • Functional • Organizational	Spatial, functional, and organizational diversities may increase members' knowledge sharing, which in turn has a strong positive impact on performance.	The positive impact of knowledge sharing on performance is stronger in teams with higher levels of structural diversity.
Fiol and O'Connor (2005) [33]	• Spatial	Spatial distance may reduce the salience of the entire team as a target for identification.	NA
Hinds and Mortensen (2005) [43]	• Spatial	Shared identity, shared context, and spontaneous communication moderate the effect of geographic dispersion on interpersonal and task conflicts.	Shared identity and shared context mitigate the negative effect of dispersion on conflicts. Spontaneous communication increases shared identity and shared context, and aids conflict resolution.

(continues)

Table 1. Continued

Global Team Boundary Literature Review Summary

Study	Boundary	Theoretical argument	Empirical finding
Metiu (2006) [64]	• Spatial • Temporal • Status	Geographic dispersion (spatial and temporal distance) and status distance reinforce each other's impact on dispersed team process and performance.	High-status members leveraged spatial and temporal distance in their informal closure strategies to reinforce status distance.
Boh et al. (2007) [7]	• Spatial	Knowledge distribution in dispersed teams is shaped by project requirements. A good match between the two increases performance.	Local or remote project requirements were significantly associated with staffing of local or remote professionals in a dispersed team. A good match between the two produced positive impact only in certain conditions.
Espinosa et al. (2007) [31]	• Spatial	Task and team familiarity helps team members to cope with project complexity. This effect is stronger in dispersed teams.	Task and team familiarity positively affected team performance. This effect was found to be stronger in dispersed teams.
Espinosa et al. (2007) [32]	• Spatial	Shared knowledge of the task, shared knowledge of the team, task awareness, and presence awareness are important team-coordination mechanisms.	Spatial distance has a negative effect on coordination in dispersed teams, but is mitigated by shared knowledge in the team and presence awareness.
Kanawattanachai and Yoo (2007) [48]	• Spatial	Transactive memory systems (TMS) in virtual teams are associated with three behavioral dimensions–expertise location, task–knowledge coordination, and cognition-based trust. Their impacts on team performance change over time.	Early task-oriented communications were critical for establishing TMS. Task–knowledge coordination became an important determinant of team performance once TMS was highly developed. The three dimensions of TMS evolved along different paths.

O'Leary and Cummings (2007) [70]	• Spatial • Temporal • Configurational	Spatial, temporal, and configurational distances are the three key dimensions of dispersion. They require different measures.	NA
Dabbish and Kraut (2008) [19]	• Spatial	Awareness display with information about a remote member's workload helps to coordinate communications and thereby improves task performance.	When members had shared rewards and common identity, awareness display with workload information benefited team performance by reducing disruptive interruptions.
Vlaar, van Fenema, and Tiwari (2008) [101]	• Spatial	Congruent and actionable understandings are essential for success of offshore system development teams.	Knowledge distributions and task characteristics affect dispersed members' sense-giving, sense-making, sense-demanding, and sense-breaking acts. These acts create shared understandings in dispersed teams.
Cummings, Espinsoa, and Pickering (2009) [18]	• Spatial • Temporal	Spatial and temporal boundaries increase coordination delays in dispersed teams. Their effects can be moderated by synchronous or asynchronous communications.	Both synchronous and asynchronous communications reduce coordination delay for members working across spatial distance with overlapping work hours.
Robert, Dennis, and Hung (2009) [82]	• Spatial	Swift trust and knowledge-based trust are important for trust intention in dispersed teams. Technology mediation decreases trust intention.	Team members would rely more on swift trust initially and then on knowledge-based trust in forming their trust intention. Technology mediation decreased trust intention.
Alnuaimi, Robert, and Maruping (2010) [2]	• Spatial	Spatial distance affects social loafing via its effects on diffusion of responsibility, dehumanization, and attribution of blame.	Spatial distance increased diffusion of responsibility and dehumanization and thereby reduced contribution of dispersed team members.

(continues)

Table 1. Continued

Global Team Boundary Literature Review Summary

Study	Boundary	Theoretical argument	Empirical finding
Carmel, Espinsoa, and Dubinsky (2010) [12]	• Spatial • Temporal	The primary factors in making "follow-the-sun" projects successful are efficiency in terms of scheduling and handing off work, and coordination within and between the worksites.	NA
O'Leary and Mortensen (2010) [71]	• Configurational	Geographic subgroups, imbalance, and isolates in a dispersed team trigger social categorization. This in turn influences member identification, transactive memory, conflict, and coordination.	Subgroups and imbalance had negative impacts on identification, transactive memory, conflict, and coordination. Teams with isolates avoided these negative impacts.
Ananth, Nazareth, and Ramamurthy (2011) [3]	• Spatial	Use of mental models can assist knowledge capture in virtual teams by creating a shared understanding among dispersed experts.	Compared with Delphi, RepGrid is a more effective mental model for reducing disagreement and capturing comprehensive sets of knowledge.
Sarker et al. (2011) [84]	• Spatial	Central positions in a trust network and a communication network are important to member performance in dispersed teams.	Trust centrality mediated the relationship between communication centrality and performance.

Suh et. al (2011) [92]	• Spatial • Temporal • Configurational	Personalized and communal computer-mediated communication (CMC) increase intragroup strength, but this effect diminishes with spatial and temporal dispersion.	Personalized CMC did not increase group strength but communal CMC did. Contrary to predictions, personalized CMC effect on group strength increased with spatial dispersion and the effect of communal CMC did not change with spatial dispersion, and temporal dispersion did not moderate either effect.
Wang and Haggerty (2011) [102]	• Spatial	An individual's virtual work and daily life experience enhances his/her virtual competence, which in turn improves virtual work performance and satisfaction.	Experiences with virtual work and daily life were antecedents of individual virtual competence. Individual virtual competence had a positive effect on work outcomes.
Daniel, Agarwal, and Stewart (2013) [21]	• Spatial • Configurational	Diversity in terms of contribution, role, and cultural differences in online open source software development teams influences project success.	Diversity has significant impacts on open source community engagement and marginal effects on open source software market success. Impacts of diversity on project success are moderated by project development stage.
Wilson, Crisp, and Mortensen (2013) [105]	• Spatial • Temporal	Objective forms (spatial or temporal) of distance in a virtual team lead to psychological distances, which in turn increase the likelihood of individuals to attribute distant collaborators' actions to abstract construal-level traits such as personality type.	NA
Bartelt and Dennis (2014) [4]	• Spatial	Nature of the task situation (habitual vs. discrepant event) affects genre rules in communication channels, which in turn influence team decision processes and outcomes.	Distinct genre rules surface in different communication channels (instant messaging and discussion forum) during habitual task situation, but genre rule differences diminish after a discrepant event.

these factors may influence the dynamic qualities of the interaction process itself (i.e., how information is exchanged and interpreted), which can also affect performance outcomes [8, 9]. We argue that understanding how temporal distance influences team interaction and how this interaction affects performance can go long ways in explaining how the association between temporal distance and performance actually happens. The investigation of these two paths in a single study can help us to understand not only whether there is an association between temporal distance and team performance, but also how, leading us to pursue two research questions in this study:

1. What is the association between temporal distance and team performance? and
2. How does temporal distance influence team performance through team communication pattern and information exchange behaviors?

We anticipate that temporal distance is associated with higher task completion speed and lower task product quality. But we also posit that the interaction patterns among collaborators and how task messages are exchanged [80] can help provide a more nuanced explanation of how temporal distance influences task performance. Finally, because the effect of temporal distance on dispersed teamwork can be especially sensitive to the nature of tasks, we run our experiments under three different task conditions—simple, complex, and equivocal. Dennis and colleagues recognized the importance of task in technology-mediated communications by conceptualizing task as "the set of communication processes needed to generate shared understanding" [25]. Our study contributes to the research literature by uncovering these theoretical relationships that explain the direct and indirect effects of temporal distance.

Theoretical Foundations

We conducted an extensive literature review to develop the theoretical foundations for the study (see Table 1). The research literature on dispersed and global teams is quite extensive, so we extracted the theoretical arguments most applicable to our specific theoretical development and hypotheses. In contrast, the literature that focuses specifically on temporal separation is very sparse, so we used most of the studies we found. To develop broad theoretical foundations on temporal distance, we complemented the dispersed teamwork literature (e.g., [16, 44]) with two other bodies of theory: computer-mediated communications research (e.g., [10, 36]), and organizational studies regarding temporal structures and communication practices (e.g., [74, 75]). We unified these theoretical underpinnings in our research framework based on the principle of interactivity [8, 9].

The most common theme in the dispersed teamwork literature relates to understanding the unique challenges faced by dispersed teams compared to traditional collocated teams. To date, researchers have examined a variety of challenges such as: conflict (e.g., [43, 44]); the common knowledge problem [16]; trust [46, 84];

social relationship strength and range [92]; coordination delay [18]; and technology-mediated communication [44, 92]. These streams of research provide convincing theoretical arguments suggesting that incidences of team interaction are the basic elements that manifest these challenges and produce team performance outcomes [62]. Some have even argued that the task itself can be conceptualized as the set of communication processes and team interaction aimed at generating shared understanding among the task doers [25]. For example, by operationalizing an interaction incident as a message exchanged, researchers have identified several salient trust-development patterns and trust-facilitating communication behaviors in dispersed teams [46]. We posit that the ongoing sequence of such interaction incidents is the essence of collaborative work and that understanding how temporal distance influences such interaction patterns and communication processes, and how this affects performance in turn, are key to learning how information technology can support temporally separated collaboration.

Computer-mediated communications (CMC) research also recognizes that human interaction can modify the predicted effects of communication modes [36, 55, 57] and media choices [97]. As pointed out by Zack, "although social presence and social cues may be attenuated to some degree in mediated channels, it is the *interactivity* effects, not the socio-relational effects, that are the primary richness constraints of CMC in ongoing groups" [109, p. 233]. Simply stated by Burgoon and colleagues [8, 9], the principle of interactivity posits that processes and outcomes in human communication vary systematically depending on how interactive the communication experience is. They further explained that such experience is affected by communication properties, including: participation—active interaction versus monologues; synchronicity—same time with bidirectional feedback versus asynchronous allowing rehearsal and editing; among others. In the context of our study, this principle suggests that as temporal distance varies, the interaction becomes more or less synchronous and more or less active and bidirectional, which in turn influences the types of communication processes used and the resulting outcomes.

Accordingly, researchers are required to decompose experiential interactivity into its constituent components in order to specify how structural factors produce variations in team processes and outcomes [8, 9]. Prior research has identified some primary components of team interaction, including: communication form, such as communication frequency (e.g., [47]) and turn-taking patterns (e.g., [109]); and communication content embodied by information exchange behaviors (e.g., [63]). These communication patterns and content provide a more precise lens for us to examine technology-mediated team interaction in dispersed teams. For example, a meta-analysis of teamwork studies reveals that the relationship between virtualness in teamwork and performance is mediated by information exchange behaviors in terms of sharing unique information and sharing information broadly among team members (e.g., [63]).

Organizational studies have identified the intrinsic relationship between temporal constraints and team interaction. Although few studies have explicitly examined the impact of temporal distance on organizational communications, organizational researchers have recognized temporal constraints such as schedules and deadlines as important structural factors in an organization's work system. For example, Harrison [40] found that the sequence of time limits (e.g., five, ten, and fifteenminutes vs. ten, ten, and ten minutes) had a significant effect on team task performance speed and this effect was robust against task interruptions. Similarly, whether deadline times are prototypical (e.g., 4:00 p.m.) or atypical (e.g., 4:07 p.m.) can affect team members' time management and task performance [52]. These and other related studies [45, 76] have provided evidence of the effect of temporal constraints on the rhythm and form of human interaction and its subsequent impact on work performance. Furthermore, previous research emphasizes that temporal structures not only constitute human actions and interactions but also are constituted by them [74]. Teams can mitigate and even take advantage of their temporal constraints by deliberately managing their interaction patterns in order to achieve ideal task performance [61, 62].

These studies suggest the value of decomposing such interaction into communication pattern and content, which allows us to more precisely explain how team performance outcomes occur. In contrast to temporal constraints examined in previous research (e.g., the sequence of time limits, task starting/ending times, and individual perception of time), the concept of temporal distance is unique in two ways. First, temporal distance is a scalar variable. Therefore, an examination of temporal distance not only can address whether temporal constraints influence teamwork but also can yield a more nuanced understanding of how team interaction, embodied by members' communication pattern and content, may vary with different gradations of temporal distance. Second, unlike project schedules and deadlines that are endogenous to team management, temporal distance in dispersed teams is typically caused by external constraints, such as time zone differences [29]. An understanding of how team interaction may reduce or leverage this seemingly rigid external constraint helps deepen our theorization of challenges and opportunities in computer-supported dispersed teamwork.

The principle of interactivity posits that structural factors (e.g., temporal distance) may have direct effects on task performance as well as influence the interaction process itself, which can further impact performance outcomes [8, 9]. Consistent with this principle, our theoretical model encompasses two paths corresponding to each of our research questions—a direct path between temporal distance and team performance, and a mediated path including components of team interaction, such as communication pattern (i.e., frequency and turn-taking) and information processing (i.e., information transmission and interpretation). Consequently, we take a two-step approach in our theoretical development about the impact of temporal distance on team performance, corresponding to each of the paths. In the first step, we address the first research question and formulate Hypotheses 1 and 2 regarding the direct associations between temporal distance and team performance. In the second step, we address the second research question and formulate the remaining hypotheses about the intervening team interaction processes, focusing on communication pattern and content, and how their various characteristics affect performance outcomes. This two-step approach allows us to examine first whether there is an association between temporal distance and performance, and then explain how this effect occurs.

Study Hypotheses

Step1: Temporal Distance and Team Performance

Based on observations of software development projects, prior research has identified two important aspects of task performance: process and product performance [15, 69, 106]. Task completion speed is a key process performance variable used in prior research [15, 23, 69, 106]. Task product quality is a key product performance variable, capturing the extent to which the task deliverable actually meets its requirements [15] and to what extent [22, 23]. When working under schedule or budget pressure, teams may choose to achieve one aspect of team performance at the expense of the other [34, 94]. By examining both aspects of performance, we can take into account the trade-offs between them (e.g., speed vs. quality) to gain a more complete view of team performance outcomes.

Traditional engineering management research suggests that batching changes helps to reduce communication time and accelerate work progress [54].[3] Because temporal distance allows dispersed team members more individual work time to batch their task requirements, it can produce a positive effect on task completion speed. Moreover, a recent study about "follow-the-sun" (i.e., the work is handed over from one time zone at the end of the workday to another in which the workday is beginning) in software development found that working across large temporal distances can help teams to achieve calendar efficiencies because one site can advance the work while members in the other site are sleeping, thus reducing development time [12]. The same study found that the need to hand over the work to another site at a given time of the day creates a "time boxing" effect and a time structure that forces members to pace themselves and be more productive, as predicted by social entrainment theory [40]. Furthermore, temporal distance leads team members to communicate more asynchronously and, as suggested by media synchronicity theory [25], asynchronous communication helps teams to exchange information more efficiently due to reduced interruptions. Therefore, we posit:

> ***Hypothesis 1:*** *Temporal distance is positively associated with task completion speed.*

Teams may be able to work faster with more temporal separation, but this can come at the expense of task product quality. Engineering management research suggests that concurrent communication, as it happens in team meetings can reduce rework because information is exchanged in a more timely way [54]. Greater temporal distance can compromise task product quality because it reduces the opportunity for concurrent communication, which is essential for prompt clarification on inquiries regarding task requirements [41]. In addition, organizational researchers find that team members connected by strong ties tend to create higher quality products because their familiarity with one another enhances coordination and information sharing [40]. But temporal distance increases the difficulty of developing such strong ties [92], and can therefore have adverse effects on quality. Furthermore, individuals tend to focus on task speed or quality according to their strategic inclinations [34]. The difficulty in informing and discussing quality issues coupled with schedule or budget pressures may even drive a team to deliberately compromise quality in order to complete the task quickly. Therefore, we posit:

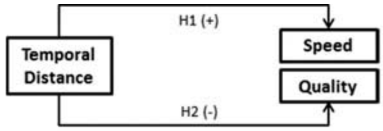
> ***Hypothesis 2:*** *Temporal distance is negatively associated with task product quality.*

Step 2: The Path from Temporal Distance to Performance: Team Interaction

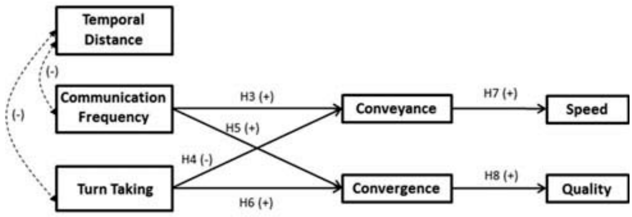
In this section we open up the "black box" (i.e., we inspect the intervening process variables that affect this relationship) between temporal distance and team performance to investigate the role of team interaction processes based on the concept of interactivity [80]. Burgoon and colleagues [9] extended this concept to the CMC context by incorporating structural factors (e.g., spatial proximity, temporal distance) and the dynamic qualities by which communication is experienced as interactive (e.g., communication pattern and information exchange behaviors). Consistent with the principle of interactivity [8, 9], our premise is that temporal distance influences team interaction, which is embodied by their constituent components—team communication pattern and content. Team communication pattern and content in turn affect team performance. As illustrated in Figure 1, our "open box" (i.e., incorporating the intervening process variables) research model includes a path from communication pattern (specified as communication frequency and turn-taking) to communication content (specified as information conveyance and convergence), and eventually to task completion speed and product quality. It is important to note that we posit that temporal distance will be strongly associated with communication patterns (i.e., more temporal distance will be associated with more asynchronous communication and vice versa). Because this association is so naturally obvious, we do not formulate a hypothesis about it, but we do test this association and also control for the effect of temporal distance when testing the paths in the "open box" research model.

Team Communication Pattern and Content

The principle of interactivity suggests that decomposing team interaction into its constituent components allows us to more precisely describe how a structural factor such as temporal distance produces variations in team performance outcomes. In dispersed teams, communication among team members has been recognized as the only visible artifact of the team's existence [1]. Given the centrality of communication



a) Black Box Model



b) Open Box Model

Figure 1. Research Model

in dispersed teams and following previous research (e.g., [47, 63, 109]), we break down team interaction into communication pattern and communication content. O'Reilly and Pondy define communication as the exchange of information between a sender and a receiver and the inference of meaning between them [72]. Based on this definition, communication pattern captures the intensity and timing of information exchange between team members. It is operationalized as *communication frequency* and *turn-taking* because these two constructs are especially suited to capture the impact of temporal distance on team interaction.

The second constituent component of team interaction—communication content—refers to information exchange behaviors [63]. O'Reilly and Pondy's [72] definition of communication indicates that there are two primary types of information exchange: *conveyance,* which refers to the transmission of information; and *convergence*, which is the extraction of meaning from the information transmitted by the various individuals involved [25, 66, 86]. These information exchange behaviors have been recognized as critical for working teams, including geographically dispersed teams [84]. Previous research implies that conveyance and convergence may exhibit distinct patterns across different degrees of temporal distance because they are subject to the influence of communication frequency and turn-taking patterns. The next four hypotheses are about the effects of communication pattern—that is, communication frequency and turn-taking, on communication content—that is, conveyance and convergence.

Communication frequency is a widely used indicator of communication pattern [47, 78, 87]. It is the number of communication instances that occur in a channel. Turn-taking provides a more precise view of the interactivity of communication because it captures the timing of exchanges; that is, the extent to which members take turns when communicating provides an indication of whether they are engaged in concurrent communications or a few communication bursts [80, 83, 109]. As temporal distance increases, the overlapping window for synchronous interaction among team members narrows. This in turn constrains team members' choices of how and when to communicate. When the work time between two team members overlap, these members have a choice of either batching information into a few communication bursts or engaging in many concurrent communications by taking turns between each other. In contrast, during nonoverlapping periods the choices are either to batch and transmit information, which will only be received in the next overlap period, or to wait to communicate concurrently during the next work-time overlap window. This variation in team communication patterns distinguishes the effects of pure spatial distance from temporal distance, which as we mentioned, are often confounded in research [18, 30].

More frequent communication allows team members to transmit more information. This also allows members to notice discrepancies in the information transmitted [16]. Moreover, more regular and spontaneous communication facilitates information sharing between remote members, thus providing a more continuous information flow (e.g., [43, 46]). In contrast, frequent turn-taking between senders and receivers reduces the time that team members have to work alone to carefully compose and process messages that have information embedded in them. In other words, turn-takings can prevent "closure" (i.e., the completion of a communication transmission segment) in communication [91]. This can result in intermittent transmission of information or the exchange of partial information. Thus, we posit:

> ***Hypothesis 3:*** *Controlling for temporal distance, communication frequency has a positive effect on conveyance communication.*

> ***Hypothesis 4:*** *Controlling for temporal distance, turn-taking in communication has a negative effect on conveyance communication.*

Researchers generally agree that inference of meaning (i.e., convergence) is a social construction process—that is, it requires subjective and social interpretation (e.g., [66, 79, 86]). In order to construct meaning, team members are required to share their individual interpretations, discuss discrepancies among their interpretations, clarify misunderstandings, and reach agreements on their interpretations. Media synchronicity theory [25] posits that convergence is enhanced through social interaction that facilitates things such as immediate feedback, personalization, and social presence that occur with frequent information exchanges by the communicating parties. Frequent communication provides opportunities for team members to perform these actions and thereby collectively construct a rich interpretation of task requirements. However, frequent communication is not likely to foster convergence if it is one sided. Media synchronicity theory argues that working together synchronously (i.e., at the same time) enables members to develop a shared pattern of coordinated behavior, which fosters convergence. Interactivity enhances communication quality [56] and it is necessary for convergence [96]. Turn-taking enhances such synchronicity, allowing immediate feedback to each other's messages, which is beneficial for sense making and sense giving, which are required for team members to reach agreement on interpretations of information. Frequent communication and turn-taking together also help members to achieve closure in their information exchange because they can attend to the information soon after it is exchanged [66, 91]. Such frequent contact and rapid feedback cycles are also beneficial to establishing mutual knowledge among team members [16]. Therefore, we posit:

Hypothesis 5: *Controlling for temporal distance, communication frequency has a positive effect on convergence communication.*

Hypothesis 6: *Controlling for temporal distance, turn-taking in communication has a positive effect on convergence communication.*

Team Communication Content and Team Performance

It is known that effective information sharing is beneficial for temporally separated team performance [18], but which specific type of information sharing benefits a particular aspect of task performance has not been resolved. Specifically, we posit that conveyance is particularly beneficial to task completion speed whereas convergence is particularly effective in driving task product quality. The completion speed of a collaborative task is contingent on the rapid exchange of task information, which is achieved primarily through conveyance [25]. More task information exchange leads to more familiarity with the task, which research has found to improve task completion speed [31, 53]. Such increased conveyance of information will result in more information available to the receiver, which can then be used to complete the task more expeditiously, although not necessarily more accurately. Thus, we posit:

Hypothesis 7: *Higher levels of conveyance communication are associated with higher task completion speed.*

Information quality is a key variable influencing the net benefits that can be derived from information systems [23, 77]. Meeting product requirements and delivering products without errors are tasks that require team members to discover and repair communication errors, clarify unclear issues, review the final work together, and provide an adequate amount of feedback, among other things. Often the information conveyed will be unclear and team members will need to engage in convergence communication for shared meaning to develop among them [25]. Without such convergence on meaning, the task is likely to be completed based on incorrect interpretations of product requirements. Correct interpretation of requirements will come from the collective interpretation of various team members and not from the single interpretation by one member of the information conveyed by another member [66]. This shared understanding required for the correct execution of the task comes from coconstruction of meaning between team members [25, 66]. In other words, team members need to converge on the interpretation of the information exchanged and develop some assurance that such agreement has been reached. Thus, we posit:

> ***Hypothesis 8:*** *Higher levels of convergence communication are associated with higher task product quality.*

Task Type

We do not offer specific hypotheses about the effects of task type because our study is focused specifically on temporal distance and communication processes. However, team performance results can vary by task type and, therefore, we control for and test the effects of task type. Prior research shows that team members' information exchange behaviors are driven by information exchange needs of tasks [20]. A collaborative task is tightly associated with the communication processes necessary to transmit relevant information and generate shared understanding from it to carry out the task [25]. A task characteristic that increases the need to communicate and interact frequently will make the task more susceptible to temporal distance, leading team members to make adjustments to their interaction patterns. For example, team members working on a simple task may simply "store-and-forward" information through the communication technology [10] and be able to share knowledge effectively across temporal distance. Conversely, a more equivocal [24] or complex task [107] may require more real-time interaction to discuss the task and exchange information cues.

Methods

Teasing out the effect of temporal distance on dispersed teams is difficult because temporal distance usually co-occurs with other global team variables like spatial distance and cultural differences. This methodological difficulty might have hindered previous efforts aimed at untangling the impact of temporal distance. We employ a method that has long been valued for its strength in controlling for confounding effects to tease out the investigated focal effects—a laboratory experiment [104]. Because temporal distance is inherently a mathematical measure, a lab study allows us to explore the effect of various gradations of temporal distance across different experimental conditions while holding the communication technology and spatial distance constant. It also allows us to test a multiple-path theoretical model. Although realism is inevitably reduced in a lab experiment, the control gained outweighs the realism lost in substantiating the theoretical model.

Experimental Design

In this experiment we simulated short imaginary workdays in which dyadic teams worked on a task across four temporal distance conditions. We varied the temporal

Table 2. 3 × 4 Factorial Design, Between Subjects Participants

	Overlap Condition				
Task Type	0 Min (0%)	5 Min (33%)	10 Min (66%)	Full (100%)	Total
Simple	10	10	12	10	**42**
Complex	11	12	11	11	**45**
Equivocal	11	11	11	12	**45**
Total	**32**	**33**	**34**	**33**	**132**

distance conditions by manipulating the degree of work-time overlap (100 percent—full, 67 percent—partial, 33 percent—partial, and 0 percent—no overlap). In addition, we implemented three task conditions to control for the varied information exchange needs of teamwork. This resulted in a 4 (temporal distance conditions) × 3 (task types—i.e., simple, complex, and equivocal) between-subjects factorial design. Each dyadic team was randomly assigned to one of these temporal distance conditions and task types. A total of 132 dyadic teams (i.e., 264 participants) completed our experiments, with at least 10 teams in each experimental condition (see participant distribution by task and time zone condition in Table 2). Approximately 41 percent of the participants were male, 66.9 percent of the participants were college students, and nearly half of the participants, 49.7 percent, were twenty-one years old age or younger. There were no systematic differences in demographics across experimental conditions in our study. After a series of pilot sessions and adjustments to the task and the instructions, we arrived at the experiment's tasks, procedures, and measures as outlined below.

Experimental Tasks

We used a digital task building fictional maps, adapted from prior studies [100]. The fictional map task requires members of a dyadic team to reproduce a set of maps collaboratively using graphical components. This task mimics four important aspects of knowledge work in today's work environments: (1) the task is digital; (2) the team interaction is mediated technologically; (3) members have shared goals; and (4) team members are highly dependent on each other. We created three variations of the fictional map task—simple, complex, and equivocal—in order to control for the potential effect of varied information exchange needs on team interaction and performance. These task conditions also help to ensure the generalizability of our findings to various teamwork complexity and equivocality settings. It is important to note that, in order to make the results comparable across task types, the correct solution for each map was identical across all tasks. What we manipulated was the number of information elements provided to resolve the task and the experimental roles for each participant.

Simple Task

For the simple task one team member played the role of a map designer and the other played the role of a map maker. Each map designer was given a set of thirteen maps on paper, with each map comprising one background image, two additional graphic icons, and a path consisting of five connected arrows (see Figure 2). Each map maker received two sets of PowerPoint slides on a computer, one set containing thirteen blank slides and the other set including eight background images and twelve icons, which were the only elements they were allowed to use to reproduce the maps. That is, rather than drawing a map from scratch, map makers could identify the correct elements from the second set of slides and insert them into the blank slides at the correct location. This minimized the potential confounding effect of different drawing skills among the participants. Map designers were assigned the task of providing instructions to the map makers on how to replicate the maps, and map makers sought to reproduce the maps accordingly in the set of blank slides using the provided background images and icons.

Map designers had no knowledge of the background images and icons provided to the map makers, and map makers were not allowed to view the maps given to the map designers. However, map makers could share electronically a read-only version of the maps they produced to show their work to the map maker. To motivate the need for communication among team members we obscured the distinction between background images and icons in the paper maps given to the map designers. The eight backgrounds provided to map makers consisted of four pairs of similar images, further increasing the need to inquire and clarify map-drawing instructions. All interaction took place through an electronic chat tool with persistent capture, so that team members could use this communication tool either synchronously or asynchronously (see Figure 3). Of the thirteen maps, the first one was used for practice and training and the remaining twelve were were used for the actual task.

Complex Task

Task complexity is an antecedent to information systems success [77]. The complex task differs from the simple task in one aspect: the number of background images provided to map makers increased from eight to twenty and the number of icons

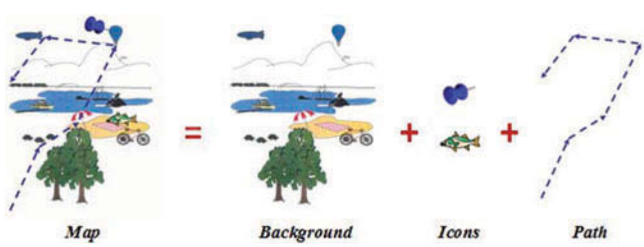


Figure 2. A Map Illustration

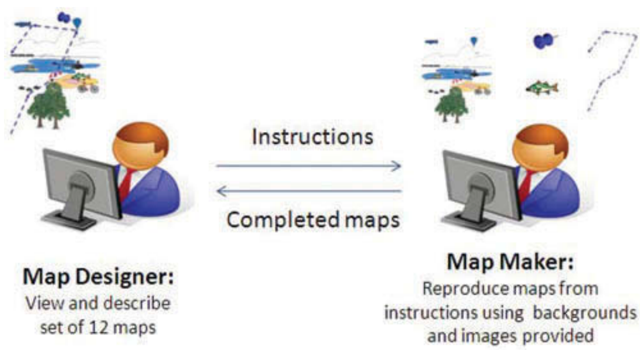


Figure 3. Experimental Task Illustration

from twelve to forty. Again, the final map solutions were identical to those of the simple task. The twenty background images comprised four sets of similar images. The twenty icons not only included several pairs of slightly different designs of the same objects (e.g., two fish images) but also consisted of a few slices of art from the background images (e.g., an eagle icon sliced from a background image including mountains and an eagle). Therefore, we added complexity to the task by increasing the number of information cues that members had to process to complete the maps [81, 107]. The path elements in the maps were unchanged.

Equivocal Task

For the equivocal task, both team members played the role of map designers. Each member received the same set of thirteen maps on paper and a PowerPoint file containing background images and icons to choose from. They worked collaboratively to provide map drawing instructions to a fictitious map maker. We retained the level of complexity used in the complex task by using the same number of backgrounds (twenty) and icons (forty) in the PowerPoint file, but we also made the task more equivocal by introducing a "hidden profile" [88, 89, 90] by providing each team member only twelve backgrounds—eight uniquely held by each member and four shared by both—and only twenty-four icons—sixteen uniquely held by each member and eight shared. In this way, no team member could produce correct map drawing instructions individually, but both members collectively had all the necessary information to produce precise drawing instructions. Team members had to communicate with each other to accurately describe each map and agree on joint descriptions of the maps. Such information exchange is necessary to resolve inconsistencies and conflicts in the knowledge acquisition process to reach consensus in geographically dispersed collaboration [13]. They were instructed to record this description in a Google Docs template that we provided. Because we used the same map solutions across the three task types, task performance could be measured on the same basis for all tasks and compared for hypothesis testing.

Experiment Procedures

Participants were recruited from two different university campuses by the coauthors. Participants were paid $20 each for completing an experiment and were incentivized with a performance bonus of $40 for each team member of the best-performing team (based on speed and accuracy) in each task and temporal distance condition. The study was conducted in sessions ranging from four to ten participants at a time (two to five dyadic teams). All participants in a given session were assigned to the same task and temporal distance condition. Before the beginning of an experimental session the participants received detailed experiment instructions and approximately forty-five minutes of training and practice. The experimenter also answered participants' questions during the practice, but once the actual experiment session started participants were no longer allowed to ask questions. Each experiment session consisted of one hour of task work, divided into four synthetic workdays of fifteen minutes each with short breaks (i.e., off work hours) between workdays. In the 100 percent (or full) work-time overlap (no temporal distance) condition team members worked synchronously and had five-minute breaks between workdays. In the 67 percent (partial, ten-minute) and 33 percent (partial, five-minute) overlap conditions, map designers started working first followed by map makers during the overlap period and then map makers worked alone for the remainder of the work day. In the 0 percent (or no) work-time overlap condition, an individual team member worked solo for a full synthetic day and then left just as the teammate "arrived" to work.

Participants did not know the identities of their teammates and were not allowed to communicate face to face, only through a custom electronic chat tool that was provided, eliminating confounds with spatial distance. The use of a single communication channel also helped us to rule out potential confounding effects of media richness or media synchronicity. During the overlap time, subjects could "chat" synchronously with their teammates anytime. On the other hand, during the non-overlap time, subjects could add instructions or comments through the chat window, but they had to wait until their partners "came to work" to receive a response, which is typical of asynchronous interaction with time-zone differences.

Data Collection and Study Variables

We collected three groups of data in all experiment conditions: objective task completion speed and product quality (i.e., accuracy); exit survey responses about perceptions of coordination and communication problems; and over 20,000 communication text entries from chat logs with time stamps. The factor loadings for the survey variables are shown in Table 3 and the descriptive statistics and correlation matrix for the study variables are presented in Table 4. We now describe how we constructed our study variables in more detail.

Table 3. Factor Analysis of Survey Items

Survey Item	Factor Loadings	
Miscommunication Problems (Cronbach Alpha = 0.869)		
Our communication with my teammate required frequent clarification	**0.586**	0.394
We often had to re do portions of the task over again due to misunderstandings	**0.527**	0.449
We had many problems due to confusion and misunderstanding (by me or my teammate) about our task requirements	**0.628**	0.508
We had many problems because my teammate or I didn't follow the procedures and rules we agreed to follow	**0.683**	0.262
We had to do a lot of re-work	**0.652**	0.450
We completed our tasks on a timely fashion	**0.797**	0.124
Our final products met requirements	**0.782**	0.128
Coordination Process Problems (Cronbach Alpha = 0.784)		
I was usually aware of the progress of my teammate's work	–0.284	–**0.639**
Typically it took a long time to get a response from my teammate	0.038	**0.673**
It was very difficult to resolve issues when they came up	0.349	**0.680**
I very often encountered problems that I could not solve right away with the information available	0.350	**0.647**
I was never certain whether the work I was doing would need further re-work	0.243	**0.719**

Team Performance Variables: Task Completion Speed and Task Product Quality

Task completion *speed* was calculated based on the number of maps a team produced divided by the total number of possible maps for the actual task (i.e., twelve) to normalize the measure to a 0–1 scale. Participants were told to work on maps in the order provided and not to start a new map until the prior map was completed. Therefore, partial maps were computed only for the last map produced by the team, based on how many map elements were completed.

Product *quality* was calculated based on the accuracy of the map reproduction. Accuracy captures two important measures of quality—lack of errors and meeting product requirements. Accuracy was measured by counting the number of correct elements (backgrounds, icons, and arrows) in the map and their correct positions in the picture, and then dividing this by the number of correct elements and positions for a perfect map (i.e., fifteen), to normalize the scale to 0–1. If the last map was incomplete, it was treated as a partially completed map, not as an inaccurate map,

Table 4. Descriptive Statistics and Correlation Matrix

	Variable	Mean	Std Dev	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Speed	0.57	0.27																	
2	Accuracy	–64.46	39.00	0.11																
3	Temporal Distance	0.49	0.37	0.28	–0.21															
4	67% (10 Min) Overlap	0.26	0.44	–0.11	–0.03	–0.26														
5	33% (5 Min) Overlap	0.25	0.44	0.10	–0.07	0.27	–0.34													
6	No Overlap	0.24	0.43	0.21	–0.13	0.77	–0.33	–0.33												
7	Location	0.35	0.48	0.52	0.10	0.10	0.12	0.018	0.03											
8	Team Rated Skills	4.02	0.73	0.28	0.17	0.14	–0.02	0.09	0.07	0.19										
9	Complex Task	0.34	0.48	–0.36	–0.08	0.02	–0.02	0.028	0.00	–0.53	–0.03									
10	Equivocal Task	0.34	0.48	0.64	0.03	–0.01	–0.02	–0.01	0.00	0.51	0.25	–0.52								
11	Communication Frequency	130.40	63.17	–0.23	0.17	–0.47	0.19	–0.16	–0.36	–0.15	–0.09	0.15	–0.39							
12	Turn Taking	41.43	35.44	–0.19	0.27	–0.80	0.22	–0.29	–0.58	0.00	–0.10	–0.06	–0.06	0.69						
13	Miscommunication Problems (perceived)	2.41	0.78	–0.47	–0.29	–0.10	–0.02	–0.18	0.05	–0.31	–0.59	0.12	–0.45	0.17	0.09					
14	Coordination Problems (perceived)	2.89	0.52	–0.26	–0.28	0.19	–0.23	–0.07	0.29	–0.25	–0.33	0.24	–0.29	–0.13	–0.25	0.65				
15	Conveyance (in+id)	57.34	38.19	–0.04	–0.02	0.05	–0.06	0.033	0.04	–0.22	–0.05	0.26	–0.43	0.73	0.10	0.09	0.03			
16	Convergence (ac + cl + co + mi + tq)	43.89	32.80	–0.37	0.28	–0.72	0.25	–0.26	–0.53	–0.15	–0.14	0.15	–0.29	0.76	0.90	0.22	–0.13	0.17		
17	Age Group	2.52	0.70	–0.16	–0.19	–0.04	–0.10	–0.2	0.14	0.04	–0.20	–0.23	–0.07	–0.04	0.06	0.26	0.08	–0.12	0.01	
18	Gender	0.41	0.38	–0.15	–0.04	0.00	–0.06	–0.07	0.07	–0.22	–0.12	0.00	–0.10	–0.06	–0.03	0.22	0.21	–0.06	–0.01	0.22

Correlation values are significant at the $p < 0.001$ for $|r| > 0\ .30$; $p < 0.01$ for $|r| > 0.22$; $p < 0.05$ for $|r| > 0.17$.

and counted as a fraction of a map for task completion speed. Incomplete maps in the middle of a series were treated as inaccurate maps. We observed that the distribution of the accuracy variable was strongly skewed to the right, with very small variance in the data. We believe that this occurred because most teams completed maps fairly accurately with only very few incorrectly selected or positioned map elements. To correct for this problem we did a rank transformation of this variable, which is a common nonparametric statistics procedure to produce a uniform distribution [14]. We reversed the accuracy rank so that high values represent high accuracy.

Task completion speed and product quality were evaluated independently by an external rater and one of the coauthors. Reliability was tested on about one-third of the maps with a reliability score of 90.5 percent. We tested for systematic differences among participants by age group, gender, and educational level and found no significant differences. Unlike the simple and complex tasks, the equivocal task produced verbal descriptions rather than actual maps. In order to measure team performance on the same basis across the three tasks, we first had two coders independently draw the maps according to the verbal descriptions submitted by each team and then apply the speed and quality measured described above.

Temporal Distance

Temporal distance was an experimental condition. We measured the work-overlap index [70], which is a ratio of the number of overlap working time to the total time in a workday. In our experimental design, we had synthetic workdays lasting fifteen minutes each and four temporal distance conditions: 1.00 or full overlap; 0.67 or ten-minute overlap; 0.33 or five-minute overlap; and 0.00 or no overlap. We used these overlap indices as a quantitative measure of temporal distance (reversed). In addition, to obtain more nuanced information about how various gradations of temporal distance affect our results, we created four binary variables, one for each temporal distance condition. For example, the 10 Minute (0.67) Overlap variable is binary and takes a value of 1 if the team worked in that experimental condition and 0 otherwise. The dummy variable of the full overlap condition was omitted from the data analysis to prevent the “dummy variable trap” [49]. Consequently, the intercept in the regression models represents the effect of the full overlap condition and the coefficients for the remaining overlap variables represent the effect of the respective overlap condition, relative to full overlap.

Task Type

We also created dummy variables for task type. The Complex variable took a value of 1 if the team worked on the complex task and 0 otherwise. To prevent the dummy variable trap problem, we included the dummy variables only for the complex and equivocal tasks in the data analysis. Therefore, the intercept represents the effect associated with the simple task and the other two task variable coefficients represent the differential effect of that task type, relative to the simple task.

Team Interaction: Communication Pattern

As we discussed above, communication pattern captures the intensity and timing of information exchange between team members. In this study, we operationalize communication pattern with two variables: communication frequency and turn-taking. *Communication frequency* is the number of communication instances that occur in a channel in a given period of time [47, 78, 87]. Consequently, we measure communication frequency as the total number of chat entries made in the entire duration of the task. *Turn-taking* captures the pattern of information exchanges in the team [80, 83, 109]. When members take more turns, they tend to perform at the same rate and have common pattern of coordinated behavior [25]. More turn-taking in a team is an indicator of more simultaneous and synchronous action. The team's interaction pattern is generally more synchronous when members take more turns, alternating their chat interaction. Therefore, we measured a team's turn-taking as the total number of turns (i.e., a chat entry by one member preceded by an entry from the other member) in the entire duration of the task.

Team Interaction: Communication Content

As we discussed above, communication content refers to information-sharing behaviors [63], which according to O'Reilly and Pondy's [72] can be of two primary types: conveyance and convergence. *Conveyance* is associated with the transmission of new information, whereas *convergence* has to do with reaching a common understanding of the meaning of the information via discussions. Therefore, we developed a coding scheme to identify: (1) *conveyance,* as any chat entry that transmitted a task instruction, task request, or information discovery statement; and (2) *convergence,* as any chat entry that referred to the discussion of the previously transmitted information, including acknowledgments, evidence or repair of miscommunication, clarifications, confirmations of activity completion, and task questions. By definition, convergence is about developing shared meaning about information already conveyed, which simplified our coding approach. In essence, any transmission of new information was coded as conveyance, whereas any discussion of previously conveyed information was coded as convergence. The specific categories we used in our coding scheme are shown in Table 5. We differentiated between task and social information [108] in our coding, but only focused on task information for the study. An independent coder coded all the chat entries. One coauthor reviewed each of these codes and discussed with the coder the coding of questionable codes (less than 5 percent of the chat entries), but allowed the independent coder to retain or change the coding of the entries involved at her discretion. A random sample of 1,250 chat entries was then given to a second

Table 5. Chat Text Coding Scheme

Type of chat entry	Description	Example
Conveyance		
Task instruction or task request	When the map designer sends specific map drawing instructions (note: the map maker does not send instructions, only the map designer does)	"Choose the picture that has a road with power lines"
Information discovery statement	When participants communicate which map elements they have	"None of my backgrounds have a barn"; "I have the electrical power tower"
Convergence		
Acknowledgments	Acknowledgment that something was understood or instructions were received	"Got it"; "Understood"
Evidence of miscommunication	When the chat entry provides evidence that miscommunication was discovered	"No, it should not be on top of factory"; "That is not the correct background"
Corrections or Clarifications	Corrections or clarifications made in reference to prior communication, because instructions were unclear or because one member wanted a confirmation of something	"The picture we are using does NOT have a sun on the top right"
Confirmations of activity completion	Confirmation that a task was completed or that an instruction was carried out; also, confirmation that what the other teammate said was correct	"Got the picture, now the arrows"; "OK, I'm done with map 2"
Task questions	When participants ask plain questions or request information about the task, but not as a clarification	"Which icons should I use?"

independent coder. After the coding was aggregated to reflect either conveyance or convergence, the reliability between coders was 0.89, measured as the ratio of total agreements to total agreements plus disagreements [65]. Consequently, we retained the full coding of the first external coder.

Control Variables

We included five control variables in various regression models: communication problems, coordination problems, team member skills, task type, and experiment location. The first three variables were measured via data from an exit survey, adapted from prior research [18]. The organizational literature [58, 95, 98] suggests that teams coordinate either through communication (e.g., meetings, debriefings, phone calls) or task programming routines (e.g., project plans, schedules, specifications). These communication and coordination routines can affect task performance, confounding the effects of temporal distance. Consequently, we used two variables to control for effects of communication problems and coordination problems that result from different coordination approaches. Factor analysis with varimax rotation supports a two-factor solution (see Table 3 for factor loadings and reliability statistics, along with Cronbach reliability scores).

In addition, participants were asked to rate their own skills and their teammate's skills in the exit survey. Since the items regarding individual skills are formative (i.e., self-rating of one's skills is not necessarily correlated to the rating of a teammate) these items were simply aggregated and not factor analyzed. Dummy variables of task types are included as the fourth control variable in all the regression models. Finally, because the experiments were conducted by two different researchers in two different locations, we included a binary variable to control for location.

Data Analysis

We analyzed the data using hierarchical regression models employing ordinary least squares (OLS) in a series of equations formulated as a path model. None of the OLS assumptions were violated, indicating that the OLS models provided the most efficient and unbiased estimators [5, 38, 60]. LISREL was not chosen due to this study's relatively small sample size [37]. We also decided against seemingly unrelated regressions (SUR) because endogeneity was not a concern [38, 93]. Finally, we did not choose partial least squares (PLS) because its estimation approach is less suitable for regression models with interaction terms [59].

Results

The descriptive and correlation statistics are presented in Table 4. The regression results are presented in Table 6 and illustrated in Figure 4. As the correlation matrix shows, we found a strong positive correlation between temporal distance and speed, supporting Hypothesis 1 ($\rho = 0.28$, $p = 0.001$). Similarly, in support of Hypothesis 2, we found a strong negative correlation between temporal distance and accuracy rank ($\rho = -0.21$, $p = 0.015$). The respective regression models (Models 1 and 2 in Table 5) with all the control variables confirmed the same results for the effect of temporal distance on speed ($\beta = 0.190$, $p < 0.001$) and quality ($\beta = -25.774$, $p = 0.006$).

In support of Hypotheses 3 and 4, controlling for temporal distance, communication frequency had a positive effect ($\beta = 0.769$, $p < 0.001$) and turn-taking had a negative effect ($\beta = -0.760$, $p < 0.001$), respectively, on conveyance communication (Model 5 in Table 6). Interestingly, without the communication pattern variables, neither the temporal distance variable nor the respective overlap binary variables had any effects on conveyance (Models 3 and 4 in Table 6). However, once we included

Table 6. Regression Model Results

Model	1	2	3	4	5	6	7	8	9	10	11	12
	Black Box		Conveyance			Converge						
Variable	Speed	Quality	Tmp Dst	Δ TZ	+ Comm	Tmp Dst	Δ TZ	+ Comm	Speed		Quality	
Constant	0.926	–20.032	97.997	102.062	15.557	16.651	81.052	–8.546	0.730	0.495	–17.552	5.789
	(<0.001)	(0.608)	(0.005)	(0.003)	(0.331)	(0.404)	(<0.001)	(0.485)	(<0.001)	(0.016)	(0.655)	(0.889
Temporal Distance	0.190	–25.774	5.368			–60.607			0.226		–1.738	
	(<0.001)	(0.006)	(0.547			(<0.001)			(0.002)		(0.908)	
10 Minute (0.67) Overlap				–7.493	–11.051		–19.820	3.568		0.086		–17.75
				(0.402)	(0.010)		(<0.001)	(0.274)		(0.103)		(0.101
5 Minute (0.33) Overlap				–0.560	–1.564		–44.893	0.478		0.155		–14.293
				(0.951)	(0.772)		(<0.001)	(0.908)		(0.017)		(0.280)
No (0.00) Overlap				4.181	4.212		–58.905	–1.454		0.229		–6.277
				(0.653)	(0.500)		(<0.001)	(0.761)		(0.002)		(0.680)
Location	0.108	5.487	0.038	1.671	–1.612	8.787	8.685	0.36	0.114	0.113	3.313	5.937
	(0.011)	(0.521)	(0.996)	(0.841)	(0.649)	(0.064)	(0.072)	(0.894)	(0.005)	(0.007)	(0.693)	(0.483)
Team Member Rated Skills	–0.032	0.073	–0.320	–0.475	–4.012	2.896	2.695	1.307	–0.017	–0.017	–0.306	–0.984
	(0.258)	(0.990)	(0.951)	(0.928)	(0.069)	(0.338)	(0.374)	(0.437)	(0.537)	(0.546)	(0.957)	(0.862)
Complex Task	0.004	–9.234	4.264	5.011	2.804	7.072	7.091	7.843	–0.015	–0.016	–18.22	–15.991
	(0.928)	(0.300)	(0.615)	(0.557)	(0.432)	(0.150)	(0.151)	(0.005)	(0.743)	(0.723)	(0.050)	(0.086)
Equivocal Task	0.253	–19.900	–36.731	–37.784	0.464	–19.886	–20.320	–7.506	0.315	0.316	–9.859	–12.281
	(<0.001)	(0.033)	(<0.001)	(<0.001)	(0.909)	(<0.001)	(<0.001)	(0.017)	(<0.001)	(<0.001)	(0.336)	(0.232)
Communication Problems (Perceived)	–0.087	–18.923	–3.524	–3.178	–7.873	9.145	8.515	4.173	–0.068	–0.068	–23.895	–23.947
	(0.017)	(0.011)	(0.600)	(0.641)	(0.007)	(0.217)	(0.202)	(0.059)	(0.057)	(0.059)	(0.002)	(0.001)

(continues)

Table 6. Continued

Model	1	2	3	4	5	6	7	8	9	10	11	12
	Black Box		Conveyance			Converge						
Variable	Speed	Quality	Tmp Dst	Δ TZ	+ Comm	Tmp Dst	Δ TZ	+ Comm	Speed		Quality	
Coordination Problems (Perceived)	–0.016	–1.461	–5.924	–8.134	3.373	–12.351	–12.586	–0.937	–0.011	–0.009	2.652	–1.153
	(0.720)	(0.869)	(0.483)	(0.350)	(0.369)	(0.012)	(0.013)	(0.744)	(0.799)	(0.842)	(0.767)	(0.899)
Communication Frequency					0.769			0.069	–0.003	–0.003	–0.402	–0.243
					(<0.001)			(0.007)	(0.041)	(0.046)	(0.113)	(0.362)
Turn Taking					–0.760			0.723	0.002	–0.003	–0.219	–0.243
					(<0.001)			(<0.001)	(0.156)	(0.046)	(0.431)	(0.362)
Conveyance									0.004	0.004	0.367	0.186
									(0.002)	(0.003)	(0.206)	(0.541)
Convergence									0.002	0.002	1.182	1.080
									(0.369)	(0.361)	(0.003)	(0.007)
N	129	129	131	131	131	131	131	131	129	129	129	129
R^2	0.572	0.174	0.206	0.214	0.865	0.639	0.644	0.893	0.635	0.635	0.635	0.282
P-value of model predictive power	(<0.001)	(0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)	(<0.001)
P-value of R^2 change					(<0.001)			(<0.001)				

Note: Values in parentheses below the coefficients are their respective significance levels (*p*-values).

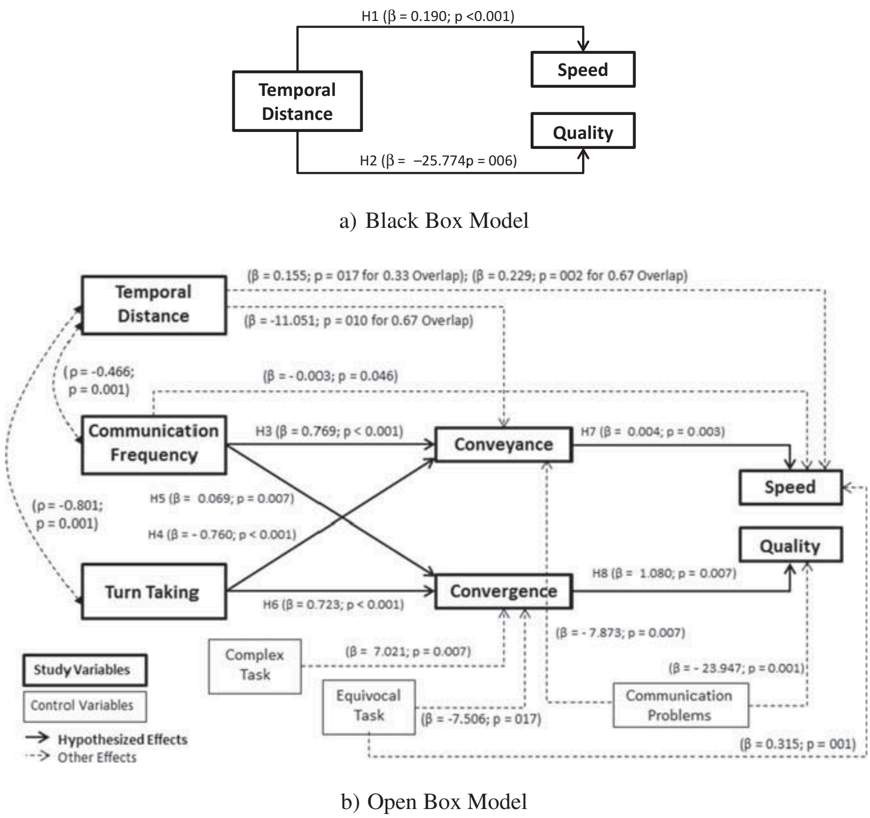


Figure 4. Results

the communication pattern variables, the 67 percent overlap binary variable became significant (β = –11.051, p = 0.010; Model 5), whereas the other overlap variables remain nonsignificant, suggesting a U-shaped effect—that is, taking communication pattern into account, a small increase in temporal distance causes conveyance of information to decrease; as teams make adjustments with further temporal distance, conveyance of information increases.

In support of Hypotheses 5 and 6, controlling for temporal distance, both communication frequency (β = 0.069, p = 0.007) and turn-taking (β = 0.723, p < 0.001) had positive effects on convergence of information (Model 8 in Table 6). Interestingly, without the communication pattern variables, temporal distance had a very strong negative effect on convergence (β = –60.607, p < 0.001; Model 6), yet the marginal effect of each increment of temporal distance decreased (β = –19.829, p < 0.001; β = –44.893, p < 0.001; β = –58.905, p < 0.001 for 67 percent, 33 percent, and no overlap, respectively; Model 7). Once we added the communication pattern variables, these effects became nonsignificant, providing strong evidence that it is the pattern of communication and not the temporal distance per se that affects convergence.

In support of Hypotheses 7 and 8, controlling for temporal distance, information conveyance had a positive effect on task completion speed ($\beta = 0.004$, $p = 0.003$; Model 10) and information convergence had a positive effect on quality ($\beta = 1.080$, $p = 0.007$; Model 12). Conveyance had no effect on quality, and convergence had no effect on speed. Interestingly, both communication frequency and turn-taking had slight negative effects on speed ($\beta = -0.003$, $p = 0.046$ and $\beta = -0.003$, $p = 0.046$; Model 10) and no effects on quality (Model 12). Similarly, larger temporal distance had a positive direct effect on speed, although the marginal effect of each increment in temporal distance decreased ($\beta = 0.086$, $p = 0.103$; $\beta = 0.155$, $p = 0.017$; $\beta = 0.229$, $p = 0.002$ for 67 percent, 33 percent, and no overlap, respectively; Model 10). There is no direct effect of temporal distance on quality (Model 12).

Finally, with respect to task type, we found that task complexity did not have a significant effect in most models. However, when taking communication pattern into account, task complexity yielded a positive effect on convergence ($\beta = 7.843$, $p = 0.005$; Model 8) and a marginally negative effect on quality ($\beta = -15.991$, $p = 0.086$; Model 12). The effects of equivocal task were mixed. Equivocal task had a strong negative effect on conveyance when communication pattern was not taken into account ($\beta = -37.784$, $p < 0.001$; Model 4), but this effect disappeared when the communication pattern variables were added to the model (Model 5). Meanwhile, task equivocality had a negative effect on convergence without ($\beta = -20.320$, $p < 0.001$; Model 7) and with ($\beta = -7.506$, $p = 0.017$; Model 8) the communication pattern variables. Similarly, task equivocality had a direct positive effect on speed ($\beta = 0.316$, $p < 0.001$; Model 10), but had no effect on quality (Model 12).

Discussion

A fundamental assumption of dispersed team research is that geographic dispersion causes performance challenges (e.g., coordination delay, mutual knowledge, and conflict). Premising this assumption, prior studies have tended to treat geographic dispersion as a nominal background while focusing on the nature, consequences, and remedies of these challenges. Our study brings temporal distance, a primary dimension of geographic dispersion [70], to the front and center of the research model. Our findings shed fresh light on the relation between temporal distance and dispersed team interaction and performance. They provide evidence that temporal distance per se may not matter as much; instead, it is the team interaction molded by temporal distance that causes performance variations. Although our analysis shows significant associations between temporal distance and task completion speed and quality, these associations become less pronounced once measures of communication form (frequency and turn-taking) and information exchange behaviors (conveyance and convergence) are taken into account. Furthermore, the differentiated effects of communication form and information exchange reveal the inner working of the relation between temporal distance and team performance. In particular, we learned that frequent communication facilitates both information conveyance and information convergence. Turn-taking, on the other hand, is conducive only to convergence but not conveyance. Information conveyance, in turn, is a significant driver of task completion speed whereas information convergence helps to ensure task quality.

In addition, our findings help to clarify the nature and boundary condition of the effect of temporal distance on dispersed teamwork. Whereas previous research studies have modeled temporal distance as a binary variable [18], our study employs both a continuous variable and a set of dummy variables to uncover more precise effects of different gradations of temporal distance on team interaction and performance. Interestingly, our data analysis revealed a U-shaped relation between gradations of temporal distance and information conveyance, and the decreasing marginal effects of temporal distance on information convergence and task completion speed. These findings speak to the nonlinear nature of temporal distance's effect on dispersed teamwork. Meanwhile, our study also shows the significant effects of task types on information exchange and team performance. These results suggest the importance of task nature as a boundary condition of temporal distance's effect on teamwork.

Taken together, our findings have three important implications for dispersed team research. First, a direct path between geographic dispersion and team performance outcomes does not fully capture how this association takes place. Although geographic dispersion poses great challenges for work teams, how these challenges affect performance will be determined by how members interact. A theoretical model that embraces both direct and mediated paths from geographic dispersion to performance outcomes helps to explain how this association occurs. In other words, our study makes evident the theoretical significance of bringing team interaction more centrally to future research on dispersed teamwork.

The second implication is that the role of technology can be better understood not by manipulating the technology features themselves, but by keeping them constant and allowing team members to appropriate the technology to perform in their specific dispersion context and task type. In our study all teams had the same technology, but used it differently. Therefore, our research approach helps extend adaptive structuration theory (AST) [28] to the dispersed team context. AST highlights the active role of humans in shaping the nature and relevance of technology in team or organizational work. By embracing the socially constructed nature of technology-mediated team interaction and performance outcomes, the AST-based research approach may provide a richer and more nuanced understanding of how technology changes the way people work together across time zones. Third, with respect to research design, this study demonstrates the value of laboratory experiments in uncovering otherwise "unnoticed causes" of team performance challenges [104]. To date, the dispersed team literature has established the significance of geographic dispersion in teamwork, but we still lacked an untangled view of the causal paths intrinsic to dispersion's impact. Lab experiments can complement field observations, minimize confounding effects, and open up the "black box" to uncover how effects of geographic dispersion take place, thus helping to disentangle this view.

Our study is not without limitations. First, the fictional map task does not fully capture the complexity of higher forms of knowledge tasks such as software development. Although the map task allows us to minimize confounding effects, future research can test time-zone effects in more realistic global knowledge work settings. Second, the task duration in the lab experiment is significantly shorter than tasks in real-world collaboration, which prevented us from studying long-term effects. Future work with field-based experiments can trace the impact of time separation in the longer run, which would be a great complement for laboratory experiments. Finally, our sample is composed primarily of university students and university staff, which may limit the generalizability of our findings. However, our sample did include several external participants. In addition, we were careful to include a wide range of age groups and educational levels, spread evenly across gender and experimental conditions. Furthermore, because the task was short and specific, compared to large organizational tasks that require long-term relationships and knowledge of the organizational context, we believe that our findings are generalizable to any type of knowledge task work in temporally separated environments.

Conclusions

Many studies on the effects of spatial and temporal distance on team or task performance have taken a simplistic approach in that they generally investigate *whether* geographic dispersion or time-zone differences affect performance. Such approaches can impede theoretical development in three respects: (1) they cannot rule out confounding variables that could provide alternative explanations (e.g., geographic distance, time-zone differences, cultural differences, task type, etc.); (2) they do not account for factors that could influence the process for effects of temporal distance to unfold (e.g., communication patterns, interactivity, management practices, etc.); and (3) they do not capture potential trade-offs between various dimensions of team performance. Our study contributes to information systems (IS) theory regarding dispersed teamwork by addressing these three caveats. We employed a controlled-experiment design to isolate the effect of temporal distance across the contingency of three types of task, ruling out confounding variables. We accounted for the process factors involved in effects of temporal distance by incorporating team interaction variables into the research model—that is, we not only investigate whether temporal distance has an effect, but also how and why. In addition, we examined two equally plausible and seemingly contradictory perspectives on the impact of temporal distance on work performance—working across temporal distance might help speed up work, but it can impose substantial coordination challenges and therefore impair quality. This approach enriches our understanding about trade-offs between different dimensions of team performance.

Our theoretical development, well-controlled experiment method, and detailed findings unify previously partial perspectives of the paths from temporal distance to performance outcomes. This unified view deepens our understanding of the duality of time and temporal structure in the organization, a topic that has long intrigued researchers and was not well understood [67, 68]. The theoretical development and empirical findings from this study speak to the fundamental questions of dispersed team literature: whether and how distance matters [73]. Our study confirms that although distance may matter [73], temporal distance really matters. More important, how we cope with temporal distance matters even more. In today's global economy, it is rare to find teams that are not dispersed across locations and time zones. This study helps us not only to understand when temporal differences may be advantageous and when they may be detrimental to performance but also how to adjust team interaction patterns to achieve the desired performance goals. Interestingly, whereas prior research has shown that information and communication technology can help bridge spatial distance, and that it has a limited ability to bridge temporal distance, our study shows that temporal distance can be effectively bridged by selecting the most appropriate communication pattern and turn-taking to convey and converge on information as needed to meet the performance goals of the task.

The ultimate goal of dispersed teamwork research is to inform effective managerial practices in the field. Therefore, we conclude with a few important guidelines for managers responsible for the success of dispersed teams:

- Common wisdom regarding temporal distance is that it is good for speed but bad for quality—that is, the dual perspective we discussed earlier. Although this wisdom generally holds true, it can lead to managerial practices that favor one performance outcome at the expense of the other. Our findings suggest the possibility of achieving both speed and quality through deliberate interventions aimed at influencing team members' communication behaviors within and outside overlap windows. For example, managers can analyze the amounts of information conveyance and information convergence required by the task at hand to meet the respective performance objectives. Based on this analysis, work schedules can be shifted in one direction or another to ensure sufficient time windows for each type of information exchange behavior.
- Frequent communication is always beneficial for both, conveyance and convergence, and with all temporal separation conditions. Managers should encourage frequent interaction among team members at all times. Besides the positive benefits on communication process, prior studies have shown that frequent communication has additional benefits; for example, it reduces coordination problems [18] and improves shared team knowledge and common ground [32].
- Managers should adopt practices that discourage interactive communication to minimize turn-taking during work-time overlap windows and during task phases when information conveyance is important, and when task completion speed is the most important performance goal. During nonoverlap windows the communication will be less interactive by nature.

- Conversely, managers should adopt practices that encourage interactive communication that maximizes turn-taking during work-time overlap windows, and when product quality is the most important performance goal. During nonoverlapping, managers should adopt technologies and schedule shifting practices [11] that will increase interactive communication and turn-taking. Recent IS literature has recognized the potential of mobile devices and wearable technologies in enhancing collaboration by providing real-time geospatial information [85], spatial audio cues for attention funneling [6], and synthesized information from heterogeneous data sources [51]. This potential affords managers novel ways to orchestrate team interaction according to the task needs and the respective performance goals in question.
- Consistent with prior studies of "follow-the-sun" practices [12], team members can take advantage of asynchronous interaction resulting naturally from temporal distance to achieve calendar efficiencies and foster speed.

Our study speaks to the unique work and research challenges associated with collaborations across temporal distance. The theoretical and empirical implications of this study lay a foundation for future explorations of temporal distance, team interaction processes, and task performance outcomes.

Notes

1. Other than time-zone differences, temporal distance can arise from factors such as work schedule shifts (e.g., day shifts vs. night shifts) of workers residing in the same time zone.
2. Our review focused on articles that incorporated global boundaries, which were published in one of five premium journals that regularly publish research work on dispersed teams: *Information Systems Research, Journal of Management Information Systems, Management Science, MIS Quarterly, and Organization Science*. We also reviewed a few frequently cited studies on dispersed teams.
3. "Batching changes" refers to the practice that a task requirement is not communicated immediately after it is generated; instead, requirements are communicated either when a certain number of requirements are accumulated or a particular review date is reached [54].

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