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Understanding the Ties that Bind: A Longitudinal Investigation of the Evolution of a Communication Network

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Current understanding of the emergence of communication networks is hindered by at least two limitations: (a) studies tend to incorporate only 1 theoretical mechanism, and (b) studies tend to be cross-sectional. We address these concerns by analyzing the influence of 11 factors on the evolution of a communication network over 2 years. Our model is grounded in the multitheory, multilevel framework, and our analysis uses recently developed actor-oriented techniques for statistically modeling network emergence. Results suggest accurate and complete understanding of network evolution depends on studies simultaneously incorporating multiple theories that offer both complementary and contrasting explanations of the phenomenon.

Keywords: Emergent Communication Networks; MTML Framework; Network Evolution

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The study of networks is an influential tradition in communication research (Monge & Contractor, 2001; Monge & Eisenberg, 1987; Richards & Barnett, 1993; Rogers & Kincaid, 1981). Networks have become prominent for explaining the behavior of organizations and their members (Dacin, Ventresca, & Beal, 1999; Granovetter, 1985, 1992; Uzzi, 1997), and were recently identified as an important strategy for advancing communication research (Miller, Poole, & Seibold, 2011). A growing number of books have addressed various aspects of organizational networks, including technical compendia of social network methods (e.g., Carrington, Scott, & Wasserman, 2005; Wasserman & Faust, 1994), edited volumes of research using social network methods (e.g., Cross, Parker, & Sasson, 2003), applications of network theory to management and consulting (e.g., Cross & Parker, 2004), and works that reconceptualize, from a network perspective, organizational communication theories (Monge & Contractor, 2003; Stohl, 1995).

Communication networks play an important role in understanding organizations. The emergent communication network is the informal structure of an organization, and reflects the interactions arising naturally (Johnson, 1992; Monge & Contractor, 2001) that augment formally mandated communication relationships. The formal structure is frequently made explicit in organizational charts, while the informal network is the ''grapevine'' or the ties that exist in the ''white space'' that connect formal bureaucratic silos (Eisenberg & Goodall, 2007). Patterns in emergent communication networks affect a variety of outcomes, including job satisfaction (Pollock, Whitbred, & Contractor, 2000), intraorganizational influence (Brass, 1984), and turnover (Feeley, 2000; Feeley & Barnett, 1997; Feeley, Hwang, & Barnett, 2008; Krackhardt & Porter, 1985, 1986). The role of communication networks has also been central to works in the Social Information Processing tradition (Salancik & Pfeffer, 1978), which has shown the influence of cues from proximate (Dean & Brass, 1985) and salient (Rice & Aydin, 1991) individuals on focal actors' attitudes and perceptions.

Scholars have identified limitations in the current body of communication network research. Specific concerns include most studies using cross-sectional data, a tendency for studies to examine the implications of only one theoretical mechanism in any given study (despite the fact that alternative theories offer differing and sometimes contrasting explanations of communication phenomena), and a large number of studies that test hypotheses using inappropriate statistical methods. These concerns do not minimize the contributions of any given study; rather, they are indicative of the current state of communication network research as a whole, and highlight areas of need for more appropriate theoretical frameworks and methodological instruments.

In the following section, we discuss these concerns about the current body of communication network studies and introduce the multitheoretical, multilevel (MTML) analytic framework (Contractor, Wasserman, & Faust, 2006; Monge & Contractor, 2003) as a conceptual strategy for addressing them. Next, we describe 11 theoretical mechanisms that influence network evolution, and analyze their individual as well as simultaneous effect on the evolution of a communication network over 13 points in time in a 2-year period. In so doing, we address the methodological limitations of previous studies by applying actor-oriented models developed for longitudinal

network data (Snijders, 2001, 2005; van de Bunt & Groenewegen, 2007) and implemented in the *Simulation Investigation for Empirical Network Analysis* (SIENA) software (Snijders, Steglich, Schweinberger, & Huisman, 2008). We conclude with a discussion of results, their implications for practitioners, limitations of the study, and directions for future research.

The Multitheoretical, Multilevel (MTML) Framework

In their review of the communication network literature, Monge and Contractor (2001, 2003) identified two substantial shortcomings. First, most network research either incorporates only one theory within a given study or neglects theory altogether (Brass, 1995), even though influential theories offer both complementary and contradictory explanations for explaining the evolution of networks. Consider the following example. Uncertainty reduction theory (Berger, 1987; Berger & Calabrese, 1975) implies two friends will have greater communication since each person in the dyad has confidence in the other's reactions. Spatial proximity theory (Rice, 1993; Van den Bulte & Moenaert, 1998) implies that people who are located close to each other in an organization will be more likely to establish and maintain a relationship. While both predict patterns of communication, currently there is little insight into whether a person will be more likely to communicate with a friend who is not proximate, or with a proximate coworker who is not a friend. A related concern is that most communication network research has only used theories either at the individual or at the dyadic level of analysis. For example, gender homophily theory (Ibarra, 1992) focuses on the *individual* level, predicting that individuals who share the same gender will be more likely to communicate. Exchange theory (Emerson, 1962; Homans, 1950, 1974) operates at the *dyadic* level, predicting that two individuals will maintain a communication relationship if both perceive it to be advantageous. Finally, balance theory (Heider, 1958; Holland & Leinhardt, 1972) predicts the emergence of *triadic* structures. Studies that incorporate only one theory at one level of analysis are unable to assess the relative influence of each of these mechanisms or their net effect on the communication network (Miller et al., 2011), which has limited our understanding of the factors influencing the evolution of a communication network.

The second main shortcoming of communication network research is that it is frequently static and cross-sectional. Communication scholars have long called for increased attention to the emergence of social networks (Monge & Eisenberg, 1987), and some research has utilized longitudinal approaches to provide insight into the changes of different types of networks over time. Burkhardt (1994) studied the role of social influence and interpersonal relationships on the diffusion of beliefs, attitudes, and behaviors following a technological change within an organization, and found that while direct interaction affects beliefs, structural equivalence is more critical for influencing attitude and behaviors. In his analysis of the International Telecommunication Network from 1978 through 1996, Barnett (2001) showed this network had a central core in the United States, Canada, and Western Europe and that, over time, the network became denser and more highly centralized. Monge and Matei's (2004)

longitudinal analysis of the global telecommunications network from 1989 to 1999 showed increased tendencies towards mutuality and transitivity. Other examples include Danowski and Edison-Swift's analysis of changes in e-mail correspondence following an organizational crisis (1985) and Barnett and Rice's application of Galileo analysis to the American air traffic network from 1968 to 1981 (1985). Recently, Whitbred, Fonti, Steglich, and Contractor (2011) provided evidence that, consistent with hypotheses grounded in structuration theory, a block of theoretical mechanisms external to an emergent communication network had less of an impact on the evolution of said network than the structure of the same network at prior time periods. These prior studies, while certainly examining important issues using appropriate longitudinal techniques, do not systematically explore the implications of the MTML framework.

Several other scholars have echoed this concern. Brass (1995) emphasized the substantive need to understand the dynamic nature of the relationships among communication networks in organizations, their antecedents, and their outcomes. Krackhardt (1994) voiced similar sentiments, by saying that "we must first agree on the fundamental process by which these networks emerge before we can agree on what effect they might have" (p. 218). Others (e.g., Ahuja, Soda, & Zaheer, 2007; Contractor, Monge, & Leonardi, 2011) have lamented the continued lack of understanding of these issues, while Stokman and Doreian (1997) underscored the importance of both providing descriptions of change in networks and understanding which theoretically derived mechanisms influence such change.

In response to these concerns, scholars have argued future studies of communication networks should adopt the multitheory, multilevel (MTML) analytic strategy, using appropriate longitudinal analytic techniques (Contractor et al., 2006). According to Monge and Contractor (2003), since "none of the theories, on their own, provide definitive, exhaustive explanations of network phenomena" (p. 21), we need studies that: (a) incorporate multiple theories that influence the evolution of emergent communication networks, (b) incorporate multiple levels of analysis, and (c) utilize analytic strategies that allow examination of the relative influences of the theoretical mechanisms over time. We respond to these challenges by introducing a MTML model that includes 11 theories of communication (see Figure 1), and utilize an appropriate analytic technique to analyze the evolution of a communication network (i.e., actor-oriented models; Snijders, 2001, 2005), which we describe in the analysis section. The following section introduces six different theoretical perspectives that account for the evolution of communication networks, as well as eight exogenous theoretical mechanisms and three endogenous theoretical mechanisms corresponding to them (some theories imply more than one mechanism). These theories and the corresponding mechanisms incorporate the individual, dyadic, and triadic levels of analysis (see Table 1).

Theoretical Mechanisms

Exogenous mechanisms explain communication between two network members based on factors external to the already existing communication relations. These include

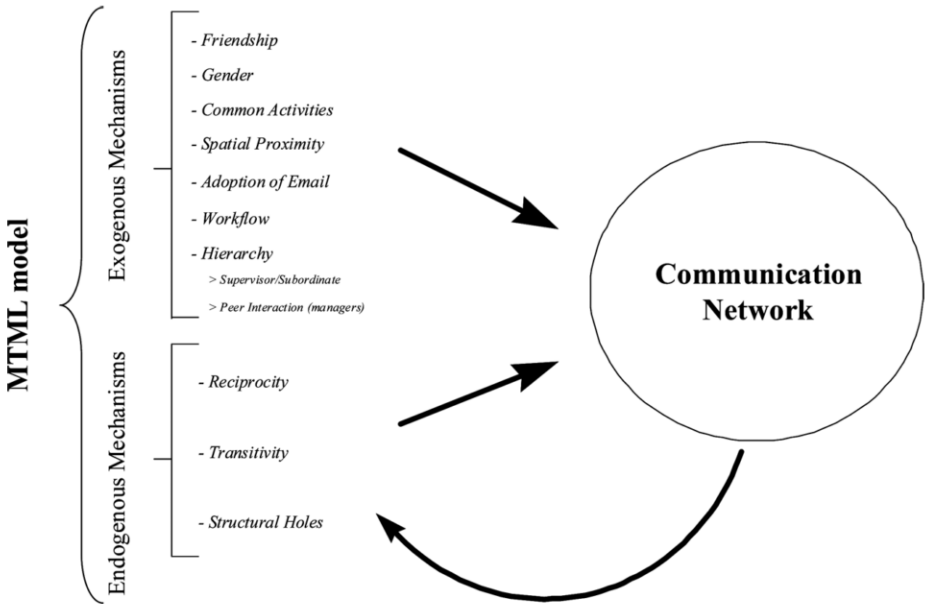

Figure 1 Exogenous and Endogenous Factors Influencing the Evolution of a Communication Network in an Organization.

attributes of individual network members, as well as other types of relations among them, such as friendship. *Endogenous* mechanisms are explanations of communication relations based on structural characteristics of the communication network itself, at a prior period in time. The structure of the communication network at a given time period (T_1) will both enable and constrain how such network can change over time, thereby influencing its structure at successive time periods. For example, if network

Table 1 Models, Theories, and Explanatory Mechanisms

Type of model	Underlying theory/framework	Mechanisms/ variables included
Individual exogenous model	Uncertainty reduction theory	Friendship
	Gender homophily theory	Gender
	Activity focus theory	Common activities
	Physical proximity theory	Spatial proximity
	Electronic proximity theory	E-mail proximity
	Coordination theory	Workflow
	Coordination theory	Supervisor/subordinate
	Coordination theory	Peer hierarchical proximity
Individual endogenous model	Social exchange theory	Reciprocity
	Balance theory	Transitivity
	Self-interest theory	Structural holes
Full model (all exogenous and endogenous mechanisms)	MTML framework	All endogenous and exogenous mechanisms

member A has several existing stable communication relations with several other network members at a given time, he/she may have more *opportunity* to meet others via these ties (structure enabling communication) but will also have less *time available* to forge and maintain these possible new links, as he/she already has many ties to tend to (structure constraining communication). Conversely, if member B has fewer existing communication ties in his/her network, he/she will have more time available to connect with others, but less opportunity compared to A. Below, we describe theories consistent with exogenous and endogenous mechanisms of network evolution and conclude each discussion with a hypothesis indicating how the respective mechanism may influence the evolution of the communication network.

Theories representing exogenous mechanisms

Our model incorporates six theoretical perspectives that represent eight exogenous mechanisms. They are uncertainty reduction theory, gender homophily theory, activity focus theory, physical proximity theory, electronic proximity theory, and coordination theory. Coordination theory has three dimensions: coordination between employees with workflow connections, coordination between supervisors and subordinates, and coordination between supervisors across the organization.

Uncertainty reduction theory. Researchers have suggested that uncertainty reduction theory (Berger, 1987; Berger & Calabrese, 1975) makes clear why those who have personal relationships in organizations are also more likely to interact about task-related issues (Albrecht & Adelman, 1984; Albrecht & Hall, 1991). The theory suggests that members of organizations communicate to reduce uncertainty in their task environment. As friendship among two individuals develops, the levels of uncertainty entailed in their relationship will decrease as each partner in the dyad becomes more confident of how the other will react in different situations. When discussing topics that involve high uncertainty, such as an organizational crisis or organizational politics, people typically feel threatened, thus seeking support from (and interaction with) those they have confidence in, i.e., their friends (Albrecht & Bach, 1997). This analysis suggests the following hypothesis:

> H1: Over time, there will be a greater likelihood of communication between members of the organization who are friends.

Gender homophily theory. Homophily theory (McPherson, Smith-Lovin, & Cook, 2001) posits that individuals who are demographically similar are more likely to communicate with each other, since such similarity fosters greater initial levels of comfort between two individuals (Brass, 1995). The influence of demographic factors such as age, organizational tenure, education, and religion on communication networks has been examined from the homophily perspective (Galaskiewicz, 1979; Liedka, 1991; Tsui, Egan, & O'Reilly, 1992; Tsui & O'Reilly, 1989; Zenger & Lawrence, 1989). Gender homophily, or the impact of similarity in gender on networks, has received particular attention. Brass (1985) reported gender similarity as significantly predicting

the pattern in an organization's communication network, whereas Ibarra (1992) found that gender similarity predicted social support networks. Hence:

> H2: Over time, there will be a greater likelihood of communication between members of the organization who have the same gender.

Activity focus theory. Activity focus theory (Corman & Scott, 1994) recognizes that much of the interaction in organizations focuses on projects and other activities that are not adequately captured by either personal relationships or formal structures, and posits that interpersonal interactions are organized in terms of "a social, psychological, legal, or physical entity" (Feld, 1981, p. 1016). People who engage in a common activity are more likely to develop interpersonal relationships, as they are exposed to one another and meet those with common interests. McPhee and Corman (1995) tested this theory in a church organization, and reported that members were more likely to communicate when they participated in common activities such as prayer meetings or church committees. Therefore:

> H3: Over time, there will be a greater likelihood of communication between employees who engage in common activities.

Physical proximity theory. There is substantial evidence that network members who are located close to each other in organizations have greater exposure to one another, which in turn increases the likelihood of communication ties (Festinger, Schachter, & Back, 1950; Monge, Rothman, Eisenberg, Miller, & Kirste, 1985; Rice, 1993). Kraut, Egido, and Galegher (1990) argued that physical proximity influences communication due to "co-location of similar others and the availability of frequent, high-quality, low-cost communication" (p. 158). Research has consistently demonstrated that close proximity is predictive of communication. Conrath (1973) reported greater communication between physically proximate employees. In a study of seven R&D labs, Allen (1978) determined that the probability of two people communicating about technical and scientific matters decreased asymptotically with physical distance, while Zahn (1991) analyzed the relationship between proximity, exposure, and communication in a manufacturing organization and found that employees who were more proximate were more likely to communicate with one another. Finally, Van den Bulte and Moenaert (1998) reported that communication among R&D teams was enhanced after they were colocated. Consequently:

> H4: Over time, there will be a greater likelihood of communication between members of the organization who are physically proximate.

Electronic proximity theory. The effect of communication technologies on communication networks has received considerable research interest (Wellman & Haythornthwaite, 2002; Wellman et al., 1996; for comprehensive reviews, see DiMaggio, Hargittai, Neuman, & Robinson 2001; O'Mahony & Barley, 1999). Information technologies that facilitate interaction among employees across geographic

boundaries create electronic proximity (Rice, 1994; Zack & McKenney, 1995). Electronic proximity increases the opportunity for two employees to interact since they no longer need to be spatially colocated, and asynchronous communication may occur. E-mail in particular has been shown to influence emergent communication networks. For instance, Constant, Sproull, and Kiesler (1996) reported that e-mail facilitated the forging of weak ties for technical advice among physically dispersed employees, whereas Hinds and Kiesler (1995) reported that e-mail was influential in creating and maintaining communication links across boundaries. Thus:

> H5: Over time, there will be a greater likelihood of communication between organizational members who are electronically proximate.

Coordination theory. To be effective, organizational members must coordinate their goals and activities. Coordination theory (Malone & Crowston, 1994) offers an interdisciplinary approach for conceptually defining coordination, specifying why people need to coordinate their activities, and identifying the influence of coordination activities on organizational processes. It is a framework for understanding how organizational members manage dependencies among goals, activities, and actors. Dependencies are managed via coordination mechanisms, which are primarily information processing activities (Crowston, 1997). Coordination theory accounts for the emergence of communication networks via three different exogenous mechanisms: workflow, supervisor–subordinate relationships, and peer hierarchical proximity.

Van de Ven and Ferry (1980) defined workflow as "the materials, objects, or clients and customers that are transacted between units, hierarchical levels, and organizations" (p. 242). Brass (1981) further conceptualized workflow in terms of a "network that locates task positions in relation to each other. The basis for the relationships or interdependencies among different positions is the patterned interactions that occur between related positions as the work flows through the organization" (p. 332). Workflow transactions are the inputs to and outputs from task positions. Since "each link in this structural network represents the acquisition of inputs by one worker and, at the same time, the distribution of outputs by another worker, the link is viewed as a mutual interdependency" (p. 332). Organizational members reciprocally depend on each other for resources, such as information about which tasks are salient, feedback about progress on previous tasks, and work skills and knowledge needed to complete tasks, which increases the likelihood of communication between them. As a result:

> H6: Over time, there will be a greater likelihood of communication between organizational members who share a workflow tie.

Within an organization, coordination also occurs via the formal channels of interaction inherent within the hierarchical structure. Hierarchy influences emergent communication patterns in two distinct ways: by means of supervisor–subordinate (vertical) relationships and as a function of peer (horizontal) relationships among managers. Supervisor–subordinate relationships are interactions between organizational members that entail formal authority over task-related activities (Jablin,

1979). This relationship is most clearly evident in organizational charts. Previous research (for a review, see Jablin, 1987) has shown that a substantial proportion of supervisors' communication is with subordinates, and that most of this communication is task-based. Such communication patterns are related strongly to the nature of the relationship, since the supervisor needs to communicate directions and procedures while eliciting feedback, whereas the subordinate must request task-related clarifications while providing necessary feedback. Thus:

> H7: Over time, there will be a greater likelihood of communication between organizational members who share a supervisor–subordinate tie.

A second influence of hierarchy on emergent patterns of communication within the organization is through peer hierarchical proximity among managers. Individuals in the upper levels of the hierarchy need to communicate more with their peers than with those at lower hierarchical levels, and these interactions involve coordination with one another on issues of strategy, while making sense of and enacting the uncertain environment in which the organization is embedded (Daft & Weick, 1984). Even though a greater volume of communication is expected among managers, this effect does not extend to lower hierarchical levels since strategic communication is more likely between network members who have relatively higher status. For instance, two high level managers will communicate more with one another than two middle level managers, since the higher the managerial position, the greater will be the strategic responsibility and the degree of environmental uncertainty managers have to face, and therefore the greater need for coordination and control associated with it. For these reasons:

> H8: Over time, there will be a greater likelihood of communication between managers as positions approach the top of the organizational hierarchy.

Theories representing endogenous mechanisms

The mechanisms just described represent exogenous factors that influence the emergence of communication networks in organizations. In addition, network evolution also has an endogenous component, where the extant structure of the communication relations within the network at a given time both enables and constrains the subsequent development of communication ties among network members. This section describes three theories which account for these endogenous dynamics (social exchange theory, balance theory, and self-interest theory) and their associated mechanisms.

Social exchange theory. Social exchange theory (Blau, 1964; Emerson, 1972a, 1972b; Homans, 1974) explains dyadic interactions on the basis of the resources each actor has to offer. For example, if actor A perceives actor B as potentially having valuable resources, then A will initiate a link with B. Whether B reciprocates will depend on whether he/she feels the same about A. Social exchange theory recognizes that person A may perceive that B has resources of value, but B may not feel the same way about A. In this situation, A will initiate interaction with B, but B will not reciprocate. Reciprocity is the mechanism associated with social exchange theory in networks,

and it represents the tendency for mutual interactions to emerge among members of social networks (Brass, 1995). Thus reciprocity occurs at the dyadic level of analysis (Monge & Contractor, 2003). It follows that:

> H9: Over time, there will be a greater likelihood of reciprocated communication between two organizational members if one had communicated with the other in a previous time period.

Balance theory. Balance theory (Heider, 1958) explains the emergence and dissolution of communication ties on the basis of cognitive dissonance. An individual is more likely to forge new communication links with friends of friends and dissolve links with friends of enemies and enemies of friends. For example, let's assume that Tom and Bill are friends, and that Jane is a friend of Bill but does not know Tom. Over time, she will hear about Tom through Bill, and it is likely that she will forge a relationship with him as well. On the other hand, if Jane is a friend of both Tom and Bill, but these two are not getting along, she will likely dissolve one of these two relationships to alleviate her imbalance. To the extent that communication between individuals is reflective of positive feelings, balance theory increases the emergence of triadic structures, a mechanism that is called transitivity (Wasserman & Faust, 1994). A triad including actors A, B, and C is transitive if, as A is connected to B, and B is tied to C, then there is also a relationship from A to C. Transitivity is an important structural characteristic of social networks (Fararo & Sunshine, 1964; Holland & Leinhardt, 1972; Rapoport, 1953). This prior research leads us to expect that:

> H10: Over time, there will be a greater likelihood of communication from A to C if during a previous time period A had communicated with B and B had communicated with C.

Self-interest theory. Certain entrepreneurial actors behave in their own self-interest by actively seeking competitive advantage as they position themselves in advantageous locations in communication networks (Burt, 1992). A structural hole reflects the lack of connections between parts of a network; individuals who bridge these structural holes—by connecting two nonredundant or disconnected actors—obtain a competitive advantage by being able to control the information flow between two previously disconnected parties. The structural hole mechanism implies that actors actively seek to forge communication ties that connect disconnected others through them. In the case of actors A, B, and C, if A interacts with B, but B does not interact with C, then A will actively pursue a tie with C to bridge a structural hole, which will in turn give A power over B and C. Burt reported that upwardly mobile actors who structure their networks on the basis of self-interest by brokering unconnected parties attain quicker organizational advancement. This analysis suggests:

> H11: Over time, there will be a greater likelihood of communication from A to C if during a previous time period A had communicated with B and B did not communicated with C.

The previous hypotheses highlight how theories and their associated mechanisms independently predict the evolution of a communication network. The MTML approach points out how most communication studies frequently incorporate only one theory at a time, thus running the risk of yielding spurious results. Complex models that include multiple mechanisms that simultaneously influence the evolution of the communication network will provide a more comprehensive and precise understanding of network evolution (Contractor et al., 2006; Monge & Contractor, 2003), allowing for the determination of whether any of the theories that independently influence the evolution of the network cease to be significant when considered in the context of the more complex model.

Method

Participating Organization

The organization studied was the Public Works Division (PWD) of a military base of approximately 35,000, located in the southeastern United States, which was charged with maintaining and developing the physical infrastructure of the base. The PWD has five departments distinguished by function. Administration acts as an interface between PWD and the rest of the base while coordinating the activities of the other departments. Engineering Plans and Services is responsible for both the maintenance of existing civil infrastructure and buildings and developing plans for future development. Facilities Management oversees ongoing construction projects and ensures funds are available for future projects. Housing addresses the housing needs of military personnel and their families. Environment assures that activities at the base are in compliance with environmental regulations.

The data we analyzed here were collected as part of a larger study examining the communication and organizational infrastructure at the PWD. Data were collected every 2 months for 2 years, for a total of 13 time periods, with a 100% response rate for each time period. As we examine the evolution of a communication network for 55 actors over 13 periods, our N is 38,610 (55*54*13) or, more specifically, it equals 2,970 (55*54) observation units for dyadic communication, traced over 13 time points. During this time, a total of 9 employees left the organization, and 11 others joined. The average age of these employees was 45, and ranged from 28 to 60 years; 40 were male, and 46 were White. The employees had worked at the base for an average of 11 years, with a range from 3 to 28 years.

Procedures and Instrumentation

Employees participated in a total of 13 structured interviews at 2-month intervals for 2 years. At the beginning of each interview, they received a letter explaining the purpose of the study and guaranteeing confidentiality of responses, along with a copy of the survey. Participants responded orally to the questions with a member of the research team recording their responses.

Task communication networks

For each time period, employees were given the organizational roster of the PWD. They were asked to read each name and determine whether or not they had any task related communication with such individual during the past 2 months. Communication consisted of ''conversations in person, in meetings, by phone, via electronic mail, or by memoranda.'' Each employee estimated the amount of weekly communication with each employee with whom they communicated in the past 2months. Responses were entered into a 55 by 55[1] asymmetric matrix, where cell *ij* equaled the number of minutes per week *i* reported communicating with *j*. This matrix was then dichotomized due to requirements of the analytic approach, so that cell *ij* equaled one if *i* reported any communication to *j*, zero otherwise.[2] This provided 13 separate matrices, one for each time period, representing the emergent communication network over a 2-year period. Dichotomizing the matrices was appropriate since our theories and hypotheses concern the presence or absence of communication between two employees, and not the strength of the communication tie.

Friendship

Employees, using the PWD roster, were asked to identify those they considered to be their friends. These data were entered in to a 55 by 55 asymmetric matrix, where cell *ij* equaled one if *i* reported *j* as a friend, zero otherwise.

Gender

Gender was operationalized using a 55 by 55 matrix, in which cell *ij* equaled one if *i* and *j* were either both males or females, zero otherwise.

Common activities

To identify which employees had common activity foci, we collected the formal job descriptions of all employees. As each included multiple tasks, these were entered into text files, with each sentence of text being treated as a separate document. The Theme Machine software (Lambert, 1996) facilitated the thematic identification of activity clusters. Theme Machine is a computer program that assigns term weights on the basis of the frequency with which words appear in a total set of documents, computes similarities between documents on the basis of the number of common words and the term weights, and clusters documents according to their similarities. This procedure yielded 161 clusters. After removing clusters based on nonactivity related language and collapsing cases where clusters referred to the same activity in different terms, we identified 130 activity types (O'Keefe, 1996), representing the specific activities carried out by PWD employees.

Each of these 130 tasks was then printed on an index card. Employees were provided these cards, asked to select which tasks they performed, and to group the selected tasks into activity piles so that tasks contributing to a common activity were together. These activity piles were taken to be activity foci in the PWD. Employees then named others in the organization with whom they worked while performing each

foci. These data were entered into a 55 by 55 matrix, where cell *ij* equaled the number of common activities *i* reported doing with *j*.

Spatial proximity

A proximity matrix was created, where cell *ij* equaled three if *i* and *j* shared the same office, two if *i* and *j* were in adjacent offices, one if *i* and *j* were in the same building, and zero otherwise.

E-mail proximity

Employees reported the number of minutes per week of electronic task communication they had with other employees during a typical work week. An employee was considered to have adopted e-mail if he/she reported at least one minute of task communication via e-mail with at least one other employee. An e-mail proximity matrix was constructed, in which cell *ij* equaled one if *i* and *j* had both adopted e-mail, and zero otherwise.

Workflow

Workflow was captured as a network of inputs and outputs in the work process. This involved use of a specific government form that tracked the principal activities performed in the PWD. Specifically, employees reported the number of forms they gave to and received from other employees in the PWD during a typical work week. These data were entered into two 55 by 55 matrices. In matrix 1, cell *ij* equaled the number of forms *i* reported giving to *j*; in matrix 2, *ij* equaled the number of forms *i* reported receiving from *j*. A third matrix was then developed for which cell *ij* was the sum of the correspondent two *ij* cells in matrix 1 and 2, providing an index of the strength of the workflow link between *i* and *j*.

Supervisor–subordinate

Each dyad in the organization was coded according to whether the actors were in a supervisor–subordinate relationship. Data were entered in to a 55 by 55 matrix, where cell *ij* equaled one if *i* was *j*'s supervisor, and zero otherwise.

Peer hierarchy proximity

Employees were classified according to their hierarchical level, using one for support staff/technician, two for specialist/engineer, three for team leader, four for area chief, and five for division chief. These codes were verified by the head of the PWD. To capture hierarchical proximity in the upper echelons of the PWD, we constructed a symmetric matrix of hierarchy proximity scores, such that cell *ij* was one if *i* and *j* were both located on hierarchy levels four or five, and zero otherwise.

Analysis

Simulation Investigation for Empirical Network Analysis (SIENA; Snijders et al., 2008) is a statistical tool recently developed to analyze longitudinal network data using

actor-oriented models for network evolution (Snijders, 2001, 2005; Snijders & van Duijn, 1997). SIENA models the communication network as emerging from the aggregate of the individual choices of network actors, who mutually constrain and present opportunities to each other. The 11 mechanisms (eight exogenous and three endogenous) previously described are treated in the MTML framework as *factors that influence the likelihood of each actor initiating, dissolving, or maintaining a communication tie with the other network members.* For instance, if actors A and B have a workflow tie, according to coordination theory they will be more likely to communicate with one another (our Hypothesis 6). SIENA uses the presence of a workflow tie as a dyadic covariate that predicts whether each of these two actors will be more likely to communicate with one another. A positive workflow parameter estimate in a SIENA model would indicate the presence of this effect. As a second example, if actor A has a communication tie to actor B, social exchange theory predicts that this tie would be reciprocated (our hypothesis nine). Again, a positive reciprocity parameter estimate would support the presence of this effect. While the MTML approach explicitly recognizes the importance of understanding the simultaneous influence of these mechanisms over time, SIENA allows the investigation of which ones significantly influence network evolution.

In addition to the effects predicted by extant theory and research, actor-oriented models recognize that communication behavior has an inherent element of unpredictability, so communication network actors' actions are also assumed to show traces of residual noise. This both avoids a deterministic model and allows for the behavior of network members that cannot be accounted for by the theories. More formally, the actors locally optimize a random utility function, in which the theoretically expected effects described as Hypotheses 1 through 11 figure as a deterministic part, and the residual unexplained behaviors figure as a random component. This can be seen in the following equation, which represents the complete model for the actors' network decisions:

$$
\begin{aligned}
\mathbf{u_i}(\mathbf{x}) = & \sum\nolimits_{\mathbf{j}} \beta^{\text{outdegree}} \mathbf{x_{ij}} \\
& + \sum\nolimits_{\mathbf{j}} \mathbf{x_{ij}} \left(\beta^{\text{friend}} \mathbf{w_{ij}^{\text{friend}}} + \beta^{\text{gend}} \mathbf{w_{ij}^{\text{gend}}} + \beta^{\text{com.act}} \mathbf{w_{ij}^{\text{com.act}}} + \beta^{\text{prox}} \mathbf{w_{ij}^{\text{prox}}} + \beta^{\text{email.prox}} \mathbf{w_{ij}^{\text{email.prox}}} \right) \\
& + \sum\nolimits_{\mathbf{j}} \mathbf{x_{ij}} \left(\beta^{\text{wflow}} \mathbf{w_{ij}^{\text{wflow}}} + + \beta^{\text{super.sub}} \mathbf{w_{ij}^{\text{super.sub}}} + \beta^{\text{hier.prox}} \mathbf{sim_{ij}^{\text{hier.prox}}} \right) \\
& + \sum\nolimits_{\mathbf{j}} \left(\beta^{\text{rec}} \mathbf{x_{ij} x_{ji}} + \beta^{\text{trans}} \sum\nolimits_{\mathbf{k}} \mathbf{x_{ij} x_{jk} x_{ik}} + \beta^{\text{str.holes}} \sum\nolimits_{\mathbf{k}} \mathbf{x_{ij} x_{ji} x_{ik} x_{ki} (1 - x_{jk})(1 - x_{kj})} \right) \\
& + \sum\nolimits_{\mathbf{j}} \varepsilon_{\mathbf{ij}} \qquad (1)
\end{aligned}
$$

Here, $\mathbf{x}$ is the (dichotomous) adjacency matrix of the network at any given time point ($\mathbf{x_{ij}} = 1$: tie present, $\mathbf{x_{ij}} = 0$: tie absent); for convenience, notational dependence of the network on this time point is dropped. The $\mathbf{w}$ stand for the dyadic (matrix) covariates, and the βs are the model parameters to be estimated. The different rows of the equation indicate the different model components: the first row contains an outdegree

effect (which is analogous to an intercept in regression analysis), the second and third rows contain the exogenous effects, and the fourth row the endogenous effects. The last row contains the residual unexplained part ε of actor **i**'s preference for a tie to actor **j**, which is the random variable.

While a more detailed technical explanation of actor-oriented models is beyond the scope of this study, further details can be found in van de Bunt and Groenewegen's paper (2007), which presents a detailed, yet accessible explanation of such models.[3]

Results

Table 2 presents the correlations among the variables in the study obtained using the Quadratic Assignment Procedure (QAP), a nonparametric technique for network variables (Krackhardt, 1988). The eight exogenous factors (friendship, gender, common activities, spatial proximity, e-mail proximity, workflow, supervisor/subordinate, and peer hierarchy proximity) were represented by single matrices. To include the communication dependent variable, the reported communication between each dyad in the network was calculated across the 13 periods, which provided a matrix in which cell *ij* equaled the average communication *i* reported to *j* over such periods. A similar procedure was followed for each of the three endogenous factors (reciprocity, transitivity, and structural holes). For example, entry *ij* of the transitivity matrix gives the average number of transitive triplets that a communication tie x_{ij} closes. Table 2 shows there are significant associations ($p < .05$) between the exogenous and endogenous factors and who is more likely to communicate. These preliminary results both replicate the findings from previous research and validate the inclusion of all 11 factors in our subsequent analyses.

Testing Hypotheses 1 through 11

Hypotheses 1 through 11 were tested by running single effect models, which are summarized in Table 3. Eleven separate actor-oriented models were run using SIENA, one for each of the eight exogenous and three endogenous mechanisms. Results are consistent with correlation analysis, lending support to all hypotheses. Specifically, two employees are more likely communicate if: they are friends (H1; $\beta = .67$, $p < .001$); they are both of the same gender (H2; $\beta = .18$, $p < .01$); they work on common activities (H3; $\beta = .17$, $p < .001$); they are spatially proximate (H4; $\beta = 1.79$, $p < .001$); they have both adopted e-mail (H5; $\beta = .42$, $p < .001$); they share a workflow tie (H6; $\beta = 1.29$, $p < .001$); they have a supervisor/subordinate relationship (H7; $\beta = 2.34$, $p < .001$); and they are both managers in the PDW (H8; $\beta = 1.34$, $p < .01$). Additionally, employees have a tendency to forge and maintain ties that are reciprocal (H9; $\beta = 1.09$, $p < .001$), create transitive triads (H10; $\beta = .05$, $p < .001$), and bridge structural holes (H11; $\beta = .09$, $p < .01$). While these models only include one predictor, it should be noted they represent one of the first longitudinal empirical tests of each of these theories.

Table 2 QAP Correlations Between Communication, Exogenous, and Endogenous Variables

	1	2	3	4	5	6	7	8	9	10	11	12
1. Communication	—	.29*	.09*	.12*	.37*	.24*	.22*	.16*	.07*	.87*	.82*	.53*
2. Friendship		—	.08*	.03	.22*	−.02	.04	.03	.03	.27*	.24*	.16*
3. Gender			—	.04	−.01	−.05	.03	.03	.05	.08	.12*	.04
4. Common activity				—	.15*	.02	.06*	.13*	.09*	.17*	.13*	.08*
5. Spatial proximity					—	−.02	.17*	.23*	−.02	.46*	.19*	.11*
6. E-mail proximity						—	.11*	.03	.06	.21*	.32*	.15*
7. Workflow							—	.25*	.04	.23*	.16*	.11*
8. Supervisor/subordinate								—	.08*	.20*	.14*	.22*
9. Peer hierarchy proximity									—	.09*	.08	.11*
10. Reciprocity										—	.80*	.55*
11. Transitivity											—	.42*
12. Structural holes												—

*$p < .05$.

Table 3 Actor-Oriented Models for the Evolution of the Communication Network[a]

	1	2	3	4	5	6	7	8	9	10	11	12
Outdegree	−0.09	−0.09	−0.09	−0.05	−0.08	−0.08	−0.07	−0.09	−0.62**	−1.37**	−0.24**	−1.43**
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.05)	(0.04)	(0.04)
Friendship	0.67**											0.53**
	(0.04)											(0.05)
Gender		0.18*										−0.01
		(0.06)										(0.04
Common activity			0.17**									0.04
			(0.03)									(0.03)
Spatial proximity				1.79**								1.36**
				(0.11)								(0.12)
E-mail proximity					0.42**							0.07
					(0.03)							(0.04)
Workflow						1.29**						0.85**
						(0.12)						(0.11)
Superior/subordinate							2.34**					1.64**
							(0.47)					(0.26)
Peer hierarchy proximity								1.34*				0.78
								(0.41)				(0.52)
Reciprocity									1.09**			0.66**
									(0.09)			(0.06)
Transitivity										0.05**		0.05**
										(0.00)		(0.00)
Structural holes											0.09*	−0.06**
											(0.03)	(0.01)

[a]Standard errors are in parentheses.
*$p < 0.01$. **$p < 0.001$ (two-tailed tests).

Test of Multitheoretical, Multilevel Framework: Spurious Results from Single Effect Models

Although there is value in the analysis to this point, the MTML approach cautions against simply accepting the results of these single-effect models, as they may be spurious and thus misleading. We explored this possibility by running a full model that includes all 11 theoretical mechanisms, which is consistent with the MTML framework. Results are summarized as Model 12 in Table 3 and provide a test of the simultaneous influence of all the mechanisms on the evolution of the communication network. Four exogenous factors were no longer significant. Specifically, employees who were the same gender, participated in common activities, had adopted e-mail, and were at managerial levels in the PDW were *not more likely to* communicate, once all the other mechanisms leading to the emergence of communication were taken into consideration. Instead, two employees were more likely to communicate if they were friends ($\beta = .53$, $p < .001$), they were spatially proximate ($\beta = 1.36$, $p < .001$), they shared a workflow tie ($\beta = .85$, $p < .001$), and they had a supervisor/subordinate relationship ($\beta = 1.64$, $p < .001$). Although we discuss possible reasons for some of the mechanisms dropping out in the following section, these results support the assertion that single-effect models must be interpreted cautiously, as they may yield spurious and misleading results.

While all three endogenous influences remained significant in the full model, the direction of the structural holes mechanism changed between the single-effect and the full model. Consistent with the single-effect models, employees tended to forge and maintain communication ties that were reciprocal ($\beta = .66$, $p < .001$) and created transitive triads ($p < .001$). However, they were also reluctant to bridge structural holes ($\beta = -0.06$, $p < .001$). This reversal in the full model clearly illustrates the value of the MTML approach: while Model 11 suggests employees act in ways to bridge structural holes, Model 12 demonstrates that this is an incorrect conclusion, as they actually do the opposite.

Discussion

The study of networks has emerged as an influential focus within the field of communication, and scholars have noted the pressing need for research that builds on previous work by incorporating multiple mechanisms into single studies to assess their relative influence on communication networks (Contractor et al., 2006; Monge & Contractor, 2003). Whenever possible, these studies need to move from the cross-sectional to the longitudinal domain. Much of what we know today about the predictors and outcomes of communication networks comes from cross-sectional studies, possibly due to the difficulty in obtaining longitudinal data on communication network and to the lack of appropriate statistical methodologies for analyzing such data. Our study addresses these concerns.

Conceptually, we implemented a model based on the multitheory, multilevel approach (MTML) framework that included eight exogenous mechanisms (friendship, gender, common activities, workflow ties, supervisor/subordinate relationship,

spatial proximity, e-mail proximity, and peer hierarchy proximity) and three endogenous mechanisms (structural tendencies toward reciprocity, transitivity, and bridging structural holes) that previous research demonstrated to influence the likelihood to communicate. Each mechanism was first tested separately to verify the associations at the cross-sectional level coming from extant research extended into the longitudinal domain. Then a full model was run which simultaneously included all theoretical mechanisms, and allowed us to identify when findings from extant research may have been spurious.

Consistent with previous research, each of the longitudinal single-effect models was significant. Conversely, four mechanisms (having the same gender, participating in common activities, using e-mail, and being part of management) ceased to significantly explain the evolution of the communication network in the full model. Further, the direction of influence of the mechanism associated with bridging structural holes changed from positive in the single-effects model to negative in the full model. These results, in line with the MTML prediction, demonstrate that the more complete model detected spurious effects that otherwise might go unnoticed.

The nature of the organization may partially account for these findings. The PWD was a bureaucracy, with an accompanying emphasis on formal structures and procedures. This may have mitigated the influence of gender as employees communicated to meet job requirements. The lack of influence of e-mail adoption suggests that, in this particular organization, e-mail adoption was randomly distributed amongst employees. The lack of influence of sharing a managerial position could also be reflective of the bureaucratic nature of the organization, whose structure may be limiting opportunities for cross-functional communication.

The MTML approach may be complemented by adopting a contingency approach. This study provides insight into how extant theories may account for the evolution of a communication network, but does not provide a particularly nuanced view. A contingency approach would encourage hypotheses about which theories account for network evolution in different contexts. For example, supervisor/subordinate relationships significantly influenced this network. This may not be the case in more fluid or virtual organizations.[4] This is consistent with Stohl and Stohl's (2007) discussion of how network mechanisms may be used to increase our understanding of terrorist networks, when they say that "the link-generating mechanisms embedded in the MTML model of Monge and Contractor (2003) provide the opportunity for terrorism scholars to test network hypotheses and understand in greater detail how communication-based rules constitute terrorist organizing" (p. 107).

Among the endogenous mechanisms, both social exchange theory (reciprocity) and balance theory (transitivity) significantly influenced the evolution of the communication network. That is, individuals exhibited a strong and systematic tendency to communicate with others who had sought them out (social exchange) and to shape their communication in order to minimize cognitive dissonance (balance theory).

In addition to providing support for an MTML approach, this study had two additional strengths. First, from an empirical standpoint there are few datasets with this many observations over such an extended time period, and even fewer that were

able to utilize a full network for each data collection period. Thus, these results are unique and allow us to shed light on the underinvestigated phenomenon of network evolution. A second strength was the use of actor-oriented statistical models of network evolution implemented in SIENA, which enabled us to enact the type of dynamic analysis that has been called for by many scholars, but that has yet to be widely implemented.

This study also had limitations. First, other theoretical mechanisms might predict the evolution of the communication network and could be incorporated in the models. We made a good faith effort to identify compelling mechanisms in the extant communication network literature; however, future research could incorporate additional theories. Second, this study examined the evolution of a single relationship, i.e., communication. Future research should aim at the development of MTML models to explain the dynamics of other relationships within the network, such as advice or trust. Third, the exogenous mechanisms in the models were held time-invariant. For instance, the friendship network and adoption of e-mail were not measured at multiple points in time, and hence could not mutually coevolve with the communication network in the model estimation. Research on topics such as the iterative relationship between communication technology usage and communication networks (Contractor & Eisenberg, 1990; Hollingshead & Contractor, 2002) suggest that future efforts should dynamically explicate the theoretical mechanisms underlying the relationship between exogenous factors and emergent communication. A final issue is the nature of the testing we were able to execute in this study. Our primary goal was to identify a series of factors that have both been shown in previous research to influence the evolution of a communication network and have a solid theoretical grounding, and we feel we have provided a unique contribution to this area. However, because of the relatively large number of theories and the fact that we collected such an exhaustive data set, we were unable to have the same level of precision and control that is possible in experimental designs. For instance, it is likely that persons will approach friends to reduce uncertainty when dealing with personal issues, and content experts when seeking to reduce uncertainty surrounding technical issues. [5] Our method constituted a necessary trade-off to pursue this type of project.

Notes

[1] Our analysis used data for the 55 individuals who were PWD employees for the duration of the study.

[2] This type of decision is always an issue in any type of social network analysis. For instance, if data is not dichotomized, dramatic errors in estimated communication (e.g., a person reporting 40 hours a week of communication with another) may be included in the data. Ultimately, these types of decision must be driven by theoretical and practical concerns, as they were here.

[3] Readers should note that the use actor-oriented models differs from an alternative strategy for mathematically modeling social processes using simulation methodologies. In this alternative approach, the implications of theories are formalized as equations, which are then simulated via many computer runs. The resulting ''simulated findings'' are treated as

hypotheses which may then be verified with empirical data. For a complete description of this approach along with its limitations, see Contractor and Whitbred (1997), or Contractor and Monge (2002).

[4] We would like to thank an anonymous reviewer for this suggestion.

[5] We thank an anonymous reviewer for this insight.

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