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Casting the Net: A Multimodal Network Perspective on Knowledge Management

Gerald Kane
Emory University

Maryam Alavi
Emory University

CASTING THE NET: A MULTIMODAL NETWORK PERSPECTIVE ON KNOWLEDGE MANAGEMENT

Gerald C. Kane and Maryam Alavi
Goizueta Business School
Emory University
Atlanta, GA U.S.A.
jerry_kane@bus.emory.edu **maryam_alavi@bus.emory.edu**

Abstract

Recent information systems research has challenged the tendency of researchers to focus upon single information system (Vertegaal 2003) or upon individuals simply as users of those systems (Lamb and Kling 2003). Responding to these critiques, this paper forwards a new paradigm through which to study knowledge management: the multimodal knowledge network. Drawing heavily upon the field of social network research, we argue that the way in which multiple individuals interact with one another and with multiple information management systems will have significant implications for organizational knowledge sharing outcomes. In this study, we conduct a comparative case study through which to begin building a theory of multimodal knowledge networks. We study five health care teams in a large health maintenance organization and find that, although these teams have identical portfolios of information management systems and a similar complement of employees, each team configures its knowledge resources differently to complete similar tasks. We find that the structures that result from these multiple interpersonal and human–systems interactions have implications on knowledge outcomes for the network. We develop propositions as a result of this analysis and outline directions for future research.

Keywords: Knowledge management, social networks, multimodal networks, health care, theory

Introduction

Considerable research has attested to the important role of information management systems, such as databases, to knowledge management initiatives in organizations (Alavi and Leidner 2001). Some researchers have commented that these information management systems (IMS) are, in fact, the cornerstone of successful organizational knowledge management strategies (Davenport and Glaser 2002). Although considerable research has investigated effective design and implementation of these systems, recent research has suggested that whether employees actually use the IMS at their disposal is a critical factor in understanding their impact on organizational knowledge management initiatives (Devaraj and Kohli 2003).

Despite the importance of this human–IMS interaction to knowledge management performance, little is understood about how individuals actually interact with IMS in organizational settings beyond the single user–system relationship. Researchers have begun to recognize that the limited view of understanding an individual solely in terms of his or her role as user of information systems significantly limits the scope of inquiry into IMS use (Lamb and Kling 2003). Individuals are not simply users of information systems, but are social actors, influenced by a number of different environmental forces that affect the way in which they interact with and value information systems. Others have further noted that it may also be limiting to examine only the way in which individuals interact with a single information system, when most individuals employ multiple information systems to manage different types of knowledge and knowledge tasks (Vertegaal 2003). IMS are embedded with distinct social assumptions by their designers (Desanctis and Poole 1994), and these embedded social structures may complement or complicate the way in which individuals interact with multiple systems.

In this paper, we forward a model to complement existing IS research by understanding the way in which multiple individuals interact with multiple IMS to manage knowledge, *the multimodal knowledge network*, defined as the collection of multiple people and multiple information management systems with which those individuals interact to provide or receive information to perform tasks (Monge and Contractor 2003). We argue that, when examined as a whole, the features of this multimodal knowledge network can help explain outcomes of knowledge management initiatives that are overlooked when only examined at the level of the system or of the single user–system relationship.

In order to identify the features of these knowledge networks, we draw heavily upon the field of social network research (Raider and Krackhardt 2002). Social network research has been used extensively in management to knowledge sharing relationships between people (Hansen 1999; Reagans and McEvily 2003; Reagans and Zuckerman 2001) and via information technology-based communication-support systems, such as e-mail and listservs (Ahuja et al. 2003; Wasko and Faraj 2005). In this paper, we aim to demonstrate that this social network paradigm can be extended to understand the way in which multiple individuals interact with multiple IMS for knowledge management. In doing so, we adopt the *embedded view* of knowledge in which the social network perspective is based—knowledge as present in the minds of individuals, in the information systems, and in the interactions between them (Nidumolu et al. 2001; Spender 1996)—rather than the data–knowledge–information hierarchy often used.

The remainder of the paper proceeds as follows. First, we review several features of social networks that have proven to be influential in the study of knowledge management: tie strength, network density, and centrality. Second, we detail our research method and setting. We conduct a comparative case study of five health care teams (HCT) in a large, national health maintenance organization (HMO). The advantage of this research setting is that the teams are comprised of roughly the same complement of people, employ an identical portfolio of information systems, and perform a common task. Despite these commonalities, we find that each configures its multimodal knowledge networks in distinct ways, and each HCT will be analyzed as an independent multimodal knowledge network. Third, following Eisenhardt (1989), we seek to use this case study to begin building a theory of multimodal knowledge networks. We first conduct a within-case analysis to identify the relevant features of these multimodal knowledge networks. Then, we conduct a cross-case analysis to identify how these features influence knowledge outcomes.

Knowledge Management in Social Networks

Several features of social networks have proven critical for predicting knowledge management outcomes. First, the strength of the relationships, or ties, between individuals has been shown to influence the ease with which particular types of knowledge are shared between them. Second, the portfolio of ties that comprise a knowledge network—measured in terms of a network's density—has also been shown to be important, both in conjunction with and independent from tie strength. Third, the configuration of ties within a network of others—particularly identifying which individuals are core or periphery to the network—has proven influential to the knowledge sharing behaviors of both the individual and the network.

Tie Strength

Network research has long examined how the nature of ties between individuals influences the knowledge sharing behavior of the network. Ties are usually described in terms of their strength, strong or weak, and two factors are usually used to determine tie strength: frequency and depth of interaction (Mardsen and Campbell 1984). Since weak ties are characterized by less frequent and more superficial interaction between individuals, they usually require less effort to maintain. Individuals usually maintain these relationships with a greater number and variety of others; thus, weak ties are typically useful for giving an individual access to a greater breadth and variety of knowledge (Constant et al. 1996; Hansen 1999). In contrast, strong ties are marked by greater frequency and depth of interaction, usually requiring greater effort to maintain. Individuals can maintain strong ties with fewer others, and they are often associated with greater trust between parties (Uzzi 1997). Because of their distinct characteristics, knowledge management researchers have explored different ways in which strong and weak ties affect knowledge sharing. Research suggests that weak ties are superior for searching for knowledge and transferring codified knowledge within a network (Burt 1992; Hansen 1999). In contrast, strong ties appear superior for transferring knowledge, particularly tacit knowledge, and individuals tend to rely on strong ties to transfer sensitive or critical knowledge (Hansen 2002; Reagans and McEvily 2003). Regardless of their particular features, tie strength is clearly an important feature of social networks for understanding knowledge management outcomes.

Density

In addition to attempting to understand the characteristics of ties that comprise a network, researchers have also sought to understand the composition of the whole relational network, measured in terms of a network's density. Defined as the ratio of actual ties to the number of possible ties in a network, density is somewhat related to tie strength (Brass 1995). Although related, researchers have found that it is necessary to examine both tie strength and network density independently to effectively capture the knowledge management dynamics in the network (Reagans and McEvily 2003). The debate as to whether high-density or low-density networks perform better has been and continues to be a key area of interest for network researchers (Raider and Krackhardt 2002) primarily because researchers have found evidence to support both sides of the argument. Some researchers have found that higher network density improves knowledge management outcomes (Ingram and Roberts 2000), whereas others have found that low-density networks are superior (Cummings 2004). Many researchers now agree that the impact of density largely depends on the knowledge management environment in which the network operates. High-density networks may be more effective for knowledge sharing *within* teams, whereas low-density networks may be more effective for knowledge sharing *across* teams (Reagans and Zuckerman 2001). Density may also be related to knowledge tasks, with high-density networks being more effective for knowledge *exploitation* and low-density networks being more effective for knowledge *exploration* (Rowley et al. 2000).

Centrality

Social network researchers have suggested that the configuration of the network is also important to knowledge sharing effectiveness, often described in terms of centrality of particular individuals in the network. Although social network analysis has developed a number of different ways to define centrality within a network, the general construct of centrality seeks to capture the same characteristic, whether particular individuals occupy a central or peripheral position within the relational network (Brass 1995). Individuals in central positions within the network have been shown to possess a number of knowledge benefits above others in the network. Central individuals have greater and timelier access to knowledge (Burt 1992) and the individuals who are central in a network may have important implications for the performance of that network. Since central individuals often serve the role of knowledge-broker for the rest of the network, the performance of these central individuals may be critical to the performance of the network as a whole (Cross and Prusak 2002). Teams have been shown to perform better if central individuals have more general knowledge than if they have specialized knowledge (Rulke and Galaskiewicz 2000). Further, centrality is not simply a function of the individual, but is also a measure of the degree to which a network values the knowledge and contribution of particular individuals (Perry-Smith and Shalley 2003).

Research Method and Setting

In order to explore the concept of multimodal networks in IMS-based knowledge sharing, we conducted a comparative case study for the purposes of theory building. We studied five primary care teams at a regional division of HealthProviders, a large, national health maintenance organization. Each team is analyzed as an independent multimodal knowledge network. These teams perform a common task, are comprised of a similar complement of employees and expertise, and possess an identical portfolio of information systems used for knowledge sharing. Despite these commonalities, however, each team assembled these individuals and information systems into different network structures. Thus, these teams should provide a valuable opportunity to isolate and examine the features of multimodal networks. Following Eisenhardt (1989), we first analyze our data by conducting a within-case analysis of each of the five primary care teams. The purpose of this within-case analysis is to identify which features of the multimodal knowledge sharing networks are likely important for characterizing these networks. Then, having separated teams into high- and low-performers, we conduct a cross-case analysis between the five distinct multimodal networks to assess how network characteristics identified in the within-case analysis lead to performance outcomes of these networks. Through the course of this cross-case analysis, we develop a series of propositions for future testing.

HealthProviders has begun to invest heavily in IMS as part of an effort to share knowledge more effectively within its organization. The organization's effectiveness relies heavily on the front-line health care teams (HCT), which consist of the primary care providers (PCP) and their support staff (e.g., nurses, administrative staff), to interact with this IT infrastructure effectively. One respondent echoed these sentiments:

> *Another success factor is while trying to keep the health care team in the middle of all the care, developing enough support systems and support resources to allow them to deliver it. What I mean by that is: we have the PCP at the epicenter of the world and we ask them to do a hell of a lot. They are only as good as the systems you supply them to work with, and how well they use them.*

The key to providing effective health care, therefore, depends on how well this team, represented as a multimodal knowledge network, can function.

Although teams occasionally seek knowledge outside the team (e.g., PCP consulting with an outside specialist), the primary function of the HCT is to manage knowledge *within* the team (medical history, test results, clinical guidelines, prescription formulary) in order to leverage the most appropriate organizational resources and expertise to care for patients. Each HCT has a common set of knowledge tasks: to use its information infrastructure to develop and maintain both specific (e.g., individual patient medical records) and general (e.g., features of diabetic patients as a population) knowledge about the patients in their charge. Geographic proximity, scheduling procedures, and colocation of paper-based records mean that PCPs within a team often treat one another's patients but rarely treat patients from other teams. HCTs are evaluated as a unit based on financial, patient satisfaction, and clinical quality metrics. Since individual bonuses for physicians and team leadership are based on these team-level outcomes, HCT members have incentives to work together.

The HCT is responsible for providing baseline assessments of patients' needs and responding with three types of treatment: acute care, referrals, and chronic care. We will focus primarily on the chronic care treatment in our qualitative research for several reasons. First, because chronic care involves patient tracking, ongoing collection of patient diagnostic and pharmaceutical knowledge, and analysis of all available information to adjust care guidelines for a particular patient, it is the most knowledge intensive of the treatment types. Second, HealthProviders places a special emphasis on chronic care, encouraging HCTs to treat *all* patient contact—including acute care and referrals—as an opportunity to address the applicable chronic care needs of the patient. Third, research has shown that costs related to chronic care of just a few diseases accounts for the vast majority of the projected increase in U.S. health care costs (Thorpe et al. 2005). Health care organizations that can learn to treat these chronic diseases efficiently and effectively are likely to leverage these treatment practices for competitive advantage (Porter and Teisberg 2004).

This setting is particularly advantageous for studying the features and performance outcomes of multimodal knowledge networks because the commonalities shared by each network allow theoretical comparisons across teams. First, these teams share a fairly similar workload, assigned approximately 2,000 patients per PCP, adjusted for patient risk. Second, each HCT is comprised of virtually identical staff. Each HCT consists of between 4 and 8 PCPs and between 8 and 16 clinical and administrative support staff members. Staffing and organizational roles are assigned at the team level, and each team is comprised of similar organizational roles, such as clinical support staff, population care managers, clinical supervisors, and lead physicians. Third, each team also shares an identical portfolio of six primary information systems (scheduling, laboratory, radiology, pharmacy, population registry, and medical abstract systems), which are used by the HCTs in performing their tasks (see Table 1). Fourth, they all have similar levels of general computer efficacy. Each team member was asked to rate their facility with systems on a scale of 1 to 7, and no significant differences were reported across the teams under study. This control of the network composition across cases permitted by the environment enabled us to isolate different features of the multimodal networks under analysis. Despite these commonalities across task, staff, and IMS, the knowledge network represented by each team was structured quite differently. This environment, therefore, represents an ideal setting for isolating the features of multimodal knowledge networks and analyzing the implications of these features on outcomes.

Case Selection

We collected both qualitative and quantitative data through multiple methods (Table 2). Over the 12-month period of the study, we attended meetings, participated in a series of information systems demonstrations, conducted both individual and group interviews, observed HCTs during their workday, reviewed company documentation, and studied quantitative data. Qualitative data was coded using AtlasTi. Coding categories and frequency of occurrence can be found in Table 3.

We selected a small sample of HCTs for analysis based on their characterization as high performers or low performers. Generating research propositions by comparing and contrasting a small group of cases strikes a balance between depth of observation and generalizability, which has been used successfully in previous theory-building research (Dubé and Paré 2003). Two criteria were used for case selection. First, we asked the chief of Internal Medicine for the region to identify HCTs that were the highest and lowest performers in terms of clinical quality outcomes. Second, this subjective assessment was corroborated using quantitative organizational data, a series of diabetes metrics highlighted by the organization as a critically important quality initiative during the past year. Yearly monitoring of three metrics is considered to be the standard of care by which the diabetes can be effectively managed: (1) HbA1C, a blood sugar measure, (2) LDL, a cholesterol measure, and (3) nephropathy, a kidney measure. If monitored effectively, these metrics enable the teams to provide proactive chronic care; the organization maintains records regarding the percentage of patients in a team in compliance on these yearly metrics.

Table 1. Description of Information Systems Employed by HCTs

System	Primary Users	Description	Comments
Lab	PCP, clinical support staff, lab technicians	PCP orders test through system, results sent electronically to PCP inbox.	Only system that requires correct password for full functionality. A new system, it had significant problems with implementation.
Scheduling	Advice nurse, call center staff, administrative staff	Manages appointments, patient flow, and patient contact/ benefits information. Permits longitudinal analysis of data.	Tacit knowledge problems, the person making appointment needs to know whether problem required 15- or 30-minute appointments, often mis-scheduled.
Radiology	PCP, clinical support staff, radiology tech, radiologist	System only used for scheduling radiology tests. Radiologist inputs diagnosis into system.	Only operational system without any data links to others.
Medical Abstract	Administrative support staff, PCP (mediated)	Summarizes diagnoses, treatment, and pharmacy data over past 10 patient visits.	Data populated entirely by other systems. No direct data input by HCTs.
Population Registry	PCM, system administrator, data clerk, PCP (mediated)	Tracks patients with chronic diseases (e.g., diabetes). Determines whether care provided within guidelines.	Intricate social network supports interaction. Each disease managed separately, patients with multiple diseases will be in multiple registries.
Pharmacy	Pharmacy staff	Tracks pharmacy refills from local pharmacies.	Not used directly by teams, but provides important data used by other systems.

Table 2. Description of Qualitative Data Used for Study

Unstructured Interviews	9 interviews; average 60 minutes per interview
Semi-Structured Interviews	16 interviews; average 55 minutes per interview
Focus Group Interviews	5 interviews; average 6 participants; average 50 minutes per interview
Conference Call	1 conference call; 19 participants; 45 minutes
System Demonstrations	6 demonstrations; average 45 minutes per demonstration
Meetings	16 meetings; 5 distinct workgroups; average 180 minutes per meeting
Observation	5 HCTs; 4 distinct facilities; average 8 hours per observation per HCT
Documentation	Meeting minutes (past 2 years); organizational IS strategy documents

Table 3. Final Coding Categories and Frequencies of Observations

General Network Characteristics		Tie Strength (General)	42
• Network Composition	39	• Strong Ties	19
• Complex MMKN Interactions	28	• Weak Ties	16
		Density (General)	29
Outcomes		• High Density	20
• Cost	24	• Low Density	19
• Care Quality	17	Centrality (General)	39
• Efficiency/Effectiveness	13	• Direct Ties	15
		• Indirect Ties	19

These key diabetes metrics were chosen as the basis for assessing performance because they represented explicitly defined organizational knowledge outcomes, they had clearly defined causal links to organizational performance outcomes, and the organization had identified them as key benchmarks by which to evaluate team performance. As the chief indicated,

> *Diabetes care is really the classic case when dealing with disease state management. It encompasses cardiovascular disease, eye disease, renal disease, and a whole host of other medical problems. When dealing with diabetes, you really summarize what is happening all across the spectrum.*

Diabetes metrics, therefore, appear to serve as an effective representative indicator for clinical quality enabled by the team's multimodal knowledge network. Further, since diabetes patients are considered high-risk, failing to monitor these patients can have significant financial implications for the organization. A single hospitalization can cost the organization $10,000; thus, even a 1 percent change in the hospitalization rates for a single team can cost $1 million.

Each of the high performing teams identified by the chief scored above average for the region, and each of the low performing teams scored below average for the region on all three diabetes metrics. The selection process resulted in the study of five HCTs, three of which were high performers and two of which were low performers. The sixth team declined to participate in the study.

Within-Case Analysis: Features of the Multimodal Knowledge Network

The first phase of analysis involved conducting a within-case analysis to identify which features seemed to be relevant across multimodal knowledge networks.

Tie Strength

Tie strength is often defined in network literature as an average of frequency and depth of interaction between two nodes in a network (Mardsen and Campbell 1984). Variation observed in both frequency of interaction with the IMS and the level of functionality used appears to translate well into a measure of tie strength with the information systems in a multimodal network. The strength of ties with the information systems in teams will likely prove important in understanding the effectiveness of IMS-based knowledge sharing.

One method for gauging tie strength involved noting differences in frequency of usage. Some individuals, both doctors and nurses alike, actively used the system as part of their workflows. As these individuals needed to interact with the systems to conduct particular tasks, they went directly to the system in order to enter or retrieve the needed information before moving on with the next task. Others seemed to interact with the system less frequently, batching the necessary tasks and entering them at a later time when it was more convenient to do so. This batched data entry could occur every few hours, at the end of the day, or after a few days of allowing the necessary tasks to accumulate. For instance, in one team, the PCPs would interact with the systems immediately following each patient visit, resulting in near real-time information update. In another team, however, PCPs would see two or three patients at a time, and then interact with the system while the nurse moved a new set of patients into the exam rooms. In one extreme situation, the PCP saved all but essential system interactions until the end of the day.

Individuals also appeared to employ higher or lower levels of the functionality available in each of the IMS at their disposal. Some used the systems only for the most basic and essential tasks necessary to their work requirements. For instance, when interacting with the scheduling program, a number of individuals simply printed out the PCP's schedule at the beginning of the day and posted that printed copy in an area where all relevant parties could track it. Others used additional functionality available in the systems and used the scheduling system to monitor and improve the information flows into the work environment. These individuals used this system functionality to track when patients arrive and how long they have been waiting, which coworkers may be running behind and could use additional help, and to monitor schedule changes that might happen through the course of the day.

Density

Teams demonstrated different overall interaction structures that might be generally categorized as *high-* and *low-density* networks (Figure 1). Some teams preferred to have individuals develop very general working relationships with every member of the team,

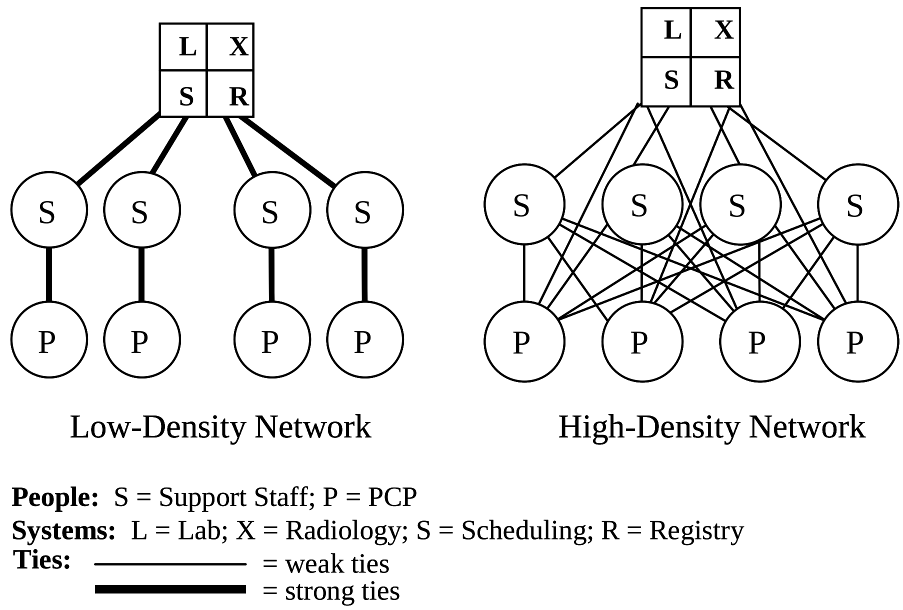

Figure 1. Multimodal Structures Observed in Teams (Density)

whereas other teams preferred to match PCP and support staff into smaller units in which very strong working relationships developed among the members and there was relatively little interaction with members of the team outside the subgroup. The decision whether to cultivate a high- or low-density network was intentional and left to the discretion of the team supervisor. As one supervisor indicated,

> *It's pretty much up to the supervisors of the team to decide. We have chosen to rotate staffing because we feel like it gives us better flexibility and cooperation across the whole team. I have colleagues in other teams, however, who swear by the other model.*

The choice made in this example resulted in a dense network of ties in which individuals had relationships with nearly all other members of the team. The alternate structure resulted in a lower-density network in which individuals often interacted with only a few others in the team.

The nature of this interpersonal network structure had implications for the way in which people interact with the information systems. Because individuals in the high-density networks were constantly working with different members of the team, they needed to interact with nearly all the information systems in the multimodal knowledge network at one time or another. Since staff roles were regarded as largely interchangeable, not knowing with whom they would be working or what tasks were required of them, general familiarity and interaction with all of the available systems was critical to effective functioning in this network structure.

In contrast, the low-density networks resulted in individuals developing more specialized and specific interactions with particular systems. Since individuals knew precisely with whom they would be working regularly, they were free to focus on a few systems that they would be required to use on a regular basis. For instance, one support staff reported a PCP's tendency to use a particular system directly, instead of relying on the clinical support staff:

> *Dr. Smith loves to use the lab program. I know that he likes to enter his labs himself. We work together on the other systems, but the labs are his domain.*

Individuals in these low-density networks interacted with a fewer number of the available systems, resulting either from a division of labor between PCP and support staff or from a mutual decision to value a particular system above or below others. For instance, more pressing needs of day-to-day treatment meant that some PCP-support staff teams underutilized systems that supported longer term goals, such as the population registry system. Because the interpersonal network was less interdependent, each subunit was free to develop its own style of interaction with the information systems in the low-density network.

Information Systems Centrality

Whereas tie strength captures average individual IMS interaction within the network and density captures the average number and strength of all relationships across the network, centrality captures particular structural characteristics of the network (Figure 2). For instance, centrality reflects which individuals are using the systems in the network. Two of the teams observed had assigned a unique role to a member of their team, that of dedicated data clerk. The primary job responsibility of the clerk was to use the systems on behalf of other members of the team. Team members would communicate to the data clerk what needed to be done within the system, and then the clerk would conduct the needed tasks. Other teams did not assign a specialist position for data entry, so these responsibilities were distributed across the team. Whereas average tie strength with the systems and network density might be equal between these two configurations, the structures of interacting with the systems are clearly quite different. One way to begin capturing these structural differences is through an examination of centrality.

On another level, centrality also captures the effectiveness of the interpersonal social network surrounding the single user–system relationship. For example, each team had a dedicated user for the population-registry system, and that person would communicate information from the system to the rest of the team.

Although frequency of usage was controlled by allotting those users a designated and equal amount of time per week to interact with the systems, the degree to which others used the information provided by the dedicated users varied across teams. As one team leader reported,

> *Dr. G is the provider on our team that actually works with the registry and will get all that information that is input into the registry system in usable form. Of course he goes through all that work, gives it to the other providers, and then some throw away the information before ever looking at it.*

Although the system may be used by the same people and for the same amount of time between teams, the efficacy of the knowledge sharing relationships between the system user and others in the team will also be an important factor in assessing the impact of IMS. These network-level interactions will also be reflected in the centrality of the systems.

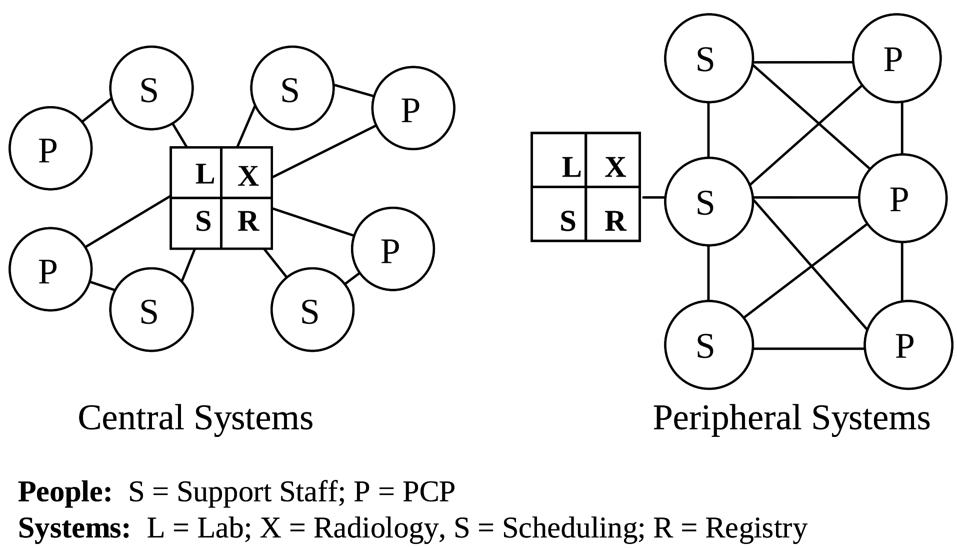

Figure 2. Multimodal Structures Observed in Teams (Centrality)

Table 4. Summary of Comparisons between Multimodal Networks

TEAM CHARACTERISTICS	Team A	Team B	Team C	Team D	Team E
# PCP in Team	6	4	4	4	8
# Patients (Risk Adjusted)	13982	9720	9504	9156	17705
# Patients/ PCP	2330	2430	2376	2289	2213
Performance (as Reported by Chief)	High	High	High	Low	Low
Diabetes Monitoring, Percent of Patients Within Guidelines: HbA1c/LDL/Nephrology	82/84/84	87/86/82	82/81/79	74/75/66	72/77/65
Average Team Tenure	5.9 years	5.84 years	8.62 years	5.3 years	6.3 years
NETWORK FEATURES					
Tie Strength	High	Mixed	High	Mixed	Low
Density	High	High	Hybrid	Low	Low
Centrality	Central	Central	Central	Peripheral	Peripheral

In summary, we made three key observations regarding the structure of multimodal networks. First, *tie strength* captures the frequency and depth with which team members directly interact with the information management systems available to the team. Second, *density* represents the total portfolio of relationships present in a network as a function of the number of possible relationships in a network. Third, *information systems centrality* captures how these knowledge sharing relationships are configured in a way that places the information systems as either central or peripheral to the overall knowledge sharing network as a function of all knowledge sharing relationships in a team.

Cross-Case Analysis: Connecting Network Features to Performance

To assess how these features of the multimodal knowledge network influence knowledge and performance outcomes, we then compared the features of the high-performing networks with the features of the low-performing ones to assess whether particular features of the networks were associated with performance (see Table 4).

One of the most interesting and significant observations of our analysis was the high degree of variance in the configuration of the multimodal knowledge network between the HCTs. Each team was comprised of virtually identical personnel, systems, and training, but each configured its multimodal network in a different way (see Appendix A). One supervisor, who had worked at two facilities simultaneously during a time of transition, confirmed our observations:

> *I think you will find that everybody is doing something very different. I have worked at two facilities for a year, both simultaneously. They do things completely differently; they really do. It's almost like being in a foreign land when you go to another team.*

Tie Strength

In our within-case analysis, we drew upon existing social network literature to define tie strength as the frequency with which individuals interacted with the system and the degree of functionality used. Observation suggests that greater tie strength between users and systems leads to greater knowledge and performance outcomes.

First and most simply, more frequent interaction seemed more beneficial than less-frequent interaction. Oftentimes the individuals who interacted with the systems less frequently by batching their work performed redundant and duplicate tasks that took significant time and energy to complete. They would record the necessary tasks on preprinted forms or simply on scraps of paper and then would file those notes away for later entry into the information systems. We observed several instances where clinical support staff members had difficulty remembering exactly what needed to be done in the system and had to clarify with the PCP to refresh their memory as to what particular notes meant.

Second, since the multimodal network often worked together to address the patient care tasks, individuals who batched their processes often left others who used the system waiting for particular information before they could begin their tasks. For instance, the lab had to wait until particular orders were input into the lab system before they could begin processing work for the patient. Frequently, lab workers had to call the HCT to remind them to enter the orders into the lab system so that they could begin processing the data.

Third, frequency of interaction also had implications for efficient access to the system. Systems in this setting each required a different password, which expired at different intervals. Individuals who used the system infrequently often found it more difficult to manage their passwords. In fact, passwords could be reset or disabled if not used within a given interval. The password protocols discouraged infrequent users from using the system. As one PCP explained,

> *I lost access to the system once because I could never remember my password. I simply did not use it enough. Then, the system kicked me out and I just had to access the system through others from then on. It was just easier to use it that way than to go through the hassle of resetting my password through the IT department.*

Thus, infrequent users were able to interact with the systems less efficiently and effectively than more frequent users.

Tie strength is also defined by the degree of functionality used within the systems, and teams that used a greater depth of functionality within the systems also performed better than teams who only used the systems for basic and essential tasks. One clinical support staff in a low-performing team used the scheduling system only by printing off the schedule at the beginning of the day. Using such a low level of functionality resulted in repeated problems and led her to question the value of the system and its information. She indicated,

> *I don't know why I even bother paying attention to the schedule. By the time I start my day, everything has already changed. Honestly, I am better off just taking things as they come, rather than trying to keep up with of how things are supposed to happen.*

Users in high-performing teams were able to use the functionality of the same scheduling system to provide real-time information related to patient flows. They found the system valuable precisely because it enabled them to track the inevitable changes in the schedule and also help others when problems arose.

These observations suggest that stronger ties between individuals and systems in a multimodal network are positively associated with knowledge and performance outcomes.

> ***Proposition 1:*** ***Tie strength between users and systems will be positively related to performance in a multimodal knowledge network.***

Density

Network density describes the total number of relationships present in a multimodal network as a function of the total possible relationships in that network. We identified that teams demonstrated one of two network structures, low- or high-density, and that these structures influenced not only the interpersonal interactions, but also interactions with the information systems. As a general rule, the low-performing teams under analysis demonstrated characteristics of low-density networks and high-performing teams opted for high-density structures.

The large number ties cultivated in the high-density networks created several distinct advantages for the team. Because they had cultivated relationships with all members of the team, members of high-density networks were more willing to step in and help one another. As one high-performing team member reported,

> *Who do you go to if you have a problem or need help with the system? What I've learned in the teams is that if you don't know, someone on your team has figured it out. Or, they'll see you struggling with a particular thing. They'll walk over and volunteer to help.*

We observed that individuals in high-density networks developed more general levels of competence with a greater numbers of systems, which meant that individuals in these networks often used the systems in similar ways. These standardized ways of interacting with the systems meant that team members could easily step in and assist others with necessary tasks because they cultivated interchangeable knowledge. A supervisor of a high-performing team noted that this interchangeability was her reason for choosing a high-density network:

> *Pretty much everyone does everything the same. In terms of prioritizing things for individuals and individual staff members, it's uniform in terms of how the day-to-day activities are organized and the systems are used. That way we can support each other better with help using the systems.*

The high-density networks reported greater commonality in the nature of the user–system relationship, aiding the willingness and the ability of individuals to help one another.

This common interaction was not observed in the low-density networks. We found that low-density networks developed subnetworks that had specialized and idiosyncratic ways of interacting with the systems. This idiosyncratic usage is not a problem in and of itself, but it became a problem when they were not able to develop shared knowledge about how to use the systems. Individuals in the network, therefore, could not rely on each other for assistance interacting with the systems. During our observation of one low-performing team, we observed one of the support staff members turning to another for help using the system. As they tried to figure out how to solve the problem, the two users realized that they were actually using different versions of the same system, each with somewhat different functionality. Because of these differences, one user was unable to help the other with her problem. One supervisor of a low-density network expressed frustration at this tendency.

> *So for at least two weeks, administrators were given the task of going around to every department and make sure they are not using the old version of the system. I would see that blue screen [characteristic of the older version] but they would see me coming and switch systems and say, "We are not in." I couldn't get some to stop using it.*

The use of different versions of applications within teams was common in low-density networks but not in high-density networks. These differences did not cause widespread operational problems, because these applications still interfaced with the same information repositories, but it did create difficulties for individuals in the team to rely on fellow users for help using the systems or developing common knowledge within the team.

> ***Proposition 2:*** **High-density networks will perform better than low-density networks in a multimodal knowledge network.**

Information Systems Centrality

Information systems centrality captures the configuration of the multimodal knowledge network through both the position of the information systems in the network and the interpersonal relationships supporting the IMS interaction. We found evidence that centrality on both of these levels influenced the performance outcomes of the multimodal knowledge network.

Information systems centrality captures the role of the information systems within the multimodal knowledge network. For instance, we observed that PCPs demonstrated several distinctive patterns of interacting with systems—dependent, independent, and interdependent—and each of these different interaction patterns would result in different centrality scores for the systems. In *dependent* interaction, the PCP always relied on support staff to interact with the systems, never interacting with the systems personally. *Independent* interaction meant the PCP insisted on always personally and directly interacting with the system, never relying on the support staff for help using the systems. *Interdependent* interaction, in contrast, reflected the tendency for the PCP and support staff to interact with the systems interchangeably. We observed that PCPs demonstrating interdependent interaction performed better, and this type of interaction would be reflected in certain centrality measures when aggregated to the whole network level.

Nevertheless, centrality is also a function of the efficacy of the interpersonal knowledge sharing relationships with system users. For instance, although the general structure of interactions was the same in the two teams with designated data clerks, the centrality of the systems was different because each clerk had significantly different relationships with others in the team. In a high-performing team, the data clerk was seated at a dedicated terminal in the middle of the team's work area. Team members frequently approached her regarding more complicated tasks in the system, to seek advice regarding one of the systems, or to use the system together, both looking at the monitor. In a low-performing team, the data clerk was located in an office that was off the regular communication and workflows of the teams. Team members rarely spoke to this data clerk, and she had a series of inboxes for data entry forms on her door, further minimizing communication. The official roles of each position and system interaction were the same, but the relationships of that individual with the rest of the team resulted in different centrality of the systems within the network.

In essence, centrality of the systems captures the degree to which the entire network interacts with the system, both directly and indirectly, through others. When asked to assess the performance of the information systems to the HCTs on a scale of 1 to 10, the Chief of Internal Medicine alluded to this importance of the entire team valuing and using the systems:

> *I would probably say that for the average team, the value of the systems is about a seven; but this depends on the team support around the system. That number may either be an eight or a nine or may go as low as a five. Example: If you have a team and everyone has taken ownership, they are going to make sure that when a patient comes in, they will check the population registry system to see what needs to be done, and communicate those needs to the appropriate people. In other teams, this desire to do the right thing is not there; and because of this lack of desire, the registry won't be checked, and then things that need to be done may or may not get done because the information is not communicated. Those teams may tend to value the systems at five or six versus other folks who take more ownership may be eight or nine. Put seven in the middle as an average.*

The value of the systems was clearly dependent upon the role of the systems within the entire network, depending both on how individuals accessed the systems, how they communicated the knowledge from the system to relevant others, and what individuals did with that knowledge once received. These observations suggest that centrality of the systems is positively related to outcomes.

> ***Proposition 3:*** ***Centrality of the information systems in a multimodal knowledge network will be positively related to multimodal knowledge network performance.***

Conclusion and Future Directions

The purpose of this comparative case study was to forward the concept of the multimodal knowledge network as a means by which to study IMS-based knowledge management initiatives. Our analysis showed that teams may have the same complement of employees and information management systems, but the way they configure these resources to manage knowledge may vary considerably, with significant implications on outcomes. We suggested that the paradigm of social network research may be a valuable means by which to study the way in which the multiple individuals and multiple IMS come together for knowledge management tasks, identifying three features—tie strength, density, and centrality—which may help describe and predict these outcomes.

Clearly, a number of possible research directions exist in relation to a study of multimodal knowledge networks. First, social network research has shown that additional features of the interpersonal knowledge network, such as relational and cognitive dimensions, may affect outcomes, and further research can determine whether these features also translate in the multimodal network setting (Nahapiet and Ghoshal 1998). Second, the propositions developed here can be tested through quantitative methods—regression analysis being the most appropriate for our method and propositions—to further corroborate the validity of the multimodal network approach. Third, the multimodal network perspective can and should be applied to IMS-based knowledge sharing in other environments. Nevertheless, the multimodal network perspective on IMS-based knowledge sharing may represent an exciting new approach to human–system interactions that complement existing paradigms in information systems research to build a robust body of research.

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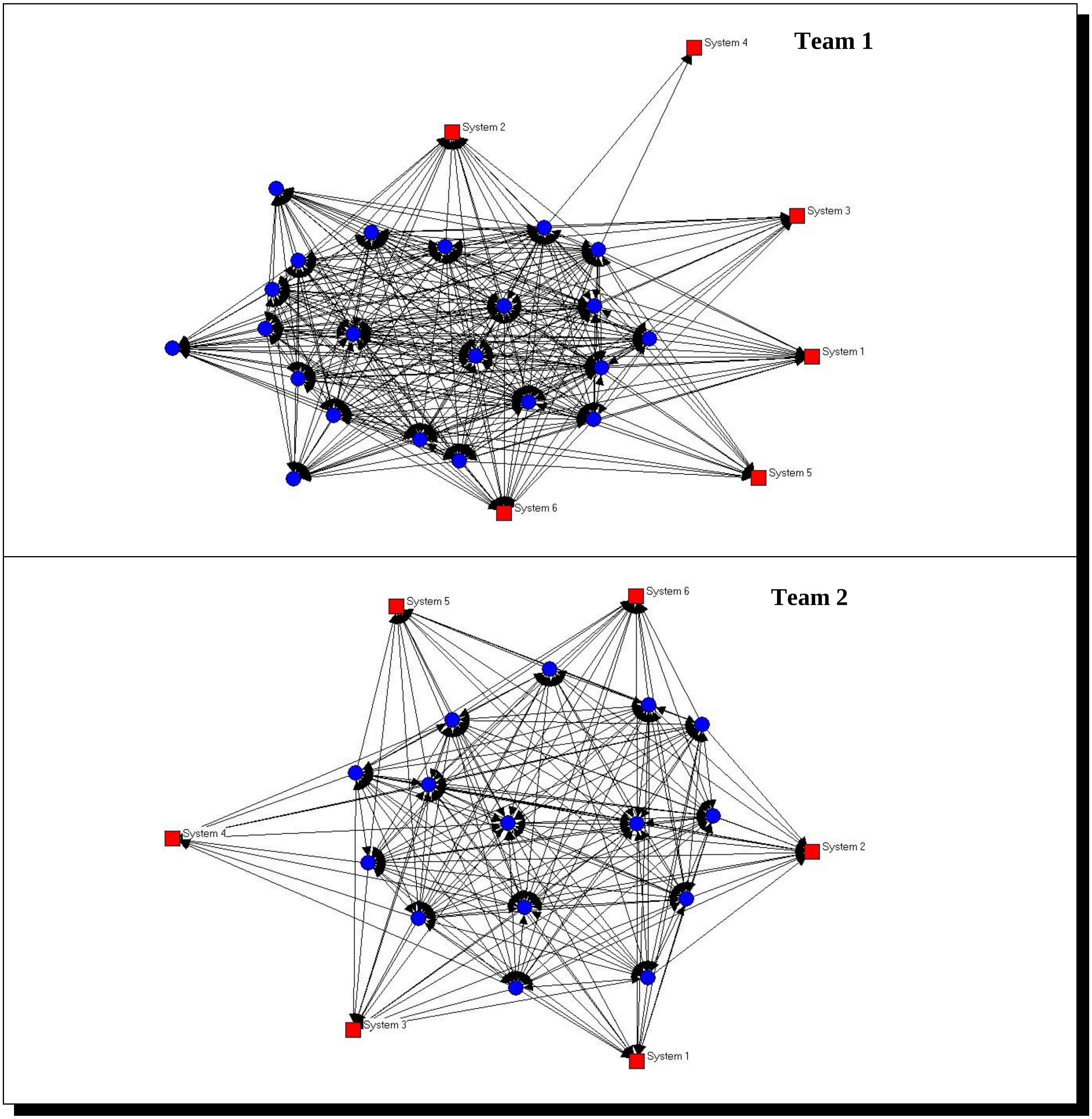
Appendix A. Difference between Multimodal Knowledge Network Configurations in HCT



The above figures demonstrate one view of how HCTs exhibit different MMKN structures. Team 1 displays different distances of the systems from the body of the network (tie strength), a relatively higher number of lines in the network (high density), and shows all the systems skewed to the right of the graph (low centrality). In contrast, Team 2 demonstrates a more consistent distance of the systems from the network (tie strength), relatively fewer number of lines in the network (low density), and shows the systems relatively evenly distributed around the network (high centrality).