Research Methods in Health Social Sciences

Social Network Analysis

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Abstract

Analysis of networks is increasingly seen as important for understanding the patterns, processes and consequences of social relationships in healthcare. Networks can be formal, mandated structures (e.g., a clinical network), can emerge from sharing a common passion, or from routine exchanges such as referrals. Braithwaite and colleagues call for the fostering of naturally emerging networks suggesting these underpin the delivery of healthcare and play an important role in driving quality and safety.

Social network analysis (SNA) emphasizes patterns of relationships and interactions between network members (actors) rather than individual attributes/behaviours or abstract social structures. SNA conceptualizes networks as composed of nodes (the actors in the group) and ties (the relationship between the actors). Ties form the structure of the network and the nodes occupy positions within that structure. This proves a basis to investigate a wide range of issues, including communication pathways between actors (including gaps, bottlenecks or opportunities to increase connectivity), the presence of "tribes" or silos, key players, networks of social support, and patterns of social influences on behaviours. This also allows researchers to investigate relationships between network structures (e.g., communication flows) and important outcomes (e.g., rapid dissemination of ideas).

In this chapter, we will introduce readers to key debates, concepts, methods and applications of SNA, drawing on the authors' own studies and the growing body of healthcare literature adopting this approach. This demonstrates the contribution of SNA to understanding different types of networks, including at the individual, group and organizational level.

Introduction

Analysis of networks is increasingly seen as important for understanding the patterns, processes and consequences of collaborative relationships in healthcare. Networks can give a more holistic picture of the complex interactions which define the health system. Networks can be formal, mandated structures (e.g., a clinical network (Haines et al., 2012)), can emerge from sharing a common passion (e.g., a special interest group or community of practice (Wenger, McDermott, & Snyder, 2002)), or from routine exchanges (e.g., referrals (Fuller et al., 2007)). Braithwaite and colleagues (2009) call for the fostering of naturally emerging, bottom up networks, suggesting these underpin the delivery of healthcare and play an important role in driving quality and safety.

A network is any group of people or objects that can be said to interact or have some kind of relationship between them. Network theory provides a powerful lens through which to understand how the elements within such a group are organised, following a set of principles. The study of networks led to the realisation that there are similarities between very diverse types of networks such as the neural networks of nematodes (Morita et al, 2001), power grids (Nasiruzzaman, 2013), and the internet (Carmi, Havlin et al 2007). In the social sciences, network theory is used to explain interpersonal relationships at various scales: from whole of communities (Putnam, 1995), to a few clinicians exchanging information about a patient (Benham-Hutchins & Effken, 2010). It provides insight into such phenomena as the influence of opinion leaders, why some companies have a competitive edge, and how effective teams work.

This chapter starts with a brief history of social network studies, followed by an introduction to basic network concepts and methods. We then describe studies which have used social network methodology to study aspects of health service delivery.

A brief history of network analysis in the social sciences

The study of patterns of social relationships has been an enduring aspect of social science (Durkheim, 1895; Simmel, 1950). Here, we focus on social network analysis (SNA) as a distinct methodology, emerging in the mid-1930s in the social and behavioural sciences and advancing slowly but constantly over the next 60 years by a small core of researchers at Harvard. As Wasserman and colleagues put it: "*It was easy to trace the evolution of network theories and ideas from professors to student, from one generation to the next*" (Wasserman, Scott, & Carrington, 2005, p.1).

Jacob Levy Moreno (1889-1974), a psychiatrist, is often cited as the father of network analysis although Freeman (1989) argues that the structure of networks was implicitly recognised long before this in the kinship structures such as descendant lists in the Old Testament (e.g., Genesis 5). Moreno's seminal study on Hudson School for girls and Sing-Sing Prison (Moreno & Jennings, 1934) was the first to use the term "network" in the sense it is understood today (Freeman, 2004, p.35). Moreno stated that the school girls' action of running away was influenced more by their position within their social network than with a conscious, independent decision. Moreno used the term "sociometry" to describe "the mathematical study of psychological properties of populations … methods which inquire into the evolution and organisation of groups and the position of individuals within them" (p.10). Put more simply, it is a method for eliciting and mapping the subjective feelings of

individuals towards each other (Borgatti, Mehra, Brass, & Labianca, 2009), focusing analytic attention on patterns of social relationships.

During the 1940s and 50s, social network research was progressed through matrix algebra and graph theory, allowing the objective identification of groups within networks (Luce & Perry, 1949). This in turn led to work exploring concepts such as leadership, group cohesiveness, group productivity, cooperation, competition, communication and problem solving, and the spread of influence within groups (Borgatti et al., 2009; Freeman, 2004). Around 1990 there was an explosion of interest in networks, spreading from the social sciences into such diverse disciplines as physics and epidemiology (Wasserman & Faust, 1994). A major contribution to network analysis was the characterisation and modelling of small world networks (Travers & Milgram, 1969; Watts & Strogatz, 1998). Small world networks have been found in many settings: in brain networks (Zhang et al., 2016), and food webs (Montoya & Solé, 2002). The distinctive structure of the network and properties of the network transcend the characteristics of the individuals within it.

Social network concepts
SNA emphasizes patterns of relationships and interactions between network members (actors) rather than individual attributes. Actors can be individuals or entities such as departments or whole organisations, while relationships, which must be tightly defined, can be things such as collaboration, friendship, information exchange, or attendance at a particular event. While attribute data (e.g., gender, age, job position, seniority) is usually also collected, the focus is on this relational data that defines the network structure (Scott, 2000). Different types of relational tie can lead to very different network structures; for example, a network of friendship ties between actors may be different from the same actors' network of reporting ties.

Ties can be directional (e.g., providing information to, seeking advice from) or non-directional (e.g., works in the same building, attend the same meeting). Ties can be recorded as simply present or absent, or weighted to signify the weakness or strength of a relationship. This can be based on emotional intensity, level of reciprocity, or more usually frequency of contact (Granovetter, 1973).

Relational tie data can be collected in different ways depending on the nature of the interaction. Face-to-face communication patterns may be directly observed (e.g., Obstfeld, 2005). Referral patterns, email communications, or collaboration may be gathered using a self-report survey (Bishop & Waring, 2012; Chan et al., 2016; Long, Hibbert, & Braithwaite, 2016) or documentary evidence (Fattore, Frosini, Salvatore, & Tozzi, 2009; Zheng, Padman, Krackhardt, Johnson, & Diamond, 2010).

SNA conceptualizes networks as composed of nodes (the actors in the group) and ties (the relationship between the actors) to generate sociograms. The ties form the structure of the network and the nodes occupy positions within that structure. This proves a basis to investigate a wide range of issues, including communication pathways between actors (including gaps, bottlenecks or opportunities to increase connectivity), the presence of "tribes" or silos, identification of key players, defining networks of social support, and revealing patterns of social influences on behaviour. This also allows researchers to

investigate relationships between network structures (e.g., communication flows) and important outcomes (e.g., rapid dissemination of ideas).

Social network theory has been used to understand processes and phenomena across a range of different industries and settings including: market competition (Burt, 1992; Uzzi, 1997), generation of innovative ideas (Bercovitz & Feldman, 2011; Hargadon & Sutton, 1997), influence and leadership (Lambright, Mischen, & Laramee, 2010; Long, Cunningham, Wiley, Carswell, & Braithwaite, 2013; Valente & Pumpuang, 2007) and group dynamics (Balkundi, Barsness, & Michael, 2009; Susskind, Odom-Reed, & Viccari, 2011).

Within health care, social network theory and analysis has been used to look at coordination and integration of health services (e.g., Ayyalasomayajula et al., 2011; Khosla, Marsteller, Hsu, & Elliott, 2016; Lower et al., 2010; Ryan, Puri, & Liu, 2013); interprofessional communication and practice (e.g., Benham-Hutchins & Effken, 2010; Chan et al., 2016; Creswick, Westbrook, & Braithwaite, 2009); strategies for translational research (e.g., Long et al., 2016; Rycroft-Malone et al., 2011); influence and leadership (e.g., Grimshaw et al., 2006; Kravitz et al., 2003); and quality and safety (e.g., Cunningham et al., 2012; Meltzer et al., 2010).

Structure versus agency

A debate within SNA research is the difference between two conceptualisations, usually referred to as structure and agency to explain human behaviour and social networks. A structuralist view focusses on the iterative patterns of social interactions that appear to constrain the individual or provide opportunities (Ansell, Reckhow, & Kelly, 2009). Agency, on the other hand refers to an individual's power to act and intentionally change their world (Apelrouth & Edles, 2008).

A structuralist perspective of networks takes the view that the resources that a particular network position affords, influences his or her actions and leads to consequences for the actor. An actor in a central position in a network might be expected to have the same opportunities and constraints as another central actor in a different network. This approach focuses on the presence or absence of ties and tends to ignore the actual content of the ties ["ties conceptualised as girders" (Borgatti & Foster, 2003, p.1003)]. An example of this approach is a study of hospital facility managers (Heng, McGeorge, & Loosemore, 2005). By graphically representing the managers' ties to other departments they demonstrated that as well as a coordinating, central role, managers were also positioned to broker between departments.

An agency perspective perceives an actor shaping his environment by using the resources of the network to his own end. Agency focused studies of networks seek to understand how the network comes to be the way it is as a result of an agent's capacity to choose his or her behaviour and then act in the world. This approach focusses on the content of the ties; more specifically, on the resources that are delivered in the ties ("ties conceptualised as pipes" (Borgatti & Foster, 2003, p.1003). A small study by Kalish (2008) considered the personality traits of students in brokerage positions in a multicultural class to understand the nature of personal agency in defining their network position.

Some studies have given equal weight to both perspectives. For example, Johnson and colleagues (Johnson, Boster, & Palinkas, 2003) described group dynamics of crew members at an Antarctic science base over three successive winters. As well as network structural data ("who hung out with who"), they observed the social roles that people took within the networks ("clown", "leader who got things done"). By combining the data they were able to describe the emergence and evolution of the network.

Both viewpoints have merit. Borgatti and Foster (2003) in their review of network research, however note that the vast majority of SNA studies take a structuralist perspective.

Methods
Social network data can be collected through self-report surveys, observation, or use of documentary data (e.g., emails, minutes of meetings). Before starting to collect data, the most important step is to define the relationship of interest. Referral or specific advice relationships may be straightforward but for self-report surveys especially, the tie needs to be understood in the same way by all participants. Long and colleagues (2016), for example used the following explanation of collaborative ties since collaboration is a multifaceted concept that had the potential to be understood in a number of different ways: "By 'collaboration' we mean either formally (e.g. on a funded project) or informally (e.g. have discussed aspects of research, supplied expertise, advice or equipment to others) … Please select those people with whom you are currently collaborating on a network activity, event or project …" This allowed the researchers to capture informal collaborative ties as well as the formal.

 Two main methods of eliciting relationship data in the self-report survey method are roster style and name generator. If the boundaries of the network are known (e.g., people signed up to an online community of practice, staff on a ward, members of a committee) a roster of names may be used (pending ethical and governance approval). In the roster style survey, the members of the network are listed, and the respondent is asked to consider each person as a potential tie. In the name generator style of survey, the respondent is asked to write down the name of the people with whom they consider they have the defined tie without any prompting. This is useful if the membership of the network is not known (e.g., social support networks). The following resources provide detailed discussion of SNA methods and the various advantages and limitations associated with them (Borgatti, Everett, & Johnson, 2013; Scott, 2000; Wasserman & Faust, 1994).

Key players in collaborative networks
SNA has allowed the identification of actors that Borgattti terms "key players" (2006) that have been given a wide range of descriptors in the literature. Key players are actors that have important roles within the network defined by their position in the overall structure. Actors that occupy central, highly connected positions in the network are termed opinion leaders (Gifford et al., 1999; Valente, 2006; Valente & Pumpuang, 2007), hubs (Buchanan, 2003; Watts & Strogatz, 1998) or connectors (Gladwell, 2000 p.38). Earlier sociometric studies used the term communication "stars," referring to actors who are chosen as friends by the most people (Moreno & Jennings, 1934 p.72) or as actors who are approached most often for advice in a work setting (Allen, 1970). The term "star" reflects the graphical depiction of such a network (Figure 1a).

Brokers are actors that link together individuals or groups of individuals (Figure 1b). They have been identified using a range of terms, the most common being: bridges (Burt, 1992; Valente & Fujimoto, 2010), brokers (Cross & Prusak, 2002; Gould & Fernandez, 1989; Shi, Markoczy, & Dess, 2009), and boundary spanners (Howse, 2005; Tushman, 1977). The broker is considered a key player as their position is inherently powerful; they may be the sole link between two non-communicating groups. This can be used for a competitive advantage in business (e.g., having information from group A that Group B does not, means the broker has a competitive edge), or to cause mischief (e.g., hoarding relevant information and not passing it along; acting as a gatekeeper and not allowing access to resources held by the other group). More positively, in collaborative networks they can broker beneficial introductions, mediate between parties that are at odds, or provide a service of some kind to both parties (e.g., an interpreter, an expert).

Both key player roles have costs associated with them as well as advantages. Maintaining ties is a time consuming exercise and beyond a certain number is unfeasible (Burt, 1992, 2002).
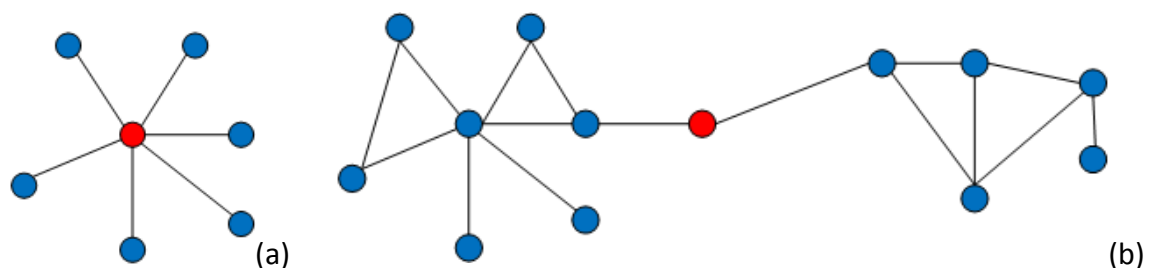

Figure 1(a): Star shaped graph: the central actor is coloured red. (b) Broker (in red) bridges two separate clusters of actors.

Social network analysis in health care

Social network analysis is a powerful approach to apply to healthcare settings. It can provide a framework to examine information flows, social and professional influence and the phenomenon of siloed thinking and action (Long et al., 2016). While SNA has been well noted for its potential to map epidemiological phenomenon (e.g., the spread of HIV (Lin et al., 2012) or SARs (Chen, Chen, & King, 2011)) over the past ten years, it has also been increasingly taken up in research on healthcare organisations and systems. A number of reasons for this interest can be suggested. The increasing focus on the shape of social networks can be seen to follow from a concern with **network forms of governance** and policy attempts to engage with, and harness, embedded professional networks. Rather than an integrated hierarchy, it has increasingly been recognised that multiple 'decentred' professional and organisational networks are involved in shaping and controlling health systems; SNA offers an approach to study such network forms.

A related concern of healthcare researchers is the nature of relationships between heterogeneous professional and occupational groups, how work is divided and the implications for the **coordination of care and fostering of collaboration**. Rather than focusing on the aggregate relations as has been common in perspectives such as sociology

of the professions, SNA allow empirical investigation of patterns of relationships at the individual and sub-group level.

Third, an increasing concern of healthcare researchers over the past fifteen years has been how knowledge, particularly new knowledge from research evidence and innovation, is translated and diffused into practice. SNA has also been used to examine the strategy of using translational research networks to bridge the "valley of death" (Butler, 2008) between basic science and bedside, "real life" practice. Again, SNA has shed light the patterns of relationships that underpin this process and how **knowledge translation and improvement** efforts can be supported. Two examples of author projects demonstrate recent applications.

Example 1: SNA of translational research strategies

Translational research undertakes the crucial role of moving biomedical discoveries out of the highly controlled laboratory environment and applying it in the complexity of patient and service delivery realities (Goldblatt & Lee, 2010; Woolf, 2008). Expertise and understanding through collaboration between both fields are necessary to achieve this yet the gaps between research and clinical domains are widening through increased specialisation and complexity (Schwartz & Vilquin, 2003; Zerhouni, 2005). Translational research networks are a strategy to facilitate collaboration by establishing a clear, joint vision, setting up an administrative structure to provide funding for joint projects, project officers and shared resources, and a social structure to maximise opportunities for collaboration, innovation and knowledge exchange. While potential partners in such networks may abound, clusters within disciplines, professions, or geographic sites and the gaps between them may hinder their initiation. This study used SNA at baseline and three further points in time to examine changes in collaborative ties between members with reference to these clusters (Long, Cunningham, & Braithwaite, 2012; Long, Cunningham, Carswell, & Braithwaite, 2013, 2014; Long, Cunningham, Wiley, et al., 2013; Long et al., 2016).
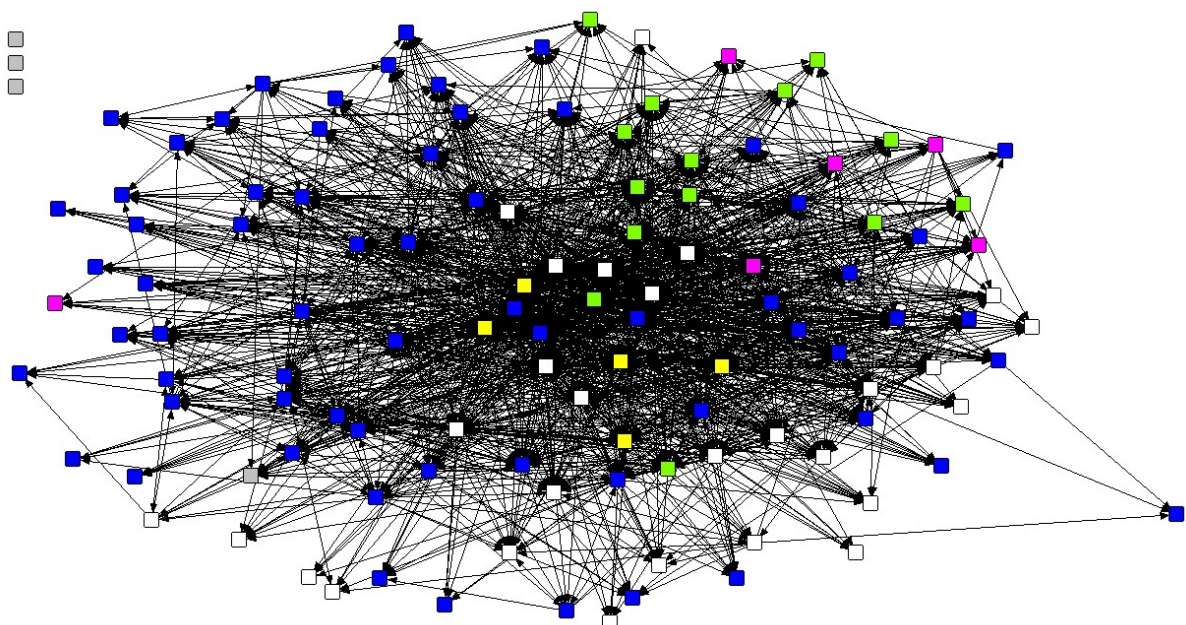
The translational research network of interest was established in late 2011 and initial membership was 68 cancer clinicians and researchers drawn from six hospital and university sites in New South Wales. An on-line, whole network survey was administered to all registered members of the network in early 2012, 2013 and again in 2015. Membership changed in that time from 68 to 263 to 244 (respectively) as people joined or left. SNA showed that at baseline, ties of the original members were reflective of long-standing teaching and research arrangements and clustered by field (clinician or researcher) and by geographic proximity. Over the next 4 years, collaborative ties were shown to be bridging the field gap and including consumers in both research- and clinically-based projects, although geographic proximity remained a feature. Key player analysis showed that the network manager was enacting a significant brokerage role in bringing new collaborative partners together, a quantitative finding that was confirmed through interviews (Long, Cunningham, Wiley, et al., 2013).

In a similar project (unpublished Long & McDermott 2017), SNA was used to examine the growth of collaborative ties within a translational research network in the field of cognitive decline. The network was shown, by the second year of operation to have successfully brokered collaborations across formerly siloed sectors of academia, industry (largely staff in residential care facilities), consumers (people living with dementia and representatives from

consumer advocacy groups), and government (policy makers, regulators and accreditation purveyors). Sociograms from the first survey at baseline (Figure 2) and after two year's operation (Figure 3) shows this growth of intersectoral collaboration. External/internal (E/I) index analyses at the two points in time showed that at baseline members from each sector were more likely to collaborate with people within their sector than with people in another sector, while after two years, members were more likely to collaborate with members outside their sector. In the last survey there were 857 new ties (n=121) described as "I have only worked with this person since joining the network." Again, key player analysis showed both the centrality of the network manager and director, and their brokerage roles.
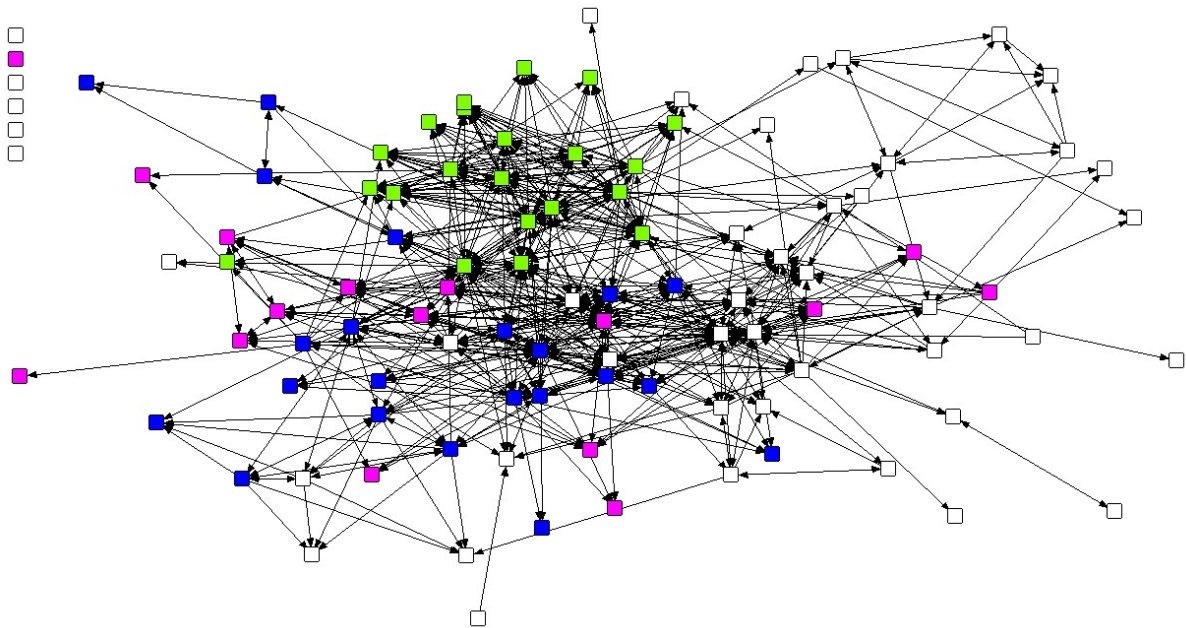
Figure 2: Baseline collaboration in a cognitive decline translational research network (n=104). The four sectors are shown by colour: green = consumers, blue = academics, white = industry and pink = government, grey = not specified.

Example 2 Mixed Methods SNA: relations between health and social care

The second example focuses on a study of knowledge sharing on issues of patient safety within a UK NHS hospital day surgery department. In light of well recognised professional silos within health organisations (Currie et al., 2008; Waring, 2004), this study aimed to investigate the patterns of knowledge-sharing within and between professional groups. The methodology involved both a quantitative SNA survey and a period of ethnographic observations. The quantitative SNA survey was designed to elicit respondents' close advice-giving contacts, asking respondents to provide named individuals within the department from whom they most commonly sought knowledge around patient safety, as well as the frequency of advice. Demographic data was also collected on the professional background, tenure and work role of the respondent. Full network data was sought from all members of the department, identified both through an initial staff list and through following up new individuals identified in the name generator of respondents (n=47, 85% response rate). Alongside this, 250 hours of ethnographic observations were undertaken, focusing on working practices and communication across settings within the department, as well as 40 qualitative interviews (see Bishop and Waring, 2012).

Results from the study brought to light a number of key issues surrounding knowledge sharing within the department (see Figure 4). Quantitative SNA results illustrated the complex web of intra-and inter-professional knowledge-sharing relationships in the department, and highlighted: 1) medics position towards the periphery of the network, 2) the central role of senior nurses in the advice network of the department, 3) the peripheral role of part time and temporary staff, and 4) that a higher number advice seeking ties were held within professional groups than between groups. These findings supported prior theorising in relation to trust and knowledge sharing within professional groups (Chan et al., 2016; Creswick et al., 2009). They also appeared to reflect aspects of service organisation, for example the central administrative role played by senior nurses within the department and medics attached to external departments of their clinical specialisms.
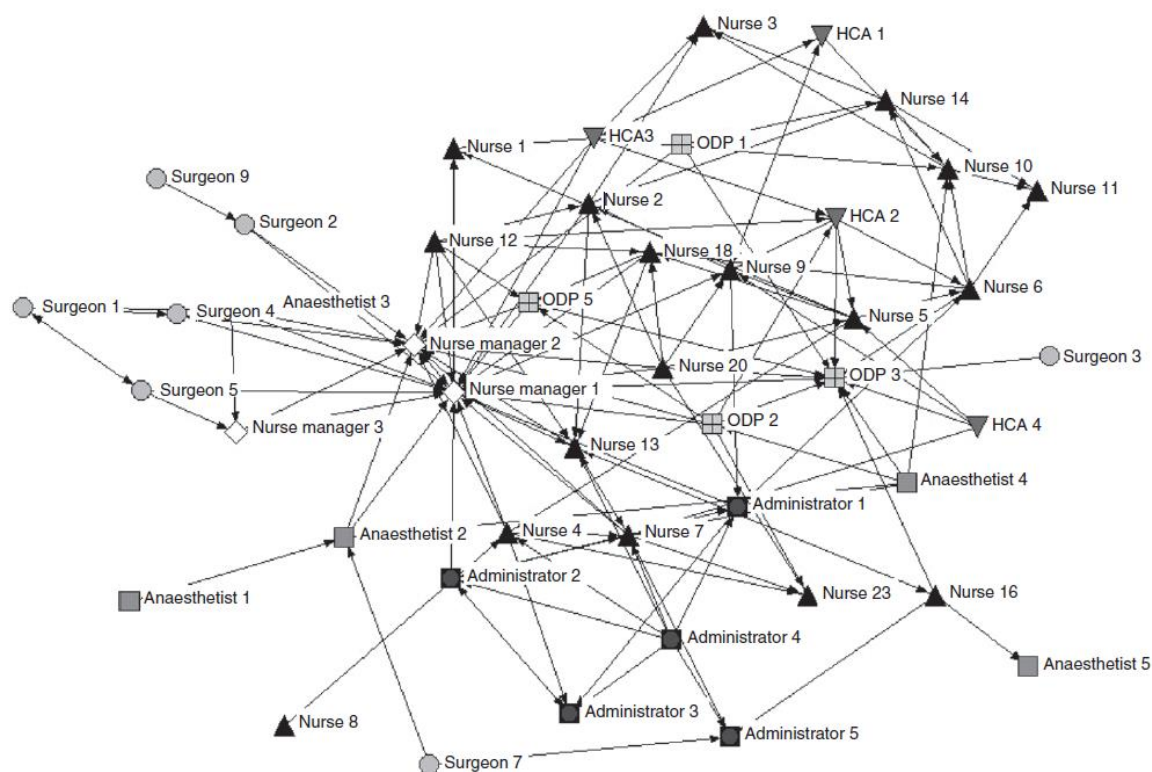
Figure 4: Network of advice seeking ties within a UK NHS hospital day surgery department.

Alongside the quantitative SNA findings, qualitative component of the study allowed further exploration of the patterns of advice giving within the quantitative SNA, and provided insight into the meaning of the identified relationships. This work included examination of how work practice shaped the opportunities for interaction, and hence knowledge sharing within and between groups. It also explored important factors shaping how individuals sought to negotiate relationships within the department while responding to conflicting demands. Bringing together quantitative SNA and qualitative research methods could therefore help to develop both an understanding of the structure of social relationship and the way these relationships are formed and maintained within the everyday practice of health organisations.

Conclusion and Future Directions

Researchers of health systems are increasingly recognising that the socio-professional relationships are an essential component of quality, safety and efficient delivery of care. SNA is a valuable tool to quantify these relationships at both an individual and organisational level. Patterns of collaboration, referral, and knowledge exchange are revealed by SNA and in combination with complementary qualitative methods such as ethnographic observation or interviews, fleshed out to give insight into social processes in health care. In addition, SNA is an important methodology for understanding emergent networks which have been shown to drive safety initiatives (Braithwaite et al., 2009).

SNA is an important methodology to analyse new social structures to drive policy and reform, cross sectoral collaboration, integration of services, and dissemination of best practice. The use of SNA to reveal the utility of translational research networks as a strategy to create a common vision and broker bridging relationships has been shown. SNA is also an important methodology for examining managed network structures as mechanisms of policy and reform. As public policy emphasises dispersed leadership and accountability within networks, an understanding of the strength of relationships and how network roles such as brokerage are enacted is important. Further theory around network development and durability of relationships is another avenue for future research.

Table 1: Some social network terms and their definitions

Term	Definition
Actor	A member of a network
Broker	An actor in a network that acts as an intermediary between two unlinked actors or clusters of actors
Brokerage	A strategy described by Burt (2005) of maximising opportunities by increasing variation in the network through weak, bridging links to multiple, non-redundant contacts outside the group. This strategy contrasts with closure.
Central actor	The actor who is nominated most often or who interacts with the most other members of a network
Centrality	A measure of which actor or actors are the most connected or who interact with the most other actors
Closure	A strategy described by Burt (2005) of increasing cohesion by reducing variation within a group by forming strong links to members of the network. This strategy contrasts with brokerage.
Cluster	A subgroup of a network in which the local density of ties is higher than across the whole network
Contagion	The process of spreading disease (in epidemiology), ideas, knowledge, or uptake of new technology through direct contact or social influence in social networks
Degree	The number of ties that actors have to other actors
Density	The ratio of the number of ties present in a network divided by the number of possible ties
Directed tie	A tie that contains information about the who initiated the tie and who receives it (e.g., information given by Actor A and received by Actor B)
Node	Element of interest in a network. In a social network, it may be an individual or organisation. In non-social networks, it may be an object, e.g., a station in a railway network
Edge (or tie)	A link or relationship between actors in a network shown on sociograms as a line
Ego	Focal actor in a network
Egonet	Social network of a single focal actor
Homophily	Defined by Rogers (2003) as the extent to which linked actors share similar attributes such as education, gender or social status
Reciprocity	A tie is said to be reciprocated when both actors acknowledge the tie.

Social capital	A measure of the advantage that comes through social ties. May refer to the advantage held by an individual through their egonet (Burt, 1992) or may refer to the quality of an entire group, e.g., an entire community (Putnam, 1995).
Strength of tie	A measure of emotional intensity, level of reciprocity, or frequency of interaction associated with a tie
Strength of weak ties	A phenomenon described by Granovetter (1973) to describe the often advantageous, novel information that comes from weak links from outside of one's closely tied network (who all tend to know the same information)
Tie (or edge)	A link or relationship between actors in a network shown on sociograms as a line
Undirected tie	A tie that does not require information about who initiated the tie or who received it (e.g., two actors on the same board, kinship ties)
Whole network survey	A survey that aims to elicit data from every member of the network, rather than a sample of members

References

Allen, T. J. (1970). Communication networks in R & D labs. *R & D Management, 1*, 14-21.

Ansell, C., Reckhow, S., & Kelly, A. (2009). How to Reform a Reform Coalition: Outreach, Agenda Expansion, and Brokerage in Urban School Reform. *Policy Studies Journal, 37*(4), 717-743. doi:10.1111/j.1541-0072.2009.00332.x

Apelrouth, S., & Edles, L. (2008). *Classical and contemporary sociological theory: text and readings*. Thousand Oaks, California: Pine Forge Press.

Ayyalasomayajula, B., Wiebe, N., Hemmelgarn, B. R., Bello, A., Manns, B., Klarenbach, S., & Tonelli, M. (2011). A novel technique to optimize facility locations of new nephrology services for remote areas. *Clinical Journal of the American Society of Nephrology, 6*(9), 2157-2164. doi:http://dx.doi.org/10.2215/CJN.01820211

Balkundi, P., Barsness, Z., & Michael, J. H. (2009). Unlocking the Influence of Leadership Network Structures on Team Conflict and Viability. *Small Group Research, 40*(3), 301-322.

Benham-Hutchins, M. M., & Effken, J. A. (2010). Multiprofessional patterns and methods of communication during patient handoffs. *International Journal of Medical Informatics, 79*(4), 252-267.

Bercovitz, J., & Feldman, M. (2011). The mechanisms of collaboration in inventive teams: Composition, social networks, and geography. *Research Policy, 40*(1), 81-93. doi:10.1016/j.respol.2010.09.008

Bishop, S., & Waring, J. (2012). Discovering healthcare professional- practice networks: The added value of qualitative SNA. *Qualitative Research in Organizations and Management: An International Journal, 7*(3), 308-322. doi:doi:10.1108/17465641211279770

Borgatti, S. P. (2006). Identifying sets of key players in a social network. *Computational and Mathematical Organization Theory, 12*, 21.

Borgatti, S. P., Everett, M. G., & Johnson, J. C. (2013). *Analyzing Social Networks*: SAGE Publications.

Borgatti, S. P., & Foster, P. C. (2003). The Network Paradigm in Organizational Research: A Review and Typology. *Journal of Management, 29*(6), 991-1013. doi:10.1016/s0149-2063_03_00087-4

Borgatti, S. P., Mehra, A., Brass, D. J., & Labianca, G. (2009). Network analysis in the social sciences. *Science, 323*(5916), 892-895.

Braithwaite, J., Runciman, W. B., & Merry, A. F. (2009). Towards safer, better healthcare: harnessing the natural properties of complex sociotechnical systems. *Quality & Safety in Health Care, 18*(1), 37-41.

Buchanan, M. (2003). *Nexus: small worlds and the groundbreaking science of networks*. New York: WW Norton.

Burt, R. S. (1992). *Structural holes: the social structure of competition*. Cambridge, Massachusetts: Harvard University Press.

Burt, R. S. (2002). Bridge decay. *Social Networks, 24*(4), 333-363.

Burt, R. S. (2005). *Brokerage and closure: an introduction to social capital* New York: Oxford University Press.

Butler, D. (2008). Crossing the Valley of Death. *Nature, 453*(12 June), 840-842.

Chan, B., Reeve, E., Matthews, S., Carroll, P., Long, J. C., Held, F., . . . Hilmer, S. N. (2016). Medicine information exchange networks among health care professionals and prescribing in geriatric medicine wards. *British Journal of Clinical Pharmacology, 83*(6), 1185–1196. doi:10.1111/bcp.13222

Chen, Y.-D., Chen, H., & King, C.-C. (2011). Social Network Analysis for Contact Tracing. In C. Castillo-Chavez, H. Chen, W. B. Lober, M. Thurmond, & D. Zeng (Eds.), *Infectious Disease Informatics and Biosurveillance: Research, Systems and Case Studies* (pp. 339-358). Boston, MA: Springer US.

Creswick, N., Westbrook, J. I., & Braithwaite, J. (2009). Understanding communication networks in the emergency department. *BMC Health Services Research, 9*, 247.

Cross, R., & Prusak, L. (2002). The people who make organizations go - or stop. *Harvard Business Review, June*, 105-112.

Cunningham, F. C., Ranmuthugala, G., Plumb, J., Georgiou, A., Westbrook, J. I., & Braithwaite, J. (2012). Health professional networks as a vector for improving healthcare quality and safety: a systematic review. *BMJ Quality & Safety, 21*(3), 239-249. doi:10.1136/bmjqs-2011-000187

Durkheim, E. (1895). *Les Règles de la Méthode Sociologique*. Paris.

Fattore, G., Frosini, F., Salvatore, D., & Tozzi, V. (2009). Social network analysis in primary care: The impact of interactions on prescribing behaviour. *Health Policy, 92*(2- 3), 141-148.

Freeman, L. C. (1989). Network representations. *Research methods in social network analysis*.

Freeman, L. C. (2004). *The development of social network analysis: a study in the sociology of science*. Vancouver: Empirical Press.

Fuller, J., Kelly, B., Sartore, G., Fragar, L., Tonna, A., Pollard, G., & Hazell, T. (2007). Use of social network analysis to describe service links for farmers' mental health. *Australian Journal of Rural Health, 15*(2), 99-106. doi:10.1111/j.1440-1584.2007.00861.x

Gifford, D., Holloway, R., Frankel, M., Albright, C., Meyerson, R., Griggs, R., & al, e. (1999). Improving adherence to dementia guidelines through education and opinion leaders. *Annals of Internal Medicine, 131*, 237-246.

Gladwell, M. (2000). *The tipping point: how little thing can make a big difference*. New York: Back Bay Books / Little, Brown and Company.

Goldblatt, E. M., & Lee, W.-H. (2010). From bench to bedside: the growing use of translational research in cancer medicine. *American Journal of Translational Research, 2*(1), 1-18.

Gould, R. V., & Fernandez, R. M. (1989). Structures of mediation: a formal approach to brokerage in transaction networks. *Sociological Methodology, 19*, 89-126.

Granovetter, M. (1973). The strength of weak ties. *American journal of sociology, 78*, 1360-1380.

Grimshaw, J., Eccles, M., Greener, J., Maclennan, G., Ibbotson, T., Kahan, J., & Sullivan, F. (2006). Is the involvement of opinion leaders in the implementation of research findings a feasible strategy? *Implementation Science, 1*, 3.

Haines, M., Brown, B., Craig, J., D'Este, C., Elliott, E., Klineberg, E., . . . Research Group, C. N. (2012). Determinants of successful clinical networks: The conceptual framework and study protocol. *Implementation Science, 7*(1), 16.

Hargadon, A., & Sutton, R. I. (1997). Technology brokering and innovation in a product development firm. *Administrative Science Quarterly, 42*(4), 716-749.

Heng, H. K. S., McGeorge, W. D., & Loosemore, M. (2005). Beyond strategy: exploring the brokerage role of facilities manager in hospitals. *Journal of Health Organization & Management, 19*(1), 16-31.

Howse, E. L. (2005). *Factors that motivate hospital nurse middle managers to share knowledge related to boundary spanning roles.* (Ph.D.), University of Toronto (Canada), Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=cin20&AN=2009283278&site=ehost-live

Johnson, J. C., Boster, J. S., & Palinkas, L. A. (2003). Social roles and the evolution of networks in extreme and isolated environments. *J Math Sociol, 27*(2-3), 89-121. doi:10.1080/00222500305890

Kalish, Y. (2008). Bridging in social networks: who are the people in structural holes and why are they there? *Asian Journal of Social Psychology, 11*(1), 53-66.

Khosla, N., Marsteller, J. A., Hsu, Y. J., & Elliott, D. L. (2016). Analysing collaboration among HIV agencies through combining network theory and relational coordination. *Social Science and Medicine, 150*, 85-94. doi:http://dx.doi.org/10.1016/j.socscimed.2015.12.006

Kravitz, R. L., Krackhardt, D., Melnikow, J., Franz, C. E., Gilbert, W. M., Zach, A., . . . Romano, P. S. (2003). Networked for change? identifying obstetric opinion leaders and assessing their opinions on caesarean delivery. *Social Science & Medicine, 57*(12), 2423-2434.

Lambright, K. T., Mischen, P. A., & Laramee, C. B. (2010). Building trust in public and nonprofit networks: personal, dyadic, and third-party influences. *American Review of Public Administration, 40*(1), 64-82. doi:10.1177/0275074008329426

Lin, H., He, N., Ding, Y., Qiu, D., Zhu, W., Liu, X., . . . Detels, R. (2012). Tracing sexual contacts of HIV-infected individuals in a rural prefecture, Eastern China. *BMC Public Health, 12*(1), 533. doi:10.1186/1471-2458-12-533

Long, J. C., Cunningham, F. C., & Braithwaite, J. (2012). Network structure and the role of key players in a translational cancer research network: a study protocol. *BMJ Open, 2*(3). doi:http://dx.doi.org/10.1136/bmjopen-2012-001434

Long, J. C., Cunningham, F. C., Carswell, P., & Braithwaite, J. (2013). Who are the key players in a new translational research network? *BMC Health Services Research, 13*, 338. doi:http://dx.doi.org/10.1186/10.1186/1472-6963-13-338

Long, J. C., Cunningham, F. C., Carswell, P., & Braithwaite, J. (2014). Patterns of collaboration in complex networks: the example of a translational research network. *BMC Health Services Research, 14*(1), 225. doi:10.1186/1472-6963-14-225

Long, J. C., Cunningham, F. C., Wiley, J., Carswell, P., & Braithwaite, J. (2013). Leadership in complex networks: the importance of network position and strategic action in a translational cancer research network. *Implementation Science, 8*, 122. doi:http://dx.doi.org/10.1186/1748-5908-8-122

Long, J. C., Hibbert, P., & Braithwaite, J. (2016). Structuring successful collaboration: a longitudinal social network analysis of a translational research network. *Implementation Science, 11*(19). doi:10.1186/s13012-016-0381-y

Lower, T., Fragar, L., Depcynzksi, J., Fuller, J., Challinor, K., & Williams, W. (2010). Social network analysis for farmers' hearing services in a rural community. *Australian Journal of Primary Health, 13*(1), 47-51.

Luce, R. D., & Perry, A. (1949). A method of matrix analysis of group structure. *Psychometrika, 14*(2), 95-116.

Meltzer, D., Chung, J., Khalili, P., Marlow, E., Arora, V., Schumock, G., & Burt, R. (2010). Exploring the use of social network methods in designing healthcare quality improvement teams. *Social Science & Medicine, 71*(6), 1119-1130.

Montoya, J. M., & Solé, R. V. (2002). Small World Patterns in Food Webs. *Journal of Theoretical Biology, 214*(3), 405-412. doi:http://dx.doi.org/10.1006/jtbi.2001.2460

Moreno, J. L., & Jennings, H. H. (1934). *Who shall survive? A new approach to the problem of human interrelations*. Washington, D.C. : Nervous and Mental Disease Publishing Co.

Nasiruzzaman, A. (2013). Complex Network Framework Based Comparative Study of Power Grid Centrality Measures. *International Journal of Electrical and Computer Engineering, 3*(4), 543.

Obstfeld, D. (2005). Social networks, the *tertius iungens* orientation, and involvement in innovation. *Administrative Science Quarterly, 50*, 100-130.

Putnam, R. (1995). Bowling alone: America's declining social capital. *Journal of Democracy, 6*(1), 65-78.

Rogers, E. (2003). *Diffusion of innovations* (4 ed.). New York: Free Press.

Ryan, D. P., Puri, M., & Liu, B. A. (2013). Comparing Patient and Provider Perceptions of Home- and Community-Based Services: Social Network Analysis as a Service Integration Metric. *Home Health Care Services Quarterly, 32*(2), 92-105. doi:10.1080/01621424.2013.779352

Rycroft-Malone, J., Wilkinson, J., Burton, C., Andrews, G., Ariss, S., Baker, R., . . . Thompson, C. (2011). Implementing health research through academic and clinical partnerships: a realistic evaluation of the Collaborations for Leadership in Applied Health Research and Care (CLAHRC). *Implementation Science, 6*(1), 74.

Schwartz, K., & Vilquin, J.-T. (2003). Building the translational highway: toward new partnerships between academia and the private sector. *Nature Medicine, 9*(5), 493-495.

Scott, J. (2000). *Social network analysis: a handbook* (2 ed.). London: Sage.

Shi, W., Markoczy, L., & Dess, G. G. (2009). The role of middle management in the strategy process: group affiliation, structural holes, and tertius iungens. *Journal of Management, 35*(6), 1453-1480. doi:10.1177/0149206309346338

Simmel, G. (1950). *The sociology of Georg Simmel* (K. H. Wolff, Trans.). New York: Free Press.

Susskind, A., Odom-Reed, P., & Viccari, A. (2011). Team leaders and team members in interorganizational networks: an examination of structural holes and performance. *Communication Research, 38*(5), 613-633. doi:10.1177/0093650210380867

Travers, J., & Milgram, S. (1969). An experimental study of a small world problem. *Sociometry, 32*(4), 425-443.

Tushman, M. L. (1977). Special boundary roles in the innovation process. *Administrative Science Quarterly, 22*(4), 587-605.

Uzzi, B. (1997). Social structure and competition in interfirm networks: the paradox of embeddedness. *Administrative Science Quarterly, 42*(1), 35-67.

Valente, T. (2006). Opinion leader interventions in social networks. *British Medical Journal, 333*(7578), 1082-1083. doi:10.1136/bmj.39042.435984.43

Valente, T., & Fujimoto, K. (2010). Bridging: locating critical connectors in a network. *Social Networks, 23*, 212-220.

Valente, T., & Pumpuang, P. (2007). Identifying opinion leaders to promote behavior change. *Health Education & Behavior, 34*(6), 881-896. doi:10.1177/1090198106297855

Wasserman, S., & Faust, K. (1994). *Social network analysis*. Cambridge: Cambridge University Press.

Wasserman, S., Scott, J., & Carrington, P. J. (2005). Introduction. In P. J. Carrington, J. Scott, & S. Wasserman (Eds.), *Models and methods in social network analysis* (pp. 1-7). Cambridge, England: Cambridge University Press.

Watts, D. J., & Strogatz, S. H. (1998). Collective dynamics of 'small-world' networks. *Nature, 393*(6684), 440-442.

Wenger, E., McDermott, R., & Snyder, W. M. (2002). *Cultivating Communities of Practice*. Boston, Massachusetts: Harvard Business School Press.

Woolf, S. H. (2008). The meaning of translational research and why it matters. *JAMA: The Journal of the American Medical Association, 299*(2), 211-213. doi:10.1001/jama.2007.26

Zerhouni, E. A. (2005). Translational and clinical science: time for a new vision. *New England Journal of Medicine, 353*(15), 1621-1623. doi:doi:10.1056/NEJMsb053723

Zhang, J., Lin, X., Fu, G., Sai, L., Chen, H., Yang, J., . . . Yuan, Z. (2016). Mapping the small-world properties of brain networks in deception with functional near-infrared spectroscopy. *6*, 25297. doi:10.1038/srep25297

Zheng, K., Padman, R., Krackhardt, D., Johnson, M. P., & Diamond, H. S. (2010). Social networks and physician adoption of electronic health records: insights from an empirical study. *Journal of the American Medical Informatics Association, 17*(3), 328-336. doi:10.1136/jamia.2009.000877