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Networks in engineering: an emerging approach to project organization studies

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The field of social science has introduced a number of qualitative and quantitative approaches that have been adopted in the engineering project organization research domain. One such approach that is receiving increasing attention is social network analysis (SNA). Introduced in the 1930s and refined in multiple domains since the introduction, SNA has become a fundamental tool for social scientists over the past eight decades. Recently, engineering project organization researchers have begun to explore the application of this tool within the engineering project domain. This paper introduces both the historical development of SNA within the social science community and the recent adoption of this approach within the engineering community. The paper traces the recent trend in papers published by the engineering community to illustrate the increasing attention paid to SNA by researchers and the evolution of its use. This background is used to propose several paths forward for future researchers to expand and mature SNA research in the engineering project organization domain. The paper concludes with a charge to the research community to both widen the application of SNA within the domain and pursue a deeper understanding of its applicability within the field of engineering project organizations.

Keywords: Project environments, project management, project networks, project organizations, research development, social networks.

Introduction

The concept that groups are social systems is rooted in the history of sociological research and study. The need to place individual facts and relationships into a coherent whole is the basis of social systems analysis. Influenced by Kohler's gestalt theories, sociologists have pursued the role that holistic thinking plays in assisting human thought to comprehend complex social relationships (Scott, 1991). The pursuit for a systems theory to describe how relationships influence individual behaviours underpinned the development of social network analysis (SNA) methods. The resulting SNA methodology has been used extensively by researchers in the social sciences over an eight-decade period. Positioned at the intersection of sociology, psychology and mathematics, social networks provide the qualitative and quantitative foundation required to analyse the dynamic properties of engineering project organizations.

In the recent context of the last 15 years, the technique has attracted the interest of researchers in the engineering project organization research domain. Although this interest developed slowly, the technique is witnessing increasing usage over the last five years as measured by the number of journal publications published in the domain. In this paper, the authors introduce the SNA methodology background and then analyse the history of SNA research within the engineering project organization domain. The paper then defines a path forward for researchers embarking on the study of engineering project organizations as networks, either as central research foci or as an analytical technique. The paper puts forward the challenge to bring more cohesiveness to the research community while expanding the application and focus of SNA in

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the engineering project organization domain. The authors' intent is to provide both a reference for future researchers to understand the current state of SNA within the domain and a charge to continue the exploration of opportunities to integrate and expand this social science methodology in engineering project organization research.

Background

SNA within the social science domain began with the introduction of the sociogram concept by Moreno (1937). Sociograms were introduced as a formal representation of the patterns of interpersonal relationships upon which larger social aggregates could be examined. Since each node in the graph could represent individuals, and the links between these nodes could represent relationships such as information exchange, sociograms were put forward as a fundamental tool for investigating the fabric of interpersonal relationships within groups of individuals. Concurrently, the concept of sub-groups or cliques as a fundamental component of community and social networks was put forward by Warner and Lunt (1941). The confluence of these developments established the initial path for researchers to begin to understand how relationships can influence individual actions.

Understanding how to map relationships within networks provided the central focus for SNA research from the 1940s through the 1960s. In this period, SNA was extensively used by anthropologists to understand the similarities, differences and changes occurring between what was termed primitive cultures and modern cultures. A key proponent of this perspective was Radcliffe-Brown (1940) who promoted the study of social structures as a component of understanding social relations. Building on these initial efforts, a school of research emerged from the London School of Economics where Barnes (1954) introduced the term 'social networks' as a way to visualize the social linkages within a Norwegian fishing village. This work was complemented by Bott (1955) who introduced the concepts of density into social network research through studies of family networks in London. A second school of thought emerged at the University of Manchester as the theoretical hub and what is now the University of Zambia as the centre of field studies (Mitchell, 1969). These studies provided formalizations for the use of social networks to support the ethnographic studies being conducted in Africa in terms of societal structure. During this period, Gluckman (1955) experimented with and advocated the use of case studies and observation to understand the relationships in tribal societies. Gluckman documented the concept of multiple relationships between individuals in what was termed multiplex relationships within a community. The extensive use of SNA concepts in ethnographic studies created a well-trodden path that influenced the next generation of network analysis researchers to expand the qualitative, ethnographic basis to a quantitative, mathematical basis.

The introduction of graph theory to sociological community analysis shifted the emphasis of SNA research towards mathematical theory (Mitchell, 1969). In translating social interactions to a mathematical basis, the field of SNA transformed from a qualitative pursuit to a mixed-methods approach where ethnographic field studies could be combined with quantitative analyses to develop holistic analyses of individual and group communication dynamics. Measurements were established for analysing the effectiveness and weaknesses of groups being studied (Alba, 1982). A critical extension of this network concept into group dynamics occurred around this time with the concept that individuals or organizations exchange information during the performance of any activity and require a focus on information processing capabilities (Galbraith, 1974; Tushman and Nadler, 1978). SNA researchers found that these exchanges can be mapped within sociograms where actors and information exchange become nodes and arcs within the graph (Mitchell, 1969). These maps then have the capacity to be analysed using a set of standardized measurements. Mitchell summarized these measurements to include the functions that can be traced forward to the measures used today including such measurements as distance, density and centrality, among others. Such measures were also used extensively by communication researchers to examine the impact of interdependence, communication patterns, communication roles and group perception (Bales, 1950; Newcomb, 1951; Fisher, 1974).

The evolution to a mixed-methods approach also enabled the formalization of SNA process and theory beyond interpersonal relationships. At the leading edge of this formalization movement was the Harvard research group led by Harrison White. White (1970) focused on the mathematical analysis and modelling of social structures. He used the mathematical constructs provided by graph theory to describe the sociological topology of groups and imbedded relationships. White *et al.* (1976) introduced algorithms that take into account positions within a network to address what they referred to as blockmodels. In contrast to existing approaches at the time, White *et al.* emphasized the overall structure of the network as opposed to measures for a single relationship. This broadening of the mathematical basis on which networks could be analysed enabled social network research to evolve from a theoretical concept to a tangible tool that had utility beyond the social science domain, prompting a broader application of SNA beyond strictly interpersonal relationships.

This expanded focus on the overall structure of networks enabled more nuanced studies of the dynamics within groups. Several key research efforts provided further refinement of the classic SNA measurements during this shift towards group dynamics. Granovetter (1973), a student of White, introduced the concept of weak ties and the importance of information exchange primacy through direct links in the network. Freeman provided the theoretical basis for expanding the concepts of centrality to the concept of betweenness where quantitative measurements could be applied to general management concepts of 'being in the loop' for information transfer (Freeman, 1977). The culmination of these advances resulted in the development of the SNA tools available to researchers today including UCINET, arguably the most popular of the SNA toolkits, in 1992 (Borgatti *et al.*, 2002).

Over the last two decades, this foundational work has expanded to multiple domains. Domains as diverse as technology innovation, global terrorism, marketing, politics and international finance have each undergone analysis through the lens of social networks (see Wasserman and Faust, 1994, for a comprehensive review). In each of these domains, a focus on centrality, density and betweenness in communication transfer has provided insights into the formal and informal networks of relationships that impact the operational effectiveness of organizations. While the specific and narrow outcomes of individual analyses have varied, the broader cross-context finding emerging from these studies is that informal networks underlie most professional activities and the relationships within these networks impact performance (Krackhardt and Hanson, 1993). As will be introduced in the next section, the merging of the qualitative and quantitative understanding of relationships in groups with an understanding of small group dynamics and the impact of formal and informal networks on performance provides the nexus for the emergence of SNA within engineering project organization research.

The project environment

SNA research by anthropologists such as Gluckman (1955) and Barnes (1954) introduced concepts of formal and informal relationships to understand the characteristics of villages. The formal networks implied by position existed in parallel with the distinct informal relationships established within the same villages. Formal authority was granted to village elders or town officials, but relationships between individuals established informal authority structures. Community norms provided the structure to enforce roles and relationships rather than contractual relationships. The models of community and village structure established in these early SNA case study efforts have strong parallels with the concept of engineering project organizations. Similar to village or community relationships, project organizations comprised individuals who, although they have shared formal and explicit goals, also have a multitude of informal individual relationships that change over time and may at times conflict with the formal goals. Additionally, the formal networks and positions documented in community networks exist in project networks through contractual relationships and explicit project positions such as project managers and project engineers. Similarly, the informal networks documented in community networks are represented by communities of practice in project networks.

These comparisons between villages and projects allow engineering project organizations to be examined through the formal and informal interactions of the individuals, teams and organizations who are in pursuit of a shared goal as per the definition of organizations by Scott (1997). The core actors in the network will routinely include the project management team, the site supervision team, the primary subcontractor leads, the design team leads and the owner representatives. The core functions within the network may be formally linked in multiple configurations depending on contractual influences and teaming arrangements.

The interactional dynamics of the core project team both reflect and direct the manner in which the project is executed. The information flows between the core network actors directly reflect the influence of the project manager to control communications and operations. Similarly, the extent to which information and knowledge is distributed throughout the network is a reflection of the contractual agreements in the network and the collaborative basis on which the project is executed (Henisz and Levitt, 2011). In this manner, the core project network executes the project as a compromise between formal processes as guided by contractual relationships and informal relationships as guided by exogenous stakeholder interactions. This project execution dichotomy between core and exogenous project elements has been a consistent theme in project management research as summarized in several studies (Oglesby, 1990; Harris, 1992; Chinowsky and Diekmann, 2004; Levitt, 2007).

In the context of these multi-level networks, projects also comprise a broad range of potential actors and exogenous influences that may impact performance. Project networks are responsible to and react to the demands of project stakeholders, community leaders, political leaders, citizens groups and others who directly or indirectly influence and are influenced by the project. Notwithstanding the challenges in defining the boundaries of networks, SNA provides a framework to explicitly document these relationships between the exogenous environment and the project (Aaltonen *et al.*, 2008; Knoke and Yang 2008). This is important because ideas, directives or policies established within the network core can radiate out with unforeseen or unintended consequences as preconceived network boundaries are breached. For example, the policy to set a specific contractual arrangement between the owner and the project team will directly influence the actors that have the willingness or capacity to propose on a given project. Conversely, such a policy can also influence exogenous actors, including the community by how the shift in participation on the project impacts project quality and the financing institutions through the financial viability of the project. Project influences can even emanate further to include the long-term economic impacts introduced by the project.

These broad impacts illustrate how engineering project organizations provide a rich tapestry of interrelations at and across multiple levels of analysis. They are dynamic and complex endeavours with affected actors whose relationship with project boundaries may not be well understood in a traditional project management context. In combination, the characteristics of projects, the environments in which they are executed and the interactions between projects and their environment set the stage for the adoption of an alternative approach to examining project interactions. Social network research provides this alternative by formally modelling core and exogenous interrelationships, as well as formal and informal project interactions. The following section analyses the adoption of SNA within the engineering project organization domain.

Research on engineering project organization networks

Research utilizing the theoretical lens of networks emerged within the field of engineering project organizations about 15 years ago. The first study crossing into this domain focused on how communications are impacted when engineering organizations are perturbed by crises (Loosemore, 1997). Since then, a total of approximately 30 papers have been published that adopt a network focus to engineering project organizations, with a large proportion of those papers being published within the last several years. Figure 1 plots the cumulative number of publications per year since the earliest identified work by Loosemore was published. In the first decade from 1997 to 2006, the number of publications per year was relatively consistent with approximately one paper being published per year. However, in the most recent five-year period, the number of papers has increased to about four papers published per year. Although this is not a large growth in terms of the absolute number of papers, this growth is illustrative of the increased attention being given to SNA as an emerging field of inquiry within engineering project organization research. In the following three sections, the history of research on networks within the engineering project organization domain is presented in three, five-year intervals.

1997–2001: Examining networks to understand communication efficiency in engineering project organizations

The earliest network research examining engineering project organizations utilized communication data to understand communication efficiency. In two studies of how crises impact communications in engineering project organizations, Loosemore (1997, 1998) collected information from project participants on four projects regarding their formal and informal communications relating to crises. These data were used to create a chronological network of interactions during crises to observe shifting patterns of communication with a particular emphasis on the efficiency of communications during periods of crisis response. The findings were used to develop a model of social adjustment during construction crises that considers how project participants influence other participants as they react to the crisis at hand (Loosemore, 1997). As an introduction to this technique, Loosemore (1998) also developed a paper that focused on the benefits of combining both quantitative and qualitative data collection approaches when using social network analytical methods to study engineering project organizations.

A second set of papers during this time period also focused on the efficiency of communications using network analysis. Mead (2001) and Thorpe and Mead (2001) studied project extranets to examine how computer-mediated communications impact the efficiency of communications in engineering project organizations. Mead collected data from individuals using surveys and personal interviews to understand how communication patterns changed over the duration of a project. He specifically examined how the centrality of the project participants changed over the duration of the project. Based on this analysis, Mead developed inferences about the impact of a web-based project website on the flow of communications on the project. The study also raised questions regarding the potential overabundance of information created when all project

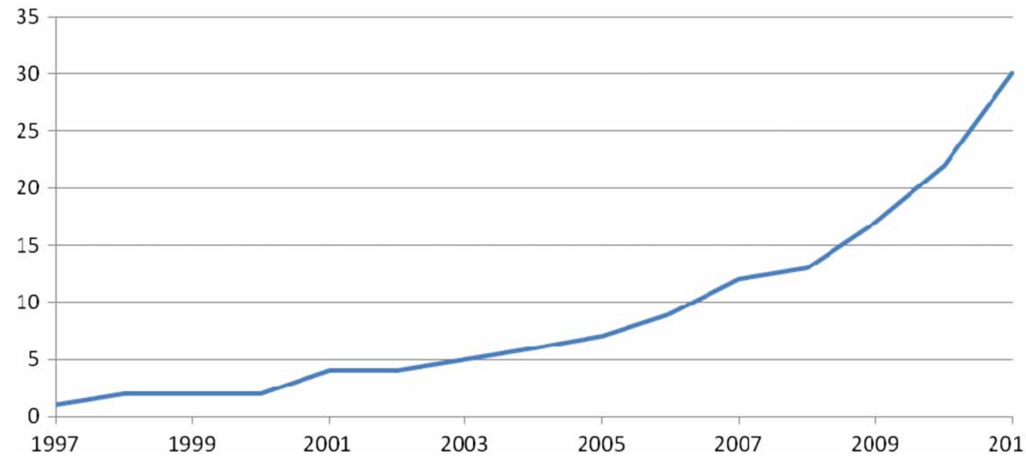

Figure 1 Cumulative number of journal papers per year published that examine engineering project organizations as networks

communications are routed to all project stakeholders using centralized web-based project extranets. Thorpe and Mead (2001) further examined web-based project extranets utilizing network analytical methods to examine and dichotomize communications into push and pull information distribution. Studying three specific project cases, they found that the web-based project extranet eliminated communication barriers that exist in push information distribution systems. However, they also found that the technology itself can be a barrier and that participants unable or unwilling to use such centralized project communication systems can negatively impact the effectiveness of such systems on communications.

Taking these early network studies on engineering project organizations together, we find that each of these studies focused their data collection and examination on individuals within projects. Each of these investigations utilized communications as the basis for data collection and derived conclusions regarding communication efficiency. They each collected data through surveys and interviews of specific project cases and each utilized centrality as an analytical perspective to make inferences regarding the patterns of communication of the individuals.

2002–2006: Examining networks to understand collaboration between firms in engineering projects

The research on engineering project organization networks expanded in focus from individual communications to firm-level collaboration during the period from 2002 to 2006. During this period, the firm-level analysis changed the focus of examination from communication efficiency to collaboration effectiveness. Papers published in the 2002–2006 period focused largely on financial relationships between firms to understand how firms interact in project networks.

Pryke published several papers during this period (Pryke, 2004, 2005; Pryke and Pearson, 2006) that examined financial incentives and contracts to understand why firms organize into coalitions on projects. In his first paper, Pryke (2004) outlined a framework for using SNA at the project coalition level to understand project governance. He later validated the framework (Pryke, 2005) across four specific case studies. Pryke found that social network analytical methods are a useful and appropriate framework to understand project governance and, moreover, that centrality and density measures can be used to compare governance across projects. In a later collaboration with Pearson, Pryke demonstrated how performance incentives can be analysed using the project governance framework, identifying nuances with respect to the impact of incentive contiguity across project cases (Pryke and Pearson, 2006).

Working during the same period, Shields and West (2003) examined financial interactions, but in the context of a reasonably fixed network. The semi-stable relationships were found to enhance inter-firm activities by allowing and encouraging coordination and the sharing of information through the network. However, this same stability also failed to eliminate the continuous negotiation and on-going bargaining that takes place in almost all project relationships. Also working during the same period, Sandhu and Helo (2006) expanded the analytical framework on firm-to-firm network analysis to consider supply chain networks. The notable contribution of this work is the move away from a dependence on communication as an analytical basis. Specifically, this work introduces for the first time in this domain a focus on trust, commitment and adaptation as relationships within the social networks.

2007–2011: Expanding the scope of phenomena examined and methodologies employed

Research during this most recent five-year period builds upon the frameworks developed over the first 10 years of research and expands the range of phenomena examined and the methodologies employed. The number of journal papers using a network theoretical framework to study engineering project organizations increased substantially during this period. Of the 30 papers identified as being published on this topic, over 20 were in this most recent period. Several of the papers build and expand upon the earlier research frameworks. Davis and Walker (2009) expanded the model to examine networks in relationship-based procurement. Hossain (2009) directly captured project communications by examining the text of emails to further analyse the effect of centrality on coordination. El-Sheikh and Pryke (2010) again expanded upon Pryke's earlier framework to examine the role of clients and client satisfaction. Finally, Son and Rojas (2011) developed an agent-based simulation model based on the original concepts to understand how inter-firm relations form in project networks.

In addition to expanding upon and refining earlier frameworks, researchers in this period began to investigate asymmetries that can exist between nodes in a network. Unsal and Taylor examined how opportunistic behaviour can impact the choice of network partners using both an agent-based simulation (Unsal and Taylor, 2010) and an empirical bidding experiment (Unsal and Taylor, 2011) to collect data on network interactions. A number of studies examined asymmetries that can exist across national cultural boundaries in networks. Comu *et al.* (2011) examined how national cultural diversity in project networks can initially have a negative impact on performance but, through sustained collaboration, can actually lead to positive returns in performance when compared with domestic-only project network interactions. Continuing a focus on network boundaries, Di Marco *et al.* (2010), Di Marco and Taylor (2011) and Ramalingam and Mahalingam (2011) examined boundary spanning that impacts project performance when national cultural boundaries are spanned in networks. Finally, Abdul-Aziz and Wong (2010) and Park *et al.* (2011) examined the impact of the national cultural boundary in networks as it relates to international expansion. Of note in these studies is Park *et al.*'s (2011) study. Departing from other studies, they based their analysis on data collected from a third-party database containing 389 cases of international collaborative ventures over a 20-year period. This research greatly expanded the depth of quantitative data studied in network-oriented engineering project organization research.

Network-oriented engineering project organization papers over the last five-year period have also sought to develop a deeper understanding of how collaboration effectiveness can impact higher level strategic aims such as achieving high-performance teams and enhanced innovation and learning. Chiocchio (2007) utilized a study of high- versus low-performing teams to examine how network analysis of collaboration could be used to achieve high-performing teams. Chinowsky *et al.* expanded upon this finding to build (Chinowsky *et al.*, 2008) and validate (Chinowsky *et al.*, 2010) a framework for using social network analytical methods to understand and achieve high-performance teams. This work was later expanded to include a measure for how the communications on a project align with the task interdependencies that exist in the network (Chinowsky *et al.*, 2011). Several studies have also been conducted to examine how the structure of project networks impacts the ability for networks of firms to innovate and learn. Boland *et al.* (2007) and Taylor and Levitt (2007) examined how 3D CAD technology implementation in project networks was impacted by the structure and ecology of the industry. Later, Taylor *et al.* (2009) formalized the structural argument into an agent-based simulation to explore how the loosely coupled structure of the industry combined with tight task interdependencies between firms in project networks can slow innovation adaptation processes. This structural finding was also observed in a survey-based network study of work group performance among knowledge workers by Chung and Hossain (2009).

The path forward for engineering project organization networks research

The potential for utilizing SNA as a mechanism for exploring relationships, behaviours and operating patterns within project organizations is evident from the research efforts of the past 15 years. The integration of this social science approach into the toolbox wielded by engineering project organization researchers may not be complete, but it has gained a level of acceptance as evidenced by the recent increase in publications in the area. However, the success of this path of research will depend on the researchers' ability to build on existing research that has proven to be both successful and repeatable. From this perspective, SNA researchers in the engineering project organization domain can continue to build upon trends in already published work in this area.

First, the wide range of methods currently employed to examine networks ensures a diversity of approaches. As detailed above, researchers are employing simulation, experimental, ethnographic observation and survey methods to collect data on the underlying organization details required to conduct an SNA. This diversity ensures that our understanding of networks in engineering project organizations is not overly focused on a narrow methodological tradition which follows the original arguments by White *et al.* (1976) that alternative perspectives are required when employing social network methodologies. Additionally, by implementing multiple approaches, the opportunity exists to conduct meta-level analyses across projects to objectively evaluate the appropriateness of the approaches and potentially provide guidance as to the scenarios in which each methodological approach may be preferred. The utilization of a diverse range of methods to examine engineering project organization networks is a positive trend which should continue.

Second, the evolution of network studies within the engineering project domain is leading researchers to address a greater degree of complexity. Of particular interest is the recognition of the dependency relationships that are a central distinction when comparing the work of engineering project organizations with non-project organizations or project organizations not executing complex engineering work. These dependencies and interdependencies are beginning to be addressed at both the interfirm level and the project execution level. Understanding these relationships is an important step towards modelling the full complexity of engineering projects including the tasks, individuals, firms and exogenous stakeholders who are interconnected within the execution of engineering projects. This trend to examine the full range of dependencies that exist in complex engineering project organization networks should be preserved and continued in future studies.

In addition to these trends in engineering project organization network research which should continue, there is also a potent opportunity to expand and enrich the path forward for research in this domain. In the following sections, we present a forward path for research inquiry in this domain to fundamentally advance our understanding of networks in engineering project organization. If the research community accepts this challenge, this forward path can provide a nexus around which network researchers can coalesce and build.

Building from the existing research foundation

Together, the diversity of methods and addressing greater complexity on projects is providing a foundation on which to develop a path forward within the domain. However, the potential of this research foundation must be tempered with an understanding of a challenge that is inherent within the research community. The papers identified as background for this review were used to examine the network linkages between previously published works on networks in engineering project organization studies. In this analysis, the references from each paper were isolated to determine the connections that existed between the papers in terms of backward citations to previously published work from members of the network. Figure 2 contains the citation network for papers published on the topic of engineering project organizations. The nodes in the network are published papers and the edges represent directional citation links to other engineering project organization network studies. The size of the nodes is indicative of the number of times each paper was cited by other engineering project organization network papers (larger size equates to more citations). It is evident from the figure that the reference network is a relatively loosely connected community that contains more papers that lack any reference to other papers in the sample than those with extensive grounding in the published work in this area. On average, papers were only cited one time by other papers in the sample and only two papers had been referenced five or more times by approximately 30 other articles. For the engineering project organization community to advance, the existing foundation of research in this area needs to be built upon so that an informed and cohesive path forward can be achieved.

Expanding levels of analysis

The body of research conducted in the engineering project organization domain has predominantly emphasized inter-organizational network studies. This emphasis is an extension of the historic emphasis on projects as inter-firm endeavours that require multiple interdependent organizations to cooperate to achieve desired results. Understanding the coordination phenomena that occur during this process has been a central topic in the field of project organization research. However, an understanding of the intra-organizational effect on project execution and development requires a compatible level of understanding. As projects are influenced by relationships within and between organizations, an understanding of the intra-firm relationships is required to achieve a comprehensive project execution perspective. Of particular concern in this research pursuit are topics including the role of the organizational boundary in both project and organizational development, the role of the project coordinators within each organization (including how they influence coordination) and the degree of integration that actually exists within organizations (including if this is organically developed or fixed *a priori*). Moreover, the execution of more intra-organizational studies will allow for comparative studies between intra- and inter-organizational contexts to

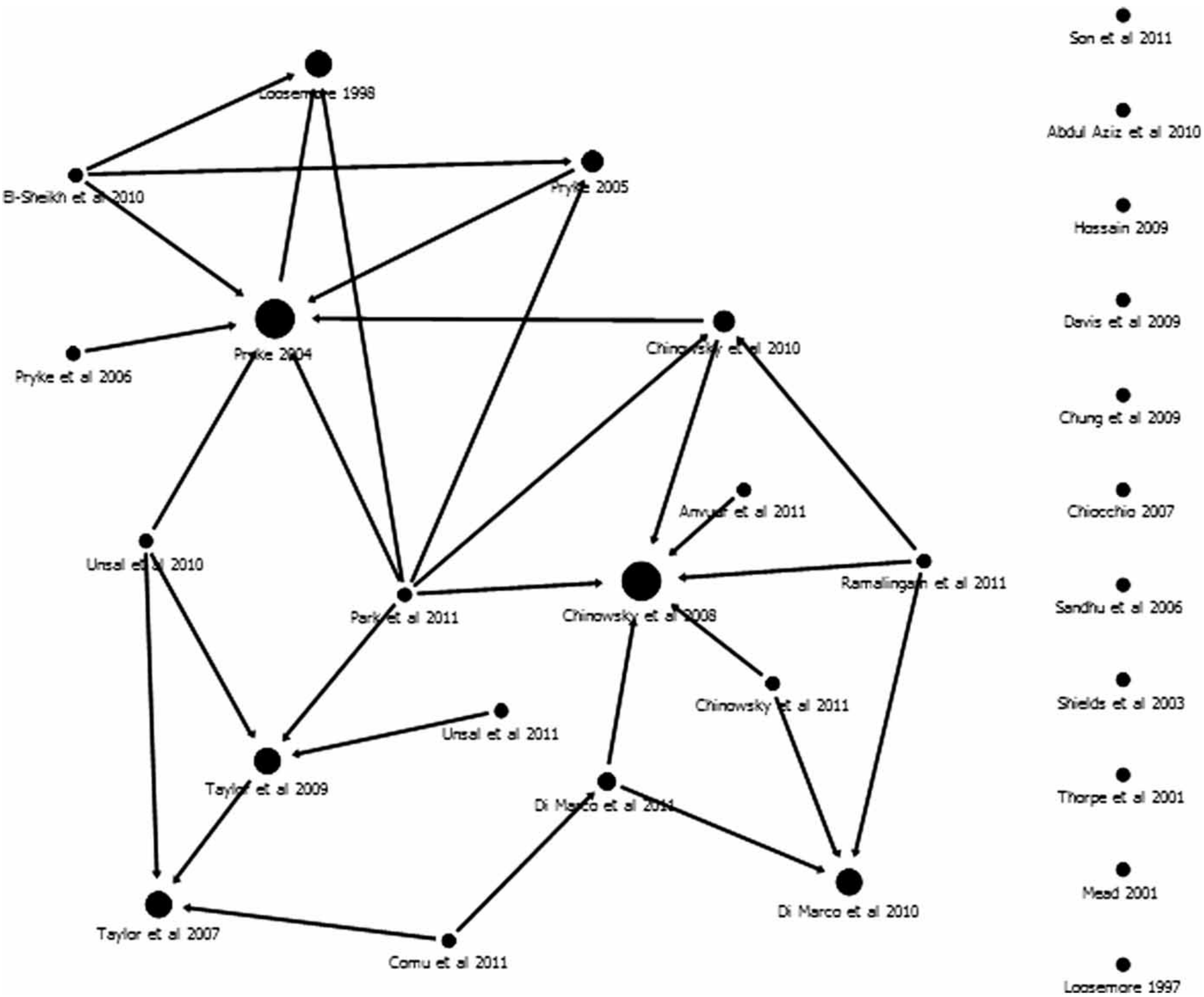

Figure 2 Backward citation network across engineering project organization network manuscripts

begin to understand the role of organizational boundaries in the execution of complex engineering projects.

In addition to understanding the intra-firm effect on project organizations, the influence of markets and sectors on project interactions is a broader form of organizational impact that requires further research. For example, the influence of globalization on organizational development and the need for new market entry strategies may have specific network impacts as relationships and interactions must be redefined for each scenario. The ability to analyse large databases of projects, their stakeholders and the characteristics of the projects will provide a picture of the networks that evolve in response to market forces. The underlying observation of interest in this analysis could be whether commonalities exist in the patterns developed from the data in terms of market response.

Continuing the theme of multi-level analysis, we must conduct research that seeks to understand how theories developed based on data collected at the individual, firm, project and/or market level, upscale or downscale to different levels of analysis. The fact that all network research reviewed in this manuscript focused on a single level of analysis emphasizes the need for future scholarship in this area to examine whether and how constructs, propositions and theories change across levels of analysis.

Expanding scope from actors and nodes to the project environment

Project networks do not operate in a vacuum. Although it provides a definitive boundary for project researchers, the project environment, as outlined above is both an influence on and recipient of project processes. The decisions made by stakeholders outside the project core directly influence the manner in which a project team operates. It is reasonably common for community stakeholders to slow progress or even block some infrastructure projects. Utilizing network analysis to understand how the contextual environment of a project may directly or indirectly impact the network of individuals and firms assembled to execute the project requires further study. Further investigation is required to provide a structural understanding of how perturbations in the external environment influence the core of the project network. Are project networks developed with sufficient resilience to external influences? Can we model the robustness of networks to these perturbations considering the multiple layers existing between the external and the core actors? These are fundamental research questions about project to environment interactions that require further study.

In contrast, decisions made by project teams can reciprocally influence the environment in which the project operates in multiple terms including economic, political, legal and social. For example, projects such as the Channel Tunnel between England and France have a cross-national impact with economic, political, legal and social implications. The impact these project teams have on the external environment has been investigated over time through economic multipliers and the role that projects have on the communities in which they reside. However, from a network perspective, this influence and impact could focus on the individual-level and firm-level relationships between the project team and actors within the environment. The continuity of these relationships over time could address how projects undertaken in a specific context can have long-term influences in terms of both future projects and community transformation. The manner in which these influences occur in either direction or in bidirectional influence studies is an unanswered question at the current time.

Achieving this broader perspective of the project environment requires researchers to consider a collaborative perspective of project execution. The inclusion of informal collaborative groups such as communities of practice differs from classical, hierarchical management theory. Within a global organization, this perspective requires a researcher to consider the impact of input from remote geographic offices as well as ideas being generated from the central project core. In multi-division organizations, this perspective requires researchers to consider the input from remote divisions, small divisions and new divisions as well as the traditional central core of the organization. In combination with small group dynamics, this research emphasis could enable researchers to address a broader spectrum of network configurations and provides the basis for studying project networks of all types and configurations in and across contexts.

Examining different stages of the project

Projects occur over multiple phases, each of which is critical to the successful execution of the project. However, the preponderance of research in the engineering project organization network domain to date describes the detailed design or construction stages of a project. This is explainable in that these phases develop definable and traceable relationships including, among others, authority, communication, trust and dependence. However, these definable relationships are not the only ones that impact the execution of projects or impact the environment. Including the front-end and downstream operational phase of projects, and the temporary relationships that evolve between these phases, would provide a more comprehensive perspective of a given project. A better understanding of these relationships both statically and dynamically over the course of the project will provide the insights necessary to determine how networks form and reform across all phases of a project and across projects over time.

Expanding the phenomenological portfolio of research foci

The most recent five-year period of network studies has focused on several specific phenomena and research in these areas has enabled the community to understand these phenomena better. However, this same understanding and phenomena have, as discussed above, occurred in a narrow field of application. For SNA to emerge as a central, social science-based methodology within engineering project organization research, the research community needs to demonstrate the method's potential in multiple areas of application. These areas need to be in both the project-specific domain and the multiple contexts in which project organizations exist. The research community needs to apply network analytical methods to understand how evolutions in project management are affecting the interpersonal relationships that comprise the core of project teams. For example, the continuing introduction of Internet technologies is purported to alter and improve project execution strategies. However, the realization of this goal has been primarily investigated through ethnographic studies or examinations of electronic records. The opportunity exists to examine this impact in terms of relationships and dependencies. Similarly, issues such as the evolution of mega-projects, globalization and workforce demographics can each be examined from a network perspective. SNA provides both the analytical and graphical capacity to qualitatively and quantitatively model networks relating to these phenomena both as snapshots in time and dynamically over time.

In terms of contextual studies, networks exist wherever projects are being executed. This network basis provides the opportunity to examine how project teams operate in multiple environments. For example, the need to operate quickly and efficiently is the basis of contexts including post-disaster periods, the erection of temporary structures and the completion of time-sensitive projects such as Olympic arenas or military complexes. In these circumstances, projects must balance the need for rapid execution with worker safety, project quality and achieving network cohesion among other concerns. The manner in which these concerns are balanced will have a direct impact on the quality of the outcome and potentially the livelihoods or safety of the network actors and individuals in the surrounding environment. Many engineering phenomena exist that adopt project organizational structures, and it is a charge to the network research community to identify and examine these opportunities to apply a network perspective and expand the current line of inquiry.

Conclusion

The introduction of SNA into the engineering project organization domain is a relatively new phenomenon dating back only 15 years. However, the technique is rooted in almost a century of social science research and validation of its application. The ability to qualitatively and quantitatively model and analyse network relationships while concurrently developing graphical depictions of the network actors and their relationships establishes a sound foundation on which to further the application of the technique within the engineering project organization domain. Currently, as this paper has documented, a body of knowledge comprised approximately 30 articles within the leading construction and project management journals defines the state of application within the project organization domain. These papers are predominantly focused in terms of application to the project execution phase and relationships that exist across inter-firm boundaries. Additionally, the research the papers are based upon has been executed in relative isolation as demonstrated by the loose coupling of the paper reference network.

The path forward for the SNA domain emphasizes both domain breadth and methodological depth. As documented, breadth is required to demonstrate the potential of the technique to multiple contexts as well as project phases. Similarly, depth is required to address the issues of scalability, repeatability and viability within the project organization domain. In each case, the path forward is established by decades of social science application and, more recently, a body of domain knowledge that demonstrates the potential of this technique to the long-term understanding of engineering project organizations.

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