Social Network Model of Construction

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Abstract: Engineering and construction projects are dependent on two fundamental elements: (1) the ability to plan and manage the technical components of the project such as the tasks and resources; and (2) the ability of the project participants to effectively develop into a high performance team. Historically, the industry has focused extensively on optimizing the project management processes associated with the former element. In this focus, organizations have emphasized the ability to develop the optimum plan, allocate resources efficiently, and utilize control functions to ensure that the project stays on schedule and within budget. Although this has been effective, this engineering focus has reached the point of diminishing results. Specifically, the engineering approach to project management has neglected to recognize the importance of the participants to the success of the overall project. Rather, the engineering approach has favored the development of an optimum plan as the path to effective project management. In this paper, the engineering-based approach to project success is reconfigured to reemphasize the need to develop high performing teams by recognizing the importance of the project network. This recognition is formalized in the social network model of construction that integrates classic project management concepts with social science variables to enhance the focus on knowledge sharing as the foundation for achieving high performance teams and project results.

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Introduction

High performance teams achieve outcomes that exceed the expectations of the project and often demonstrate unique or innovative approaches within a final solution. These teams challenge conventional expectations by combining individual strengths and knowledge to generate solutions that exceed the capability of an individual team member. These high performance teams focus on exceeding traditional measures rather than focusing on meeting the benchmark accepted by previous project teams. This concept of high performance is documented and routinely implemented in diverse industries including healthcare and transportation (Poulton and West 1993). However, high performance teams and solutions receive less attention in the construction domain. Rather, the measurement of success within a construction project is often based on meeting historical benchmarks for the classic factors of time, cost, and quality. As with any long-standing benchmark, the question of whether these classic benchmarks can be increased to a new level should be periodically examined together with the question of how to achieve a new level of performance. In the context of construction projects, the research effort discussed in this paper focuses on the development of a model for achieving high performance results from project teams, including enhanced innovation, learning, knowledge exchange, and a notable increase in the classic project benchmarks.

The motivation for this research centers on the extension beyond the traditional construction perspective on project management. In the traditional perspective, project management focuses extensively on the use of tools to preplan tasks and develop schedules that are as detailed as possible. The concept behind this perspective is that a majority of issues can be identified and engineered prior to the start of the project. Additionally, this emphasis is intended to enhance the efficiency of the process by identifying information that is required to be exchanged between participants during project execution. Research in critical success factors has identified this efficiency of information exchange as a key element in producing projects that achieve benchmarks in time, cost, and quality (Ashley and Jaselskis 1991).

The limitation of this “efficiency” approach is that it produces a reactive project execution model. In this model, the schedule and its logic emphasize the mechanics of requesting and retrieving information from project participants to achieve individual goals. The information exchange is guided by the necessity generated by individual tasks within the developed schedule. This reactive approach is in direct contrast to the methods employed by high performance teams. In high performance teams, the focus is on the ability of team members to continuously exchange knowledge and insights, in addition to project information, to enhance the collective group output (Katzenbach and Smith 1993). The success of these teams is not based on an engineered approach to project execution where requesting and retrieving information is the basis for project execution. Rather, a social network approach to project execution emphasizes the dynamics of interaction and the free flow of knowledge between project participants. This focus on networks as the basis for high perfor-

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mance is extended in this paper to present a social network model for Construction that emphasizes team development and knowledge exchange as the foundation for producing high performance construction projects.

Background

The research foundation for the social network model was developed through a series of incremental steps that the writers have undertaken to integrate a number of diverse specialties into a single model. In summary, the foundation has been built through the following steps:

1. The writers initially investigated the hypothesis that project teams experience delays and suboptimal results due to the instability in the project network. Specifically, the constant changing of personnel from one situation to the next results in a network that must be continually reformed and refocused.
2. The focus on networks led to an investigation of social network analysis (SNA) as a potential methodology and tool for investigating network relationships and modeling. This approach has emerged as a critical aspect of the project and is discussed in more detail in the following.
3. The selection of SNA methodology as an appropriate modeling tool led to the question of what project variables should be analyzed within the network. The initial answer to this question emerged from two established bodies of research. The first, critical success factors, provided both a general project approach and a specific construction context to study what variables impact the success of project teams (Pinto and Slevin 1987; Ashley et al. 1987; Ashley and Jaselskis 1991; Chua et al. 1999; Cooke-Davis 2002; Chan et al. 2004). The second, communication and interaction variables (Hirokawa 1980; Poole and Roth 1989), provided a bridge to the social communication research that established a new foundation for developing high performance project teams.
4. Given the selection of a modeling methodology and an approach to selecting model variables, the writers were able to test the concepts on increasingly more complicated projects to obtain the initial results necessary to develop the proposed social network model.

Throughout this process, the research team incorporated a broad base of research to develop the social network model. The following sections introduce the key concepts from the fields of Social Network Analysis and Communication utilized to develop the model.

Social Network Analysis

SNA has been an instrumental tool for researchers focusing on the interactions of groups since the concept was introduced by Moreno in 1934 (Moreno 1960). In the original concept formulation, sociograms were considered a formal representation of the patterns of interpersonal relationships upon which larger social aggregates are created. In this representation, graphs are used to represent relationships between individuals in a group or community. Original studies focused on relationships between individuals in communities such as New England communities to study their social and political relationships (Moreno 1960). Graphs, or sociograms, were created with the nodes representing individuals and the links between the nodes representing relationships between the individuals, such as information exchange. In this context, sociograms were put forward as a fundamental tool for investigating the fabric of interpersonal relationships within groups of individuals.

The extension of the sociogram concept into group dynamics occurred in combination with the concept that individuals or organizations exchange information during the performance of any activity (Scott 1991; Haythornthwaite 1996; Chinowsky and Taylor 2007). Given the premise that any activity requires a transfer of information and knowledge, the extension of this foundation is that these exchanges can be mapped within sociograms where actors and information exchange become nodes and arcs within the graph (Wasserman and Faust 1994). The translation of these social interactions to a mathematical basis was the foundation of the strength and validity of the network approach to communication analysis. Specifically, the ability to apply mathematical analysis to network information exchange provides researchers with established measurements for analyzing the effectiveness and weaknesses of the group being studied (Alba 1982).

In formalizing the connection between graph theory and SNA, several key concepts in graph theory were adopted by SNA researchers to formalize the analysis of graphs and relationships including:

- Network density—a measure to indicate the amount of interaction that exists between the network actors. Density reflects the number of actual links that exist between nodes in comparison to the number of potential links that exist if all nodes were connected through relationship links. The larger the density number that is calculated, the greater the number of relationships that actually exist in the network. An example of a dense network would be a project where a large percentage of the participants are actively interacting on a regular basis.
- Centrality—a key measure that reflects the distribution of relationships through the network. In a highly centralized network, a small percentage of the nodes will have a high percentage of relationships with other nodes in the network. In contrast, a network with low centrality will have relatively equal distribution of relationships through the network. An example of a highly centralized network is one where an individual such as the project manager serves as a filter for a high percentage of communications rather than communications being distributed throughout the network.
- Geodesic distance—a graph theory-based measure that indicates either the distance between the two nodes with the greatest separation in a network, or the distance between two specific nodes in question. In this measurement, distance is based on the minimum number of links that must be traversed to get from one node to another. The focus of this measurement is to highlight the number of individuals who must transfer information as intermediate steps between the communication originator and the receiver. For example, a project network with a large geodesic distance between the steel erection subcontractor and the structural engineer would indicate that several individuals would have to transfer a request for information between the two parties before an answer is originated and returned. The potential problems are extended time periods for processing the request, increased potential for miscommunications, and increases in the barriers between the parties.

These measurements represent only a few of the graph-based measurements available to SNA researchers. However, they represent the core of the theoretical constructs which directly relate to the field of construction projects. In terms of the social network model for Construction, the well-established fields of graph theory and network analysis provide two key advantages:

1. The use of established mathematical measurements provides a validated foundation for analyzing quantitative relationships within the network and of the overall network topology.
2. The use of an established visualization and modeling technique provides an established methodology for capturing the relationships, interactions, and attributes of and between network constituents.

Given these two fundamental advantages as starting points, Social Network Analysis provides the opportunity to visualize the relationships and contrasts between high performance and underperforming construction networks.

SNA Application

Networks are found in every aspect of professional activities. In each of these networks, the network follows a set of underlying principles that guide the transfer of information, responsibilities, and outcomes between members through the developed interconnections. In an area such as construction, networks tend to demonstrate reduced cohesion as the associated parties focus on individual plans and goals in equal or greater proportion to the overall network success. In these less cohesive networks, graph measures such as density of communication and nodal distances become critical in the visualization of the relationships and the identification of network weaknesses.

The concepts of cohesion, density, distances, and relationships have been applied by researchers in many diverse and distinct domains. Classic SNA research focused on sociological networks involving individuals in the workplace and their exchange of information to complete tasks (Krebs 2004). This approach was expanded to specific areas such as research and development to encourage technological innovation within technology-based industries (Allen 1977). Additional studies focused on international relationships in areas such as research collaboration and international investment (Krebs 2004). The ability to map these relationships within a structure that can be visualized using graphics techniques is a significant benefit to network researchers. Specifically, work in network visualization techniques is providing researchers with the ability to isolate relationships, visualize network principles such as dominance, centrality, and egocentricity, and graphically present results that were previously limited to mathematical matrices (Hanneman and Riddle 2005).

Recently, the network analysis approach has been receiving attention within the engineering and construction field, where concepts such as trust and communication between project participants are receiving significant attention (Morton et al. 2006; Katsanis 2006). The understanding that engineering projects are unstable networks that get reinitiated for each project is changing the focus on what constitutes a successful network team. This connection between traditional social analysis and project enhancement is the motivation for extending the network concept to the area of high performance teams where each construction project is a combination of social interaction and project collaboration.

Communication Variables

Complementing the foundation in social network analysis is the field of communications research. Understanding what affects the transfer of information between individuals and organizations, and improving this communication, is at the core of the model concept. Of particular relevance to the proposed model is communications research regarding the communications variables that separate effective versus ineffective teams (Hirokawa 1980). This research found that decision-making effectiveness is not so much dependent on the types of behaviors produced within a discussion as it is on the sequencing of these behaviors over time. Specifically, the results suggest that not only do group members in effective groups produce more procedural statements than members of ineffective groups, but effective groups consistently spend more time interacting on procedural matters. The conclusion relevant to the proposed model is that effective groups spend considerable time understanding the problem and how they are going to interact to solve the problem prior to putting forward suggested results.

An additional category of communications research that is relevant to construction projects is the role of communications within small groups. Similar to product development groups, project teams, and quality groups, construction teams are required to interact effectively to produce desired results quickly and efficiently. To this end, the factors that affect small group communications are a critical background component. The research in this area is well established and provides critical insights into the variables that impact this success. Beginning in the 1950s, researchers have determined that small group communication is impacted by issues such as interdependence, communications patterns, communication roles, and group perception (Bales 1950; Fisher 1974; Newcomb 1951). Within this original and continuing research, it has been found that all groups experience a similar set of linear communication stages during the development of task solutions (Fisher 1974). The groups that have the ability to understand this process and the variables that impact the stages have the greatest opportunity for effectiveness in a given task (Poole and Roth 1989).

Recent work in the area of communications and engineering project success has extended these general areas to a specific engineering context. Thomas et al. (1998) found that three barriers to communication within engineering projects were: (1) lack of a common vocabulary; (2) lack of adequate representation for project stake holders; and (3) excessive layers of organizational filters. Shohet and Frydman (2003) focused on the difference between effective and ineffective projects in terms of communications within the project team and with external project participants. In each case, these studies represent a first step toward bringing formal communications theory into the context of an engineering domain.

Social Network Model

As stated earlier, the motivation for developing the social network model for construction is to alter the focus of construction project management from efficiency of projects to high performance projects. However, as documented in high-performance research, the requirement for creating this change is a greater focus on the individuals within the team and their ability to collaborate to create a higher standard of success for the entire team. This focus on the project team network rather than the project schedule is a shift away from the classic project management emphasis on engineering the project to an optimum schedule. In the social network model, the underlying hypothesis is that projects need to be managed as social collaborations to achieve results that exceed traditional expectations. If projects can be viewed from a social collaboration perspective, then an increased emphasis will be placed on developing teams that have shared values and trust among the participants. As demonstrated in the high-performance research, teams that have this as a basis will focus on sharing knowledge to produce high-performance results. Additionally, these teams will work in a proactive mode that is motivated to excel and encourages the identification and resolution of project issues prior to the issues being discovered as a reaction to the project schedule.

Overall Model

The introduction of a social collaboration perspective as the basis for the social network model motivated the development of a model that incorporated the social network perspective and did not abandon the positive aspects of the traditional information exchange model. Specifically, the development process recognized the need for both elements as complements in the overall achievement of high performance. The social element is needed to recognize the importance of collaboration and knowledge exchange, but the information element is still required to achieve the pragmatic requirements of task completion. The challenge in the model development process was the identification of the relationship between the two components and how they interact to produce the high-performance result.

The answer to this challenge is the relationship between knowledge exchange and trust. As detailed in the high performance literature, the key to high performance is the recognition by the team that the success of the team is of primary importance and that this success is based on the individuals openly exchanging knowledge for the benefit of the solution (Losada 1999). However, as further outlined in the research, the key to knowledge exchange is a level of trust between the members of the team (Katzenbach and Smith 1993). This connection between trust and knowledge exchange provided the connection required for the model to integrate traditional information-based perspectives with the social dynamics. The fundamental principle for the model is that the achievement of trust in a social network will lead to the project participants progressing beyond information exchange to a greater exchange of knowledge, thus resulting in enhanced solutions and high performance results.

The manifestation of this fundamental principle is the overall social network model illustrated in Fig. 1. As illustrated, the model contains two basic components, the dynamics and the mechanics. The latter of these components, the mechanics, can be viewed as the "what" in a project, or the items that are exchanged to execute a project. The mechanics contains both the classic emphasis on information sharing and exchange as well as an emphasis on knowledge exchange. The goal of the model is to achieve knowledge sharing as the mechanics that drives project execution. The former of these components, the dynamics, can be viewed as the "why" in a project, or the reasons that motivate project teams to exchange items listed in the mechanics. The dynamics represents the social collaboration component within the project team. In this component, the goal of the model is to enhance knowledge exchange by achieving a greater level of trust and shared values between the project participants.

Combined within the model, the dynamics drives the success of the mechanics by serving as the motivator for the team to move past efficiency to high performance. Building on communication concepts such as those previously introduced by Hirokawa, a separation between ineffective and effective teams is the ability to communicate beyond required tasks to additionally focus on

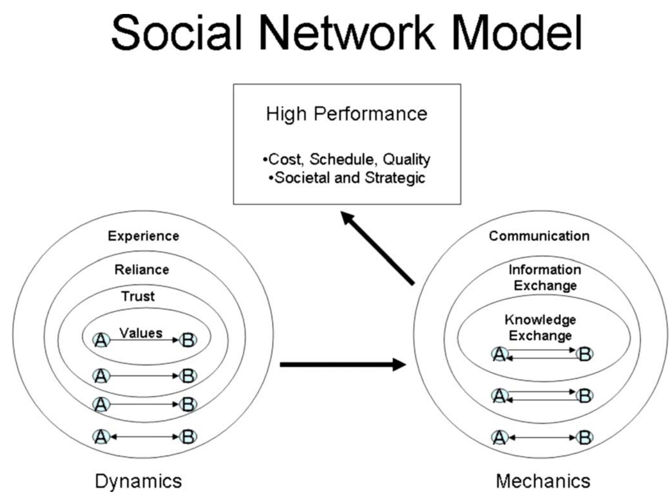

Fig. 1. The social network model for construction including both the mechanics and dynamics that are required to achieve high performance

methods and procedures. The social network model advances this concept by combining the need for interaction with the concepts of trust as underlying motivators for knowledge exchange. Specifically, the underlying concept of this relationship is that by achieving trust and shared values within the project network, the project team will increase the exchange of knowledge and information, which will result in high performance output.

The definition of this output is defined along two dimensions, traditional and emerging measures. In the former, time, cost, and quality remain as measures of success for the project. However, high performance teams will continually strive to exceed the traditional performance benchmarks to set new standards in project output. In the latter, high performance construction projects will extend the concept of measurement to emerging issues such as societal and strategic concerns. In these measures, the teams are working toward solutions that not only meet the needs of the client, but address societal issues such as environmental and energy concerns as well as strategic concerns such as long-term business viability and emerging markets.

Dynamics

The first of the two primary components in the model, the dynamics, focuses on the motivators for individuals to increase performance on a project. The rationale behind this component is based on the research that high performance teams require trust and shared values to achieve the knowledge sharing which results in enhanced solutions (Kotter 1996). However, the writers recognize that this level of social network is not automatically achieved on a project. Rather, the instability of construction project teams, where new teams are configured on a regular basis, often hinders the development of trust relationships. Therefore, the dynamics component includes several layers of relationships through which a project team can progress when striving for the preferred goal of shared values (Fig. 1).

- Experience—the first level of motivator that can affect knowledge exchange is a familiarity that exists between individuals based on previous experience working together on projects. On the whole, if one individual does not have any previous experience with another, reliance, trust, and value sharing are unknown qualities between them. Specifically, people who are new to an organization network will not feel comfortable exchanging anything beyond required information until they are fully assimilated and have developed a favorable perception of other network actors (Cross et al. 2002). The impact of this need for assimilation is that the instability of project networks is a detriment to developing social network relationships and thus in building the trust that is required for enhanced knowledge sharing.

- Reliance—a construction project schedule is a blueprint for reliance on a construction project. In this blueprint, dependencies detailed on a schedule dictate what information is to be exchanged within the project network and when this exchange is going to take place in the context of the overall project. These dependencies establish reliance between network members in that one member is reliant on another to complete their task and provide required information for the next member to complete their required task. A fundamental requirement in a network such as a construction project is that each member believes that they can rely on other members to complete their given tasks based on their skills and competence (Blois 1999). The underlying concept of traditional project management is that defining a detailed schedule and staffing a project with competent people will result in success based on the members relying on each other to successfully complete their task in the project schedule. Although this concept is a critical success factor for the development of efficient projects, it is only a necessary condition for reaching the levels of interaction required for high performance projects.
- Trust—the third level of dynamics is the concept of trust within a network. Trust and reliance are often confused and are frequently used interchangeably. Although there are multiple differences between the two concepts, the relevant difference in this model is expectation. Specifically, in a trust relationship, one member of the network trusts that another member will go beyond just completing their task to act in a manner that is mutually beneficial to both parties. This trust leads to an emotional connection within the network whereby if one member does not act in a mutually beneficial manner, then the other member feels let down. This is in contrast to reliance where one only expects that the stated task be completed and if this fails to occur then a network member may experience annoyance, but no emotional hurt is experienced (Blois 1999). The importance of this trust concept is that a member who trusts another individual to work for mutual benefit will have a greater likelihood of sharing knowledge than an individual who believes that no mutual benefit will occur.
- Values—the goal within the dynamics component of the model is to have a network where the members share values pertaining to the project and the context in which it is being developed. These values include both social values such as responsibility, integrity, honesty, morality, quality, and timeliness, as well as context values such as client interaction, worker treatment, and environmental stewardship. If a network can be formed where the members share the contextual values as well as a segment of their social values, then they will reach the performance context that is required to fully share knowledge and achieve high performance results (Katzenbach and Smith 1993). Specifically, the team will adopt the motivation to freely share the knowledge that drives the project mechanics.

Mechanics

The second component in the social network model, the mechanics, focuses on the information and knowledge that is exchanged during the completion of the project. This can be considered as the "what" of the project, or the measurable characteristics that affect project efficiency. The model identifies a series of these characteristics that, similar to the dynamics, get increasingly difficult to achieve, but are increasingly related to high performance results. Once again, the goal for the network is to move beyond reactive communication and information sharing to proactive knowledge exchange.

- Communication—communication in this context is the most general parameter to be measured. A significant body of work exists in terms of measuring communications on a construction project (Thomas et al. 1998). However, in the current context, the number of communications between members is not the focus of the model. Rather, communications are examined to determine the informal network that exists within a project team. Informal networks are critical to a construction project due to their ability to accomplish tasks quickly and to activate when unexpected problems arise (Katzenbach and Smith 1993). Therefore, the first element of the mechanics is to establish a social network that has communications connections that extend beyond the formal hierarchy and connect as many personnel as possible.
- Information exchange—the second level of mechanics emphasizes the network of individuals that a member interacts with to complete specific tasks. In this network, information is exchanged in two directions. In one direction, a member has a key set of individuals from which information is obtained to assist in completing assigned tasks. In the opposite direction, a member provides specific information to others to assist them in completing their required tasks. These networks may be different depending on the tasks, levels of experience, and the impact of the social dynamics. These networks are important because they are an indicator of the efficiency of information transfer within a project. If individuals are obtaining and distributing information over a wide network, then information transfer becomes more efficient as bottlenecks are reduced and the informal network begins to operate. This level of mechanics is often the focus of project research as it is quantifiable and it can be related back to the information exchange requirements set forth by the project schedule.
- Knowledge exchange—the final level of mechanics, knowledge exchange, is the strategic component for achieving high performance results. To move from a reactive project process to a proactive process, the team must transfer the exchange focus from information to knowledge. In this transfer, the team moves its focus away from simple task implementation and individual goals to why tasks are being done in specific ways and how the tasks can be improved for mutual benefit. The motivation for achieving this level of exchange is explored in depth within the knowledge management literature (Chinowsky and Carrillo 2007). However, motivation by itself will not achieve the intended results. Rather, this level of interaction is difficult to achieve until the concurrent level of social dynamics, trust and value sharing, are achieved within the network. Once these concurrent levels in dynamics and mechanics are achieved, then the team can move to a context where high performance has a greater likelihood of emerging and producing high performance results.

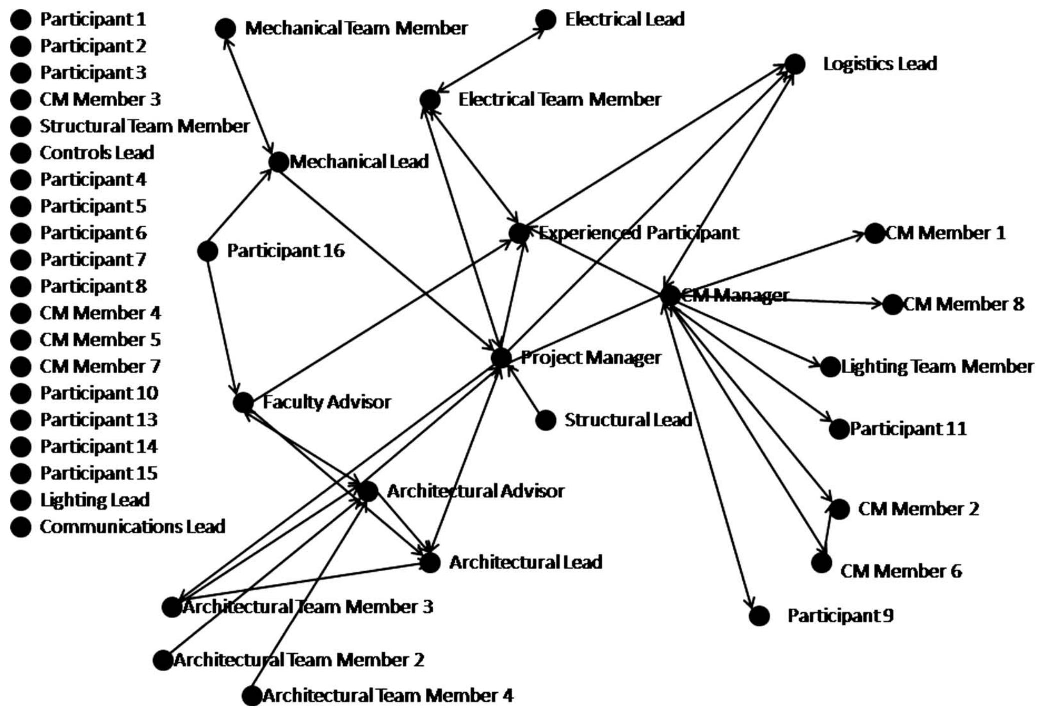

Fig. 2. Project network with the project manager having a very central position for all specific project communications

Initial Social Network Example

To illustrate how the social network model can identify strengths and weaknesses in project teams, a representative construction project was selected for an initial analysis. The project focused on an international design and construction competition for energy-efficient housing. The project required teams comprised of architects, engineers, and contractors to work together to produce a working residential model that utilized state-of-the-art energy-efficiency technologies. The team that the writers chose to follow was comprised of 35 individuals in a classic project hierarchy. The writers used a survey instrument in SurveyMonkey to acquire input on several dynamics and mechanics variables. Each of the members of the project team was surveyed to obtain a complete picture of the perspectives within the team. The results of the survey were input into UCINET, a SNA analysis and visualization package (Hanneman and Riddle 2005).

As illustrated in Figs. 2 and 3, the visualization technique provides significant opportunity to identify structural concerns within the project network. For example, Fig. 2 illustrates how the project network followed a centralized pattern with the project manager controlling most communications related to project decisions. Similarly, Fig. 3 illustrates how the architectural team became isolated from the construction and engineering components during the decision-making process. This diagram illustrates the frequency in which specific project decisions included members of the team. As illustrated by the lack of a link between the two groups, the architects were in infrequent contact with the team during the majority of decision-making processes.

Following the development of the social network visualizations, the results of the competition were analyzed to determine if any correlations existed between poor performance and network dynamics. To support this analysis, the research team used the results of the competition which judged the teams in ten areas. The team followed by the researchers performed in the bottom half of the competition in five of the ten areas (Table 1). For each of these areas, the results were compared with network measurements to find critical variables that could explain the reason for the poor performance.

As documented in Table 1, the poor performances in four of the five areas could be directly related to specific deficiencies in the social network model of construction related to individual-based measurements. The fifth area, hot water, as discussed in the following is related to an overall network measurement. These five deficiencies are highlighted as follows:

- Architecture—the poor result in architectural design correlates to the network variable, flow betweenness. This variable measures the amount of information that is routed through an individual to distribute to the team. In the case of the competition team, the project architect had a very low betweenness rating. Translated, this rating, which was confirmed through follow-up interviews with the team, indicated that the lead architect was not sufficiently involved in discussions regarding the integration of engineering requirements and architectural design. The result is that the lead architect developed a design which did not fit the context of the competition.
- Appliances—this category is closely aligned with the architecture category. Specifically, the lack of connection between the staff architect and the remainder of the team led to a lack of communication concerning appliance selection. In addition to the betweenness measurement, this category is indicated by a low density measurement in the specific communications variable. This rating measures the number of links between the members in the network. In the case of the team, a low density rating indicated that a minimal number of team members were involved in design decisions.
- Hot water—the hot water category performance reflected on the team failing to design a system that worked consistently through the competition. The ability to perform well in this category is dependent on all facets of the team, design, engineering, and construction, working together, and trusting each

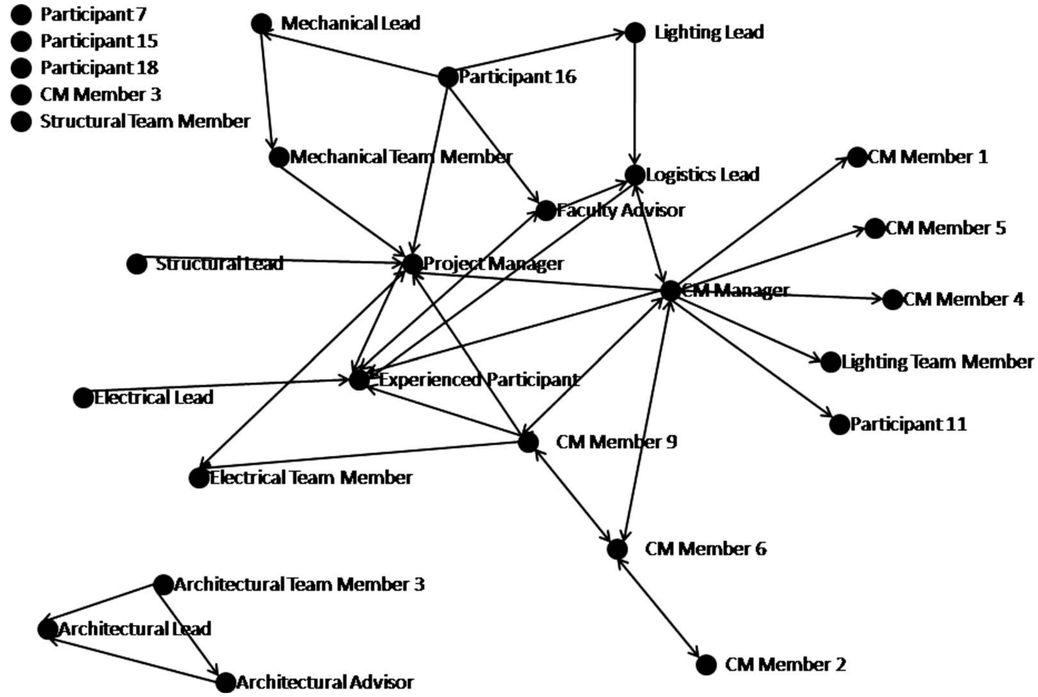

Fig. 3. Project network illustrating how the architecture group became separated from the main network when project requirements were being discussed

other to bring innovative ideas to the process. The competition team failed to achieve either of these requirements. The indication of this is the low density scores in the trust variable and the specific communications variable. Each network was found to have only 10% of the potential links present between members. This means that for every ten people that an individual could interact with, either trusting them or communicating with them, only one connection was actually present in these networks. In the latter case, the lack of density in specific communications indicated that the team was not fully integrated in regards to the design and thus did not bring all relevant knowledge to the design process. In the former variable, the lack of trust in the team inhibited the team from freely exchanging knowledge and thus did not achieve the innovation required to perform at a top level in this category.

- Communication—the communication rating reflected on the team's ability to communicate to the jury the theme, innovations, and implementation of the competition residence (this is not to be confused with the communication variables in the model). The poor performance in this category could be anticipated based on the betweenness, power, and centrality ratings of the lead engineer assigned to this task. Specifically, the individual assigned to lead this task was positioned in the network in such a manner that the network was left vulnerable to actions taken by the lead engineer. Although communication had a high level of responsibility for the engineer in charge, this responsibility was not reflected in the network. Instead, the individual was positioned on the periphery of the network with little power or centrality. This positioning made the network vulnerable to the individual leaving the project, which occurred in the latter stages of the project. When this occurred, no other team member had the full range of knowledge required to successfully perform the communication task at the competition. Thus, the lack of centrality commensurate with the importance of the task resulted in a vulnerability that ultimately materialized in a lack of network capacity to complete the required task.
- Comfort zone—the final category that the team performed poorly in was the comfort zone category, which focused on the implementation of automated controls to monitor and adjust the temperature and humidity within the residence. In this category, innovation and the demonstration of creative solutions is rewarded. The key to a successful outcome is dependent on a team working together, exchanging knowledge, and having leadership to guide the innovation process. As demonstrated in the trust variable, the competition team lacked this trait in

Table 1. Four Poor Performance Categories of the Competition Team That Were Related to Individual Team Leads and the Related Measurements That Could Potentially Predict the Outcome

Category	Variable	Individual	Betweenness	Centrality	Power
Architecture	Specific communication	Lead architect	11th	6th	16th
Appliances	Specific communication	Staff architect	13th	8th	7th
Communication	Information exchange	Communication lead	28th	28th	22nd
Comfort zone	Trust	Controls lead	24th	26th	27th

Note: The measurements represent the relative ranking of the measurement within the 35 member team, with 1st being the highest score, such as having the greatest centrality position in the network.

regards to the individual assigned to lead this effort. With a low density rating in the reliability variable and the trust variable, the team failed to achieve the integration required to implement an automated controls solution. Additionally, the individual assigned to lead this effort was isolated from the central decision-making structure, thus reducing his ability to provide the leadership necessary to integrate the various disciplines into a successful solution.

In summary, the poor performance of the competition team could be traced back to deficiencies in the project network in each category where the team scored poorly. A combination of overcentralized decision making, lack of information and knowledge integration, lack of trust, and isolated individuals resulted in a solution that did not reflect the capabilities of the individuals within the team. Although this is an illustration of the social network model analysis on a limited project, it spotlights the potential to rapidly visualize the attributes of successful and unsuccessful project networks based on the social network model components. This mapping and visualization focus represents the intersection of information technology and project management as the maps derived from the graph-based relationships indicate appropriate network relationships required to enhance project teams.

Conclusion

The social network model for construction outlines an innovative and transformative approach to enhancing project team performance. The historic approach of emphasizing a continuing refinement of tasks as a basis for achieving high performance teams is not a viable approach to achieving significant performance improvement in construction projects. Rather, it is time to recognize the key role of individuals within project networks, including the communication and trust that is the basis for achieving high performance results. The social network model addresses fundamental research questions in this domain through the integration of social science and engineering concepts. As outlined in this paper, research into communication has been a mature area in the social sciences domain in terms of Social Network Analysis. However, until this time, the infrastructure domain has been perceived as too dynamic for existing modeling techniques. The social network model breaks this barrier by demonstrating that new technology combined with a greater understanding of project networks and interdependencies provides a foundation for achieving high performance outcomes.

However, it must be noted that significant challenges exist in the construction domain that will affect the implementation of the social network model. First, the construction industry is based on network instability where project participants are regrouped on almost every project with little regard to past network connections. This instability places the network in a scenario where minimum experience exists between the participants and thus forces the network to rebuild a significant portion of the trust relationship in each project. Second, construction networks are often required to move from the formation stage to the collaboration stage very rapidly due to schedule constraints. This leaves little time for the participants to build trust prior to the execution of the project tasks. And finally, the contractual relationships defined in a project context can serve as barriers to the free exchange of knowledge due to liability concerns. Although it is beyond the scope of this paper to further explore the relationship between social networks and these issues, it is recognized that these issues will impact the successful implementation of the social network model.

Placing these concerns for implementation in the background, the current effort and example application of the social network model illustrates how the integration of social science concepts such as trust can affect the outcome of construction networks. In projects where trust and value sharing are not evident, the impact on information and knowledge sharing can be significant. The reduction in this open sharing results in an equally significant impact on the final project outcome. It is anticipated that this result is not limited to a particular type or size of project. Rather, construction networks are fundamentally based in social networks and therefore to achieve high performance, the network must be managed based on a social collaboration perspective to achieve the next level of performance improvement.

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