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Social network analysis of change management processes for communication assessment

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ABSTRACT

Change management requires effective communication between diverse project participants to control delays and costs. This study applies social network analysis (SNA) to the change order process, mining tremendous volumes of change-order data. Furthermore, this study evaluates change-order related social network characteristics. SNA measures structural characteristics of the communication network at project, inter-organizational, change-order and time-dependent levels. Communication data are extracted from a project and used as a case study. This study describes how individuals are engaged in and impact the communication network, and emphasizes the significance of effective communication in process-efficiency enhancement. The results quantitatively illustrate the communication network and highlight the roles that key participants play. Key participants who influence the social network are revealed at different levels of the study. This research contributes to the literature by applying SNA to discover social networks in the change management process, and to provide better insight into communication network characteristics.

1. Introduction

Throughout the lifecycle of a construction project, iterative cycles of changes are common; these changes can cause uncertainty and complexity in construction management [1–3], resulting in significant cost overruns and delays. A change can refer to any variation or a modification to existing conditions, assumptions, or requirements in construction work [4]. Changes usually lead to issuing change orders to deal with variations in scope of work, material, design, etc. The implementation of change orders can cost approximately 5.1–7.6% of the total project [5]. A review of change orders in construction has shown that changes can range between 10 and 15% of the contract value and cause 10–20% losses in productivity. A 40% increase in project duration was observed in one case study [6]. The full cost of changes increases nonlinearly with the cumulative size of all changes [7], and a change control system is required to control the overall management of change orders [8]. While several studies have developed change management systems for construction projects [8–10], the importance of project participants in the change management process has not been widely studied. Construction projects require collective effort, communication, and coordination among project participants, especially in the change orders process for a project [11].

In a construction project, a network of organizations works together and enters into various communication arrangements to create value and achieve the project goals [12]. These organizations are interdependent and influence each other. They need to exchange large amounts of information about activities, processes, and decisions used to deliver the project. In project-based organizations, communication plays an important role in project success. Although the impact of communication on projects has received attention in academic research [13], there has been limited research on the effects of communication and coordination across different organizational levels for project change orders. Communication and coordination can be viewed as valuable resources or intellectual assets. The communication performance of project participants is an important factor for efficient project change management and needs to be assessed periodically during the execution of the project to identify bottlenecks, enhance performance, and improve the change order process.

This research emphasizes the impact of communication and information exchange between participants to enhance efficiency. Project participants not only exchange project information as formally determined, they also continuously exchange knowledge and insights to enhance collective project performance. The network of this information exchange can be quite complex and impossible to analyze manually. Therefore, there is a need for big linked data analytics among communication networks to effectively support project success. This

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study explores change order communications; describes how individuals are engaged in and impact the communication network; and emphasizes the significance of social processes, patterns, and practices in process-efficiency enhancement. Social network analysis (SNA) has been the main approach adopted within multi-organizational networks to identify and analyze participant relationships, roles, and overall network structure [14]. SNA is a powerful tool to study complex systems. Here, SNA is employed to measure and analyze the communication of change order information. A case study project provided by a construction company in Alberta, Canada, is used to examine the communication performance in a multi-organizational working system. The findings contribute to an understanding of how communication impacts the change order process and, in turn, the project.

The existing literature on change management and communication impacts is reviewed. A systematic approach to identify the social networks embedded in the change management process is then presented. The concept of social network is introduced and network modeling at different organizational levels is explained. Finally, a case study provided by a construction company is discussed, followed by a discussion of limitations, conclusions, and directions for future research.

2. Literature review

2.1. Change orders

Change orders are the most common factor for cost and schedule overruns in construction projects [15], and they often impact the project quality, time, and cost. Several studies have examined the effects of change orders on different aspects of construction, including labor productivity [16] or cost and schedule overruns [17]. These impacts can be attributed to multiple causes, including variations in project scope, lack of project communication, poor site-management, improper planning of material quantities, or vendor changes. Change orders can strain the relationships of the owners, contractors, subcontractors, and other organizations involved in the construction process. Lee et al. [18] proposed a dynamic planning and control system to evaluate the negative impacts of changes and other conflicts on the construction project performance. Zhao et al. [19] developed a methodology to predict changes due to the responsible factors from information flow. Moselhi et al. [20] and Ibbs [21] focused more on the cumulative impacts of changes, and they showed that disruption due to changes overshadows productivity. Many researchers have stated that lack of communication leads to change orders and rework [22–25]. However, past research lacks quantitative analyses of impact that project participants have on the change-management process.

2.2. Communication in change management

Project participants are often geographically dispersed while they exchange a massive amount of information to enhance project success [11]. Communication is of utmost importance to coordinate goals in construction projects. While much research has been conducted to study the role and benefits of good communication on the overall success of a project [26], little work has been devoted to studying the effects of communication in more detailed aspects or processes, such as those involved in change-order management. Recent work in the construction and project management literature has shed light on the importance of good communication to achieve success in projects [13,27–30]. Ineffective communication for change orders by one party can cause disputes and delays of work of other parties in the project. Padalkar and Gopinath [31] conducted an extensive literature review and found that although there was an increase in project communication research between 2011 and 2015, communication is a minimally represented knowledge area. Smit et al. [13] investigated communication preferences of project participants to evaluate how modern communication media impact project participants and outcomes. Butt et al. [11] presented a qualitative study for understanding the effects of communication between project stakeholders on the change management process in two construction projects. They concluded that effective communication created clear change management processes that found innovative solutions for problems. Charoenngam et al. [32] developed a web-based tool to establish a good communication framework between project stakeholders for effective management of change orders. At this time, there is no suitably developed framework for analyzing the communication performance of project participants in a change order in the construction industry. Three centrality measures are used in this study to compare and evaluate the performance of each participant in the network – i.e. how involved a participant is in the communication (degree centrality), how a participant controls the flow of information (betweenness centrality), and how active a participant is in exchanging information (closeness centrality). This paper deals with the assessment of communication to fill this gap in the construction domain.

2.3. Social network analysis

The characteristics of communication networks involved in the change management process can be studied using social network analysis (SNA) [14]. The concept of social network analysis was first introduced by Moreno [33] to study social interactions, and has recently been utilized in the fields of engineering and construction [34]. Social network analyses broadly identify social structure interactions. Graphs or sociograms are created with nodes representing the parties in a network and links between the nodes representing the relations between the parties. Social network analysis emphasizes the relational measures among the parties represented in a graph or sociogram. Many researchers use SNA to identify and analyze structural properties of various relationships in the construction management domain [35,36]. SNA can also be used to compare project participant performance as predefined and shaped by contractual agreements and communication links. This approach appeals to researchers in the construction domain because of its capability to investigate various relationships among project participants and organizations.

3. Research framework

Change management data contain all of the change orders and activities requested or ordered by project participants. This section focuses on the application of SNA to analyze communication among project participants in the change management process. Change management data are used as a means to discover social networks in these communicative processes. The main challenge in using change management data is that tremendous volumes of change orders are stored in unstructured text formats with both noise and outliers, making them difficult to process and analyze. Fig. 1 illustrates the framework for discovering social networks from change management data. The proposed framework is detailed in the following sections and is composed of three main steps: (i) social network data mining, (ii) social network modeling, and (iii) social network analysis. The change management data are used as a data source in the first step of the network mining. The next step is to extract the required data for social network analysis, which is the first step of data generation.

3.1. Network mining

The data mining procedure first consists of data extraction, wrangling, and cleaning to obtain change order communications from several participants over the course of a project in a comma separated values (CSV) format. The challenge is to mine data for a directed network consisting of n participants, which requires identification of the properties of $n(n-1)$ pairs of participants. Any change order requires multiple participants to work together to address the requirements.

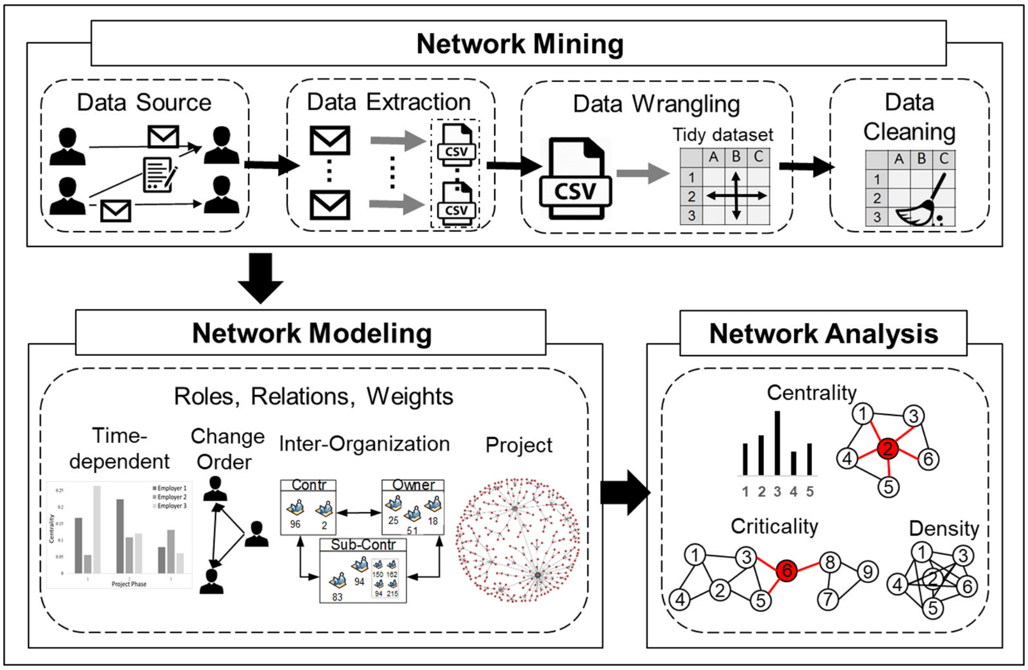


Fig. 1. Research framework.

Change orders often exist simultaneously, leading to a substantial number of communication links. To streamline change order communications from different project participants, each link is transferred into CSV format.

In the data extraction step, all the information related to the participants in the change order communication network is extracted from change management data. Information about participants is saved using the participant's name and organization (or a unique ID number) in the extracted CSV file, and each line in the dataset represents an interaction between multiple project participants. Several other items such as the change order number/description and timestamp are pulled out and stored in the CSV file, as well. For example, Participant #2 sends a letter to Participants #25, #92 and #94 regarding Change Order #2 in June 2013. This observation in the extraction step of data mining is stored in one row with multiple columns; each column represents a feature related to the observation. The information in this row is relevant to three different observations and should be reflected in three communication links in the network in the data wrangling step. In data wrangling, the dataset is reshaped and combined into compatible and interpretable formats. All CSV files are combined into one file containing all related information regarding change orders and participants. In the final file, each line represents an interaction between two participants. In the data cleaning step, data points that are not true (noise and outliers) for the communication application are removed. For example, a communication between a participant and themselves is an outlier in the dataset, and null or missing values (i.e. blank email messages) are noise. Table 1 illustrates a sample of the extracted CSV file after the data-mining process.

3.2. Network modeling

Social network modeling develops a sociogram representing relations among multiple participants in a network. To create a social network, three main components need to be determined from the change management data: participants, relations, and weights. Participants of the network can initially be identified in the traces left behind in the change management data. Relation weight is measured by the total number of links sent by a participant and received by another participant in the network. There is no standard or metric to construct social networks as they are tailored to the application or the objective of the study. SNA is conducted to measure the structural characteristics of the communication network at the following levels:

3.2.1. Project level

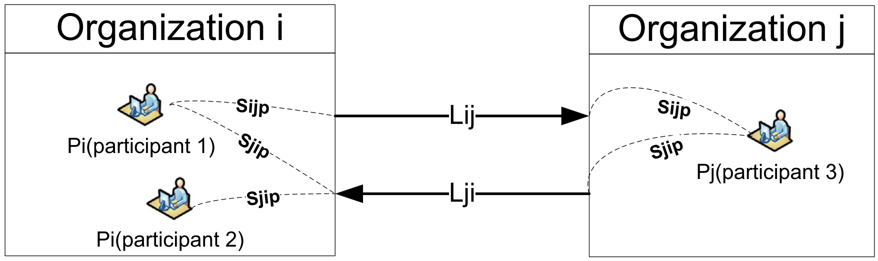
At the project level, SNA analyzes and measures characteristics of a network to enhance the understanding of participants' communication from the perspective of the whole project. Moreover, SNA is used to evaluate the position of each node in the project by calculating centrality measures as will be described in the Network Analysis section below. Three centrality measures (degree, betweenness, and closeness) are typically considered in SNA.

3.2.2. Inter-organization level

In order to accomplish a multi-organizational project, organizations must be willing to communicate, coordinate, and share their knowledge. In construction, a network of organizations works together to achieve the goals of the project and to tackle the change orders.

Table 1
Sample of the extracted CSV file.

Sender ID/organization	Receiver ID/organization	Timestamp	Subject
92/Contractor	25/Owner	3/7/2013 11:49:38	“COR 03 Pending action”
54/Contractor	144/Subcontractor2	14/12/2013 6:42:48	“COR 10 Lake travel allowance”
94/Subcontractor1	92/Contractor	11/1/2014 13:38:44	“Executed COR 19”
144/Subcontractor2	54/Contractor	15/12/2014 6:27:52	“COR 42 Snow removal”
137/Subcontractor2	92/Contractor	9/3/2015 10:36:30	“COR 114 Tanks handrail”
25/Owner	92/Contractor	8/4/2015 9:43:17	“COR 152 Approved”



$$L_{ij} = L_{ijp(participant\ 1)} + L_{ijp(participant\ 2)}$$

$$L_{ji} = L_{jip(participant\ 3)}$$

Fig. 2. Inter-organization communication.

Organizations are usually geographically separated but still make interdependent decisions. Effective communication among involved organizations is, therefore, vital for smooth change-order execution, to maintain compatibility, and to achieve project objectives. At the inter-organization level, only links between organizations are needed to evaluate a social network. Social network analysis can be used to depict both formal and informal organizational links. In this research framework, a communication network between different organizations is built based on the cleaned data summarized in Table 1. To calculate the strength/contribution of a participant in the inter-organization level, the authors created a percentage calculation. First, let L_{ij} represent total number of links sent by organization i to organization j. A communication matrix is built to represent the weighted relation of links among the main organizations, as shown in Fig. 2. For example, the weight of the link from Organization 2 to Organization 3 is calculated to be L_{23}.

Next, let p be the ID of a participant within organizations i or j. Let p_i be the ID number of a participant within organization i and p_j be the ID number of a participant who works for organization j. L_{ijp} is the total number of links sent if p belongs to organization i and received if p belongs to organization j. The calculation of the strength/contribution of a participant is given by Eq. (1)

$$S_{ijp} = L_{ijp}/L_{ij}, \quad if\ L_{ij} > 0 \& i \neq j \tag{1}$$

where S_{ijP} serves as an indicator to measure the strength or contribution of participant p ($p = 1, 2, \ldots, P$) on communication links L_{ij} ($i, j = 1, 2, \ldots, N$).

At this level, the strength, betweenness, and closeness centrality measures refer to organizations, rather than to individual participants. Here, strength centrality measures the extent to which an organization is connected to adjacent organizations. An organization's in-strength and out-strength centralities represent the degree to which the organization is a receiver or sender, respectively, of information from or to the organization's neighbors. Betweenness centrality measures the extent to which an organization controls the flow of information between different organizations. Critically, these interstitial organizations keep the network together [37]. Closeness centrality measures the distances of an organization to every other organization in the network, reflecting its dependency/independency. An organization with high closeness centrality is highly dependent, making it difficult to act independently without others knowing. A centrality index is defined for each company using the average of the three centrality measures. The centrality index of a company—and the number and direction of the links exchanged between the participants—could be measured easily using a programming language, such as R [38]. The centrality measures of an organization indicate the position, intensity of power, and influence of this organization in the network.

3.2.3. Change order level

Typically, when a change order is identified in a project, the responsible organization will try to evaluate and quantify its impacts. Depending on its complexity, the schedule and cost impact of a change order can be estimated; however, the cumulative impacts of the change order or its impact on downstream activities is not as straightforward to calculate. Participants themselves may impact the duration of the change order, based on their individual proficiencies. SNA at the change-order level evaluates the position of project participants involved in processing a specific change order. To identify the network for a specific change order, Table 1 needs to be filtered based on the subject of a change order. The filtration process results in the identification of participants, their organizations, and timestamps of the communication links. The involved participants and the duration of their actions is then identified and evaluated in each step during processing. By analyzing the network at the change order level, different stages to a change order are revealed. The results also provide insight into delays due to the processing time between liable participants. In each step during processing, the involved participants and the duration for their actions are identified and evaluated. The results provide insight into bottlenecks in the process, creating a decision-support tool for project managers that will enable them to improve their change management system.

3.2.4. Time-dependent level

At this level, SNA is applied to evaluate the network of the change-management process at different project phases. Participant roles may change during the construction phases of the project. Some participants, such as a cost engineering managers, play more important roles in project initiation and project closeout. A procurement specialist is usually more involved at the peak of construction, which might require more change orders related to procuring different materials. Here, SNA shows the centrality of the most important participants over time. The results provide insight into participant performance during construction.

3.3. Network analysis

This section clarifies the network analysis calculations and metrics that are conducted at different levels of the change order. These metrics include network descriptions, degree centrality, betweenness centrality, and closeness centrality.

3.3.1. Network characteristics

SNA provides an effective tool to measure network size, density, average degree, etc. The elements of $N = \{1, 2, \ldots, n\}$ are the nodes or participants of the network, while the elements of $L = \{l_1, l_2, \ldots, l_K\}$ are its links or edges. A directed network consists of two sets N and L, such that $N \neq \emptyset$ and L is a set of pairs of N. Here, a node is referred to by its order, I, in the set, N. In a directed network, each link is defined by a couple of nodes, i and j, and is denoted as l_{ij}. The order of the two nodes is important: l_{ij} stands for a link from i to j, and $l_{ij} \neq l_{ji}$, with $l_{ij} = 0$ representing the absence of an edge from i to j. Network size is the total number of nodes or ties. Network density is the proportion of existing connected ties over all the possible connections (see Eq. (2)). Networks with high density are highly connected, and information or resources can quickly move across the network. Network density is a representative of the cohesion of the entire network and can be used to provide more insight into how connected participants from different organizations are at the project level. Average degree measures the average number of neighbors per node (see Eq. (3)). The average degree is closely related to the density.

$$D = \frac{L}{n(n-1)} \tag{2}$$

$$AD = \frac{L}{n} \tag{3}$$

Here, D is the density of a directed network, L is the number of existing links, n is the total number of nodes/participants in the network; AD is the average degree. The diameter is the longest path of all the calculated shortest paths in the network. In other words, diameter is the largest distance between the farthest nodes in the network. In SNA, distance is calculated by the number of links in the shortest possible paths from one node to another. The mean distance provides a measure of communication efficiency for an entire network by averaging the shortest possible path between all nodes. The measure of reciprocity defines the proportion of mutual connections, in a directed graph. In other words, it is an index to measure the tendency of participants to reciprocate. It is most commonly defined as the probability that the opposite counterpart of a directed link is also included in the network. Social network analysis facilitates comparison between project participants' actions within their communication channels. Network centrality measures describe the intensity of power, prominence, and influence of a network participant.

3.3.2. Degree centrality

Degree centrality is the number of adjacent edges or ties a node has as a participant representative. It is an indicator of how connected a network participant is to other participants. A higher degree centrality indicates higher interaction, more influence, and stronger involvement in the network. Degree centrality is calculated using Eq. (4)

$$DC_i = \frac{\sum_{j=1}^{N}(L_{ij} + L_{ji})}{2(N-1)}, \; 0 \le DC_i \le 1 \tag{4}$$

where DC_i is the degree centrality of the ith node in network, L_{ij} is the number of links that a node j receives from a node i, N is the total number of the nodes in the network. The weight or importance of an arc is not reflected in the degree centrality. For a weighted network, strength centrality is a better representation of each node connection or links. A weight of the relationships can be used to represent the strength of the relation between participants in a communicative environment. Strength is calculated by summation of the weight of adjacent edges. Therefore, it counts for both the number of adjacent edges and their weights. If the strength of the relation is required, the weight of each relation should be taken into account. DC_i measures the node degree centrality by the sum of the weights.

3.3.3. Betweenness centrality

The betweenness centrality of a node is the number of times a node acts as a bridge along the shortest path between two other nodes (see Eq. (5)). In other words, betweenness centrality measures the extent to which a participant is located in the shortest path between two other participants in the network; potentially, this participant controls this flow through the network. Participants with a high betweenness centrality occupy critical network positions; poor performance by participants at these critical points can harm the network. A higher betweenness centrality may indicate a participant who takes on an informal leadership position in the network and may encourage a participant to contribute more to solutions in response to the problems encountered in the project. In Eq. (5), BC_i is the betweenness centrality of the ith node in network, $\sigma_i(s,t)$ is the number of the shortest paths that pass through node i, and $\sigma(s,t)$ is the number of shortest paths between all nodes.

$$BC_i = \sum_{s,t:s \neq t \neq i} \frac{\sigma_i(s,t)}{\sigma(s,t)} \tag{5}$$

3.3.4. Closeness centrality

Closeness centrality reflects the extent to which the network is concentrated around one participant. The closeness centrality of a node is the average length of the shortest path between one node and all other nodes in the network. The more central the node, the closer it is to all the other nodes. A node/participant with a high closeness centrality can be very active and quick in exchanging information with other participants in the network. Calculation of the closeness centrality is given by Eq. (6)

$$CC_i = \frac{n-1}{\sum_{k \in N} d(i,k)} \tag{6}$$

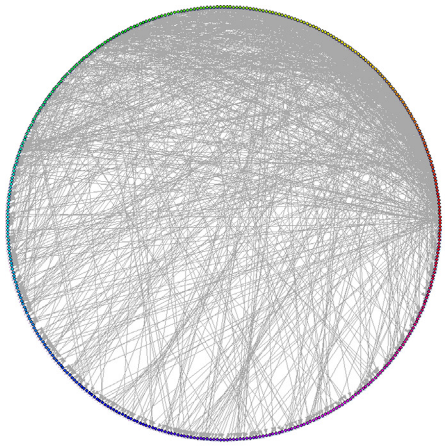
where CC_i is the closeness centrality of the ith node in network, and $d(i,k)$ is the length of the shortest path (geodesic distance) between nodes i and k. In problem solving that relies on communication links, efficient solutions occur when a participant has the shortest communication paths to the other participants. Communicating with a participant with high closeness centrality can be accomplished in an easier, more direct, and more efficient manner.

4. Case study

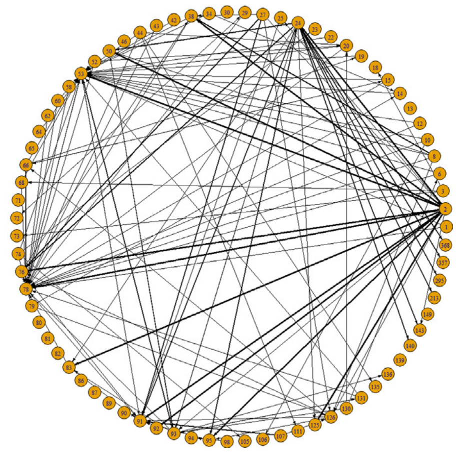
A large dataset of change orders for an oil and gas project was provided by a construction company located in Alberta, Canada, and used to demonstrate the feasibility and applicability of the developed approach in this research. The construction company played contractor role in a design-bid-build project to build an industrial plant. The major stakeholders in this project were the owner, main contractor, and subcontractors 1–3. The main contractor was responsible for delivering the project on time and budget to the owner. This project was a lump-sum contract with an original contract value of approximately 700 million dollars (CAD). The contract price was increased by 150 million dollars due to the change orders.

To create the network, change orders were read automatically to capture the records of communications. After the data cleaning step, a total of 3402 communication links were generated among different project participants dispersed across different organizations and stored in a CSV file. Each line in the file corresponded to information about a single sender/receiver set, a timestamp, and a change order description, as shown above in Table 1.

Two main components are required to create a social network: participants and their relationships. Project participants were identified by extracting unique IDs using the CSV file and were then stored in a separate CSV file, the node file. There were 412 nodes (participants) in our node file. Each node was a representation of a unique participant in the change-order network who worked for one of the organizations: contractor, owner, or subcontractor. Each was marked with a unique label. After each participant was labeled, the links between nodes were saved in an arc file, which contained the 3402 links between labeled nodes.



(a) All nodes and relations



(b) Nodes with strength>20

Fig. 3. Social network at project level.

4.1. Results

In this section, the node and arc files are utilized to visualize and interpret the social network of communication. These facilitate better understanding of communication characteristics between participants at numerous levels.

4.1.1. Project level

At the project level, the cleaned dataset contains information about 412 participants. Fig. 3 shows the social network built based on the relations among project participants. The communication network description is a directed network with 412 nodes and 3402 arcs. Fig. 3(a) represents all participants involved in the entire project and all of the communications between them. In Fig. 3(b), only nodes with strength centralities greater than 20 are shown. The widths of the links correspond to the weight/frequency of communication. Table 2 summarizes the communication measured at the project-level.

As provided in Eq. (2), network density falls within the range of 0–1. At a value of 1.00 (highest value), all participants are connected to each other; the network has total connectivity. At a value of 0 (lowest value), none of the participants are connected; a network is absent and all participants are isolated. Here, the network density is 0.008, which shows that in this network only 0.8% of all possible links among project participants are present, suggesting a low level of network cohesion. The total number of nodes/participants was 412, which is very high and indicates that there are many unrealized, potential relationships in the network. The average degree of the network is 6.49, indicating that each participant among the 412 participants in the network is connected to six to seven other participants on average. For a weighted network average, strength is a better measure than average degree because strength accounts for both the number of links and their frequency. In this case, the average strength of the network is 16.51 – almost 2.5 times the average degree – which could be a result of the intention/preference of participants to make communication with the previously interrelated participants in the network. Considering the close relationship between average degree and density, the results indicate that the structure of a network can be affected by a high concentration of links in a few participants, even if the other participants have few connections as shown in Fig. 3. The value of the network diameter is 23, representing the distance between the two farthest nodes in the network. The mean distance of the network is 4.14, meaning one node could traverse 4.14 nodes to touch another node. The reciprocity of the interactive network is 0.142 which shows the network is poorly reciprocal.

Table 2
Characteristics of the network at project level.

Symbol	Description	Value
N	Number of nodes	412
E	Number of edges	3402
D	Density of network	0.008
R	Reciprocity of network	0.142
DM	Diameter of the network	23
MD	Mean distance of the network	4.14
AD	Average degree of the network	6.49
AS	Average strength of the network	16.51

As mentioned earlier, centrality measures are used to evaluate the embeddedness of nodes and their positions in the discovered social network. Here, the results show that Participant #2 has the highest degree of centrality in the project level, indicating their high activity and involvement in the network. Participant #2 is the procurement specialist working for a contractor who is the sender and receiver of a large number of communication links. Participant #66 has the highest betweenness centrality and is able to control the communication flow easily. Participant #66 is a senior project manager for the contractor whose higher betweenness value indicates a leadership position in the network. It is highly effective for Participant #66 to contribute to solutions in response to the change order problems encountered in the project. Participant #174 has the highest closeness centrality and is very active in communicating information to other participants.

When the project is studied at the change order level, there are many people involved, which makes it difficult for human eyes to recognize the most important participants in the visualized network shown in Fig. 3(a). However, the configuration of the network and centrality measures of the participants can be easily seen in a tabular format (Table 2). In particular, strength centrality can be used to reveal the key participants and connections that have a significant impact on the change order communication at the project level. The results of the centrality measures, however, cannot be generalized to all projects because each project is unique; the change orders will be completely different. It is also expected that there would be a connection between the most frequent change orders and participant responsible for those types of changes due to the nature of their positions. In this case study, for example, most of the change orders are related to changes in material, which is why the procurement specialist has the highest degree centrality in the network.

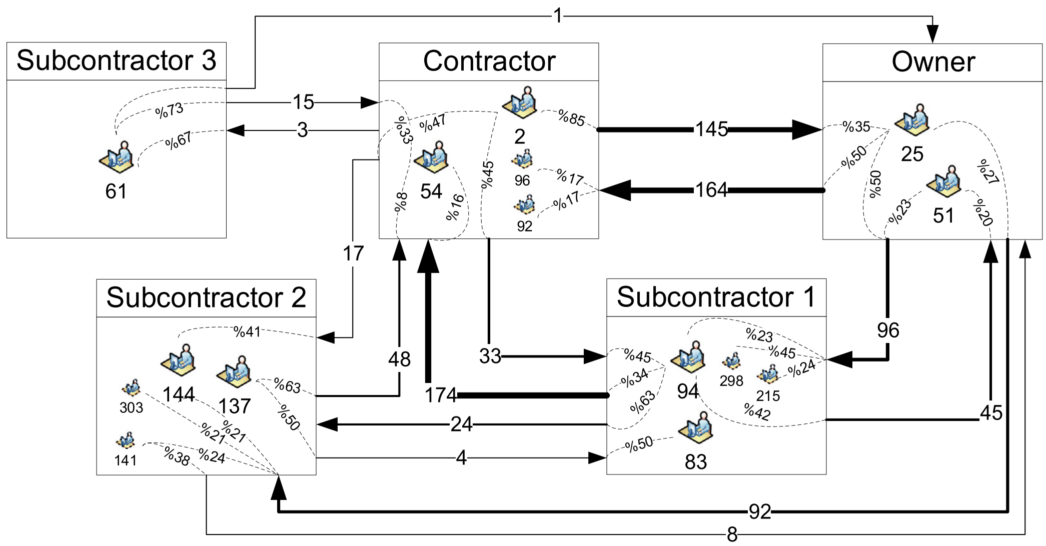


Fig. 4. Social network at the inter-organization level.

4.1.2. Inter-organization level

Based on the cleaned data summarized in Table 1, the active participants are mostly distributed among 5 major organizations. For simplicity, a communication network has been built for the 5 main organizations (Fig. 4). A weighted relation assesses the strength of the communications between organizations and project participants. Frequency is reflected in weighted arrows, with each arrow showing the number of communications. The contractor here communicates with the owner more than the subcontractors because the contractor is mainly responsible for delivering the project with all the changes requested by the owner and is also responsible for getting the approvals. Simultaneously, the owner has sent communications to the contractor 164 times. The sent/received links are represented as percentages of the total number of communication links to show the contributions of the participants. For example, Participant #2 contributed 85% to the communication links sent by contractor and received by owner. Therefore, Participant #2 has a stronger role in the relationship as compared to other participants who belong to the same organization. Participant #25, on the other hand, received 35% of the links sent by the contractor.

Several participants belong to tightly connected organizations, as shown in Fig. 4. Many of the other participants are completely isolated from the inter-organization level, thus are not represented. The bridging roles that connect different organizations in the network can be identified for improving information sharing within the project. Participants #2, #25, #54, and #94 are all involved in most inter-organizational communications. These participants keep in close touch with more than one organization, acting as boundary spanners to provide an information channel among different organizations. These participants play a significant role in communication and knowledge sharing in the network. By contrast, Participants #83, #141, and #303 are seen only in one inter-organization link, indicating that they are considerably isolated. The results of centrality calculations at the inter-organization level are presented in Table 3. The centrality values are normalized so that they range between 0 and 1. The centrality index is used to represent the average of the three centrality measures in Table 3.

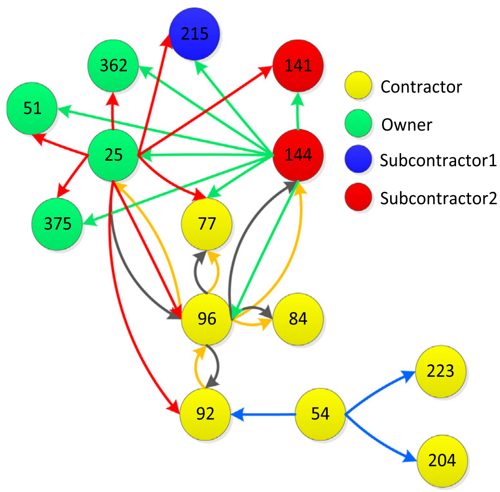
The network centrality of an organization is an indicator of its power and influence, representing how strategically an organization is connected in the network. The contractor has the highest centrality index with the highest degree, betweenness, and closeness measures. High-degree centrality for the contractor indicates high activity and involvement in the network. As shown in Fig. 4, the contractor is connected to all the organizations in the network and is the sender and receiver of a large number of communication links. The contractor has the most central position in-betweenness measurements and is able to control the communication flow easily. In this study, a higher betweenness value of contractor indicates a leadership position in the network. The contractor here is very active in communicating information to other organization because of their high closeness centrality. Analysis of the inter-organization level shows which participant might be the bottleneck in communicating change orders between different parties in the project due to their burden. These results can help organizations to improve the communication skills related to change management process.

Table 3
Centrality measures at inter-organization level.

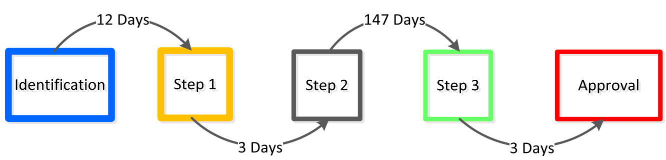
Organizations	Normalized centrality measures			Centrality index
	Degree	Closeness	Betweenness	
Owner	0.396	0.9	0.028	0.441
Contractor	0.430	1	0.278	0.569
Subcontractor 1	0.332	0.9	0.028	0.419
Subcontractor 2	0.199	0.8	0	0.333
Subcontractor 3	0.014	0.686	0	0.233

4.1.3. Change order level

In this section, one change order is considered as an example to show the results of SNA at the change-order level. This change order is related to the procurement of pipe. SNA is applied to evaluate the performance of the participants at the change-order level. As shown in Fig. 5, four organizations and 14 participants are involved in these change order communications. Each participant is shown using a colored circle with a number inside it to represent the unique ID of the participant. The color of the circle provides information about the organization to which the participants belongs. In Fig. 5, participants belonging to contractor are shown in yellow. In Fig. 5(a), the colored arrows correlate with the timeline of the change order as shown in Fig. 5(b). The change order is identified, and blue is used to show the links at identification step. It took 12 days for change order participants to analyze and send change-order information out. In Fig. 5(b), the timeline from identification to approval of this change order is shown. There is a gap of 147 days from Step 2 to 3 in the process of the change order, which may be the result of a performance deficiency of the participants involved in Step 2. This delay may cause additional delays and costs to the project and should be used to evaluate performance.



(a) Network of change order



(b) Timeline of the change order

Fig. 5. Social network at change order level. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

Table 4
Centrality measures at change order level.

Participant ID	Normalized centrality measures			Centrality index
	Degree	Betweenness	Closeness	
25	0.212	0.051	0.366	0.209
51	0.039	0	0.228	0.089
54	0.058	0	0.276	0.111
77	0.077	0	0.236	0.104
84	0.039	0	0.23	0.089
92	0.077	0.064	0.295	0.145
96	0.231	0.138	0.347	0.239
141	0.039	0	0.228	0.089
144	0.193	0.048	0.363	0.201

The participants of each organization keep in close touch with three other organizations' employees, acting as the boundary spanners to provide an information channel among different organizations. Participants #25, #96, and #144 play a significant role in communication and knowledge sharing in the network of this change order. By contrast, Participants #223 and #204 show up in only one communication link, indicating that they do not keep in close connection with the other participants. The results of centrality calculations at change order level are presented in Table 4. The centrality values are normalized so they range between 0 and 1. The centrality index represents the average of the three centrality measures.

The top participants in this change order ranked in degree and closeness centralities are Participants #25 (contract administrator) and #96 (project director); the top participants ranked in betweenness centrality are #25 and #92 (cost engineering manager). Participant #96 has the highest centrality index.

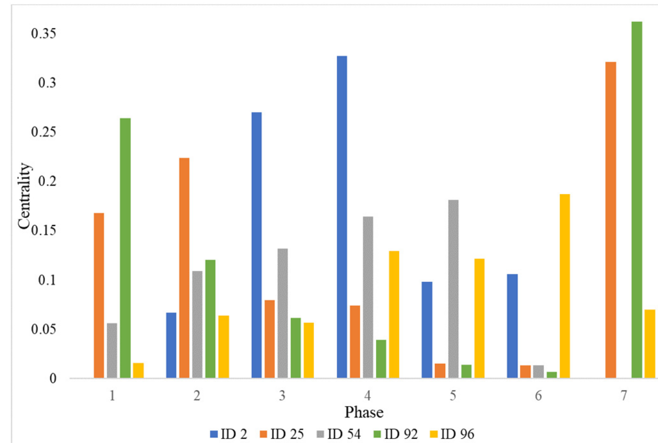


Fig. 6. Participant centrality vs time.

4.1.4. Time-dependent level

In this section, to capture the importance of participant roles at the granular level of the project timeline, the project duration is divided into seven phases from initiation to close out. In each assumed phase, SNA is applied to analyze the change-management network, and the centrality of participants is calculated. The participants with higher centralities are compared at different periods of the project. Here, the roles of five participants are evaluated at these assumed phases. Participants #2, #25, #54, #96 and #92 are compared. The comparison results for these five participants are shown in Fig. 6. Participant #92 is a cost engineer manager who works for the contractor whose role is more important in the first and last periods of the project compared to other participants. Participant #2, alternatively, has a more important role in the third and fourth periods of the project.

5. Discussion

The change order process is a combined effort among the owner, contractor, and subcontractors. Each participant involved in the change order network is expected to communicate the required information at the appropriate time to avoid delays. Issues and problems arise due to a lack of a clear schedule for change orders, too many arriving on a participant's desk at a given time, unclear tracking processes, and ultimately, information not being communicated in a timely manner.

SNA metrics and concepts applied in this research provide useful information about network formation, centrality, and connectedness of network. In terms of the overall network, network density is used to indicate the strength of the connections in a network. A low-density value indicated that a network focuses on individuals rather than on collaboration over a network. Such networks need to be redesigned by project managers to increase their density for a more efficient communication structure. Therefore, SNA is applied to discover underlying problems in change management communication network that can be later investigated to identify misalignments that impede project effectiveness.

Using this approach on an ongoing construction project can illustrate important communication barriers that exist in early project stages. By analyzing network communication performance, project managers can detect potential phenomena leading to communication problems and difficulties. Later, the communication network can be redesigned to involve the same participants more effectively, utilizing their skills and leading to a better change management process.

The findings in this research can help construction project managers define appropriate staffing and task allocation strategies during or after execution of a project. For example, as shown in Fig. 4, the project manager needs to take into consideration that Participant #2 may create a bottleneck in the network. If Participant #2 is overloaded with many change orders to be processed, it may cause delays. The project manager can assign another team member to distribute the workload. Additionally, historical records of communication and actual performance provide an unprecedented opportunity for change management. Project managers can use historical records of the quantified communication in making critical staffing decisions, such as selecting the leader of the change management team or grouping the team members to work on specific change orders. Fig. 6 shows that Participant #2 has more involvement in phases 3 and 4 of the project, but their involvement in phases 1 and 7 is negligible. This can help the project manager to allocate resources over project phases.

The quantified change management communication network in this research also provides useful information to identify bottlenecks in change order process development. A change order may be delayed because the liable participant has not reviewed it; as a consequence, corresponding follow-up measures have not been taken, including reassigning the work to other available participants. For example, as shown in Fig. 5(b), proceeding from step 2 to step 3 takes 147 days, which should be a red flag for the project manager to further investigate the reason for the delay and assess its impact on overall project timeline. Visualizing the communication features of the change management network also shows places that the change order process needs improvement. This improvement could entail replacing personnel, adding more staff, changing the configuration of the team, or assigning team members to different tasks.

The quantitative analysis of change management communication could also provide the project manager with critical information to develop targeted training programs for team members who are anticipated to run into difficulty in upcoming projects. Customized knowledge management can be developed to share the lessons learned from past communication strategies to enhance change management in future projects. Leadership training can be provided to key team members based on team decision- making in past projects and their performance in managing change orders.

6. Limitations and future work

Mining tremendous volumes of change management data that are stored in different formats to explore the communication network is a tedious task. One limitation is the need for a data adapter to harvest, wrangle, and clean the change order communication data and convert them to the required CSV format. Additionally, many organizations are involved in the change management process, which makes it difficult to develop a unified system to collect all change management data. Depending on the project delivery system and other contractual arrangements, the communication network may change, and the findings of this framework are only applicable for similar projects within a company. One other limitation is the type of communication that was used; informal phone calls or face-to-face conversations were not captured for this study.

As the case study demonstrates, identifying network participants and their links manually is not feasible. Therefore, one of the benefits of using the proposed framework is automating the network extraction and analysis. Networks from similar historical projects could be used to predict the communication network and be further analyzed by project managers to better allocate tasks and staff.

The results of the SNA discussed above are for the combination of formal (contractual) and informal communications. However, social network studies have another category for studying the relationship between the environment (e.g., contractual relationship and conditions) and network structure that is beyond the scope of this work, but could be studied in the future. Future work could also explore the relationships between change order characteristics and social network attributes. Further information about change orders (e.g., cost and time impact, or type of change) could be taken into account when analyzing relationships between communication network characteristics and change orders. The effective use (pros and cons) and implementation of the proposed framework could be expanded by interviewing project participants, and further information about project participants (e.g., gender, age, experience in the industry) could also be taken into consideration.

7. Conclusion

Change order data were analyzed to assess the communication performance and centrality of project participants in a change-management network. Measuring communication through time-consuming content analysis to reveal the communication performance is difficult. This study measured centrality and performance using social network analysis. Project management may use the proposed framework and subsequent results to improve individual and team performance in the project change order process. This research contributes to the state-of-the-art by proposing an innovative use for a trusted methodology to discover social networks. Practitioners may use this framework to provide insight into relationships between characteristics of a communication network, or to quantitatively measure the performance of individual project members. Project managers can refer to these centrality measures during project execution to troubleshoot communication problems. Centrality measures can be used to understand performance and avoid delays and cost overruns.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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