Safety Science 82 (2016) 338–351

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Exploring associations between resilience and construction safety performance in safety networks

Farah Wehbe, Malak Al Hattab, Farook Hamzeh *

Dept. of Civil and Env. Eng., American University of Beirut, Lebanon

ARTICLE INFO

Article history:
Received 11 June 2015
Received in revised form 10 September 2015
Accepted 17 October 2015
Available online 11 November 2015

Keywords:
Safety performance
Social Network Analysis
Network resilience
Risk management
Simulation

ABSTRACT

Safety management plays a major role in construction as negligence may result in loss of lives and detrimental project consequences. The Middle East witnesses poor safety management where companies need to improve their performance instead of hiding their deficiencies. This study aims at evaluating safety performance and network resilience to risks by studying safety-related interactions among the construction team. Safety on three mega-projects is evaluated by analyzing their respective networks for communication and safety management and mapping them using Gephi. Using Social Network Analysis (SNA), visualizations and various metrics were computed revealing network characteristics and communication patterns. Resilience metrics were measured using actual safety performance data and overall network resilience was simulated through agent-based modeling using NetLogo. Results and correlations show that networks with better interaction and structure have higher resilience to prevalent risks and have better actual safety performance.

1. Introduction

Safety performance remains the top concern of project managers as poor safety increases project failures and impacts all other Key Performance Indicators (KPI). For instance, unsafe work environment will undermine the quality of work and consequently incur additional time and subsequent costs to cater for such conditions. Safety remains marginalized in the Middle East, leading to high accident rates with a number of undisclosed incidents. The work environment is described as a place where "no international safety and health standards currently exist" (Kenrick, 2012). The construction industry in the region has been growing significantly over the last years and is expected to provide projects worth 500 billion dollars by 2015 (Kenrick, 2012). In Qatar, where construction work is booming in preparation for the 2022 World Cup, the fatality rate is around eight times as high as the UK (Sultan, 2013). Contracting companies need to improve safety management practices to reduce the current rate of injuries. Researchers have been studying safety practices but are faced with lack of accident reporting and absence of safety records. However, it is important to distinguish between two interpretations of what accident reporting value indicates. On one hand, a greater number of incident reports can be a result of improved reporting culture, and on another hand, it can be a result of an increase in reportable events and accidents. Moreover, the reporting frequency does not necessarily reflect the severity of incident cases, where an increase in reporting can a result of frequently occurring incidents with low consequences and not necessarily cover more severe incident occurrences.

Construction projects are known for having inherent risks with high levels of uncertainty. Risks vary with project complexity but remain inevitable; hence safety and risk management should be more emphasized on construction projects. To improve safety performance and implement proper risk management on a project, it is important to track how people interact with each other and how they deal with unfavorable conditions that jeopardize the work environment.

Safety management and risk analysis in practice are normally handled as isolated occurrences without accounting for root causes or investigating the phenomenon within an interactive human network. Construction and project managers require all individuals to undergo safety training and that incidents and safety issues be reported. However, such data needs not only be reported and statistically summarized, but also necessitates that improvements and prevention measures be employed. Alsamadani et al. (2013) used SNA to study safety communication in small work crews in the US by looking at safety performance of different crews, investigating socio-grams, and detecting communication patterns

* Corresponding author at: 406 E Bechtel, American University of Beirut, Riad El Solh-Beirut 1107 2020, Lebanon. Tel.: +961 1 350000x3616; fax: +961 1 744462.

E-mail addresses: faw01@aub.edu.lb (F. Wehbe), mja28@aub.edu.lb (M.A. Hattab), Farook.Hamzeh@aub.edu.lb (F. Hamzeh).

http://dx.doi.org/10.1016/j.ssci.2015.10.006
0925-7535/

visually. However, their data analysis suggests that the general SNA metrics are not significant measures that distinguish high from low performing crews. This study challenges the last finding and introduces the concept of resilience to differentiate robust networks from weak ones.

Available literature on SNA and safety studies are limited to examining communication patterns across social networks and their safety performance. However, this limitation in research does not assist in proactively managing risks and safety matters, where understanding a network's behavior and readiness to prevent risks and be robust against hazards is of ample importance. Therefore, to address this limitation and fill the gap in knowledge, this study provides a new perspective on safety management in social networks by evaluating safety performance and assessing the system's resilience to prevalent risks.

In this regard, this research employs SNA to map the network of people and their communication patterns on a project and looks at different metrics to evaluate system resilience which describes the ability of the system to avoid failures as well as to recover quickly once they occur. Results from this study can assist construction managers in understanding the importance of communication patterns for proper safety and risk management. The contributions of this paper is in relating communication networks to network resilience and safety performance. Safety management is presented and demonstrated through case studies as a social collective effort that relies on proper communication among the network of people within an organization.

2. Background

2.1. Safety management

Safety is a critical performance indicator as it reflects work conditions, injuries, and the loss of human lives which impacts project duration, cost, and quality. Hence, monitoring safety should be integrated at all stages of the project. As "you can't manage what you can't measure", proper safety management requires the tracking and monitoring of several safety performance indicators to enable the identification of safety issues, continuous improvement of work processes, and better accident prevention measures.

Various indicators are used to measure safety performance: the Occupational Safety and Health Administration (OSHA) recordable incident rate (RIR), the DART injury rate which stands for "days away, restricted, or transferred" work, and other measures that contractors use as benchmarks to assess their overall safety performance. In fact, the records of OSHA rates show that the construction industry has significantly improved in terms of safety performance between 1989 and 2009. However, an interesting observation is that the rate of improvement has declined since 1998 (Hinze et al., 2013).

As safety management dictates policies and practices that help reduce hazards on a project, the production control system establishes process planning and decisions to ensure a safe work environment (Mitropoulos, 2012; Hinze, 2002a; Aslesen et al., 2013). A model integrating safety job analyses in the Last Planner System (LPS) helps reduce hazardous situations by allowing the detection of these early on. Wehbe and Hamzeh (2013) also suggest the integration of Failure Mode and Effect Analysis (FMEA) at the look ahead planning level of LPS as a risk management practice that avoids the emergence of safety hazards. Alarcon et al. (2011) identify seven safety practices that are statistically significant to reducing accident rates, such as accident and incident reporting, management commitment, and safety incentives.

The safety culture is perceived as a social and collective effort (Aslesen et al., 2013) and hence, the network of people (including communication patterns) in a company is a determining factor that reflects how the system performs. This is where SNA helps map the project network for further research and analysis.

2.2. Social Network Analysis (SNA)

Social Network Analysis is an effective method for analyzing social interactions among individuals and organizations which can be used to reveal the underlying mechanisms and dynamics driving such relationships within complex systems (Easley and Kleinberg, 2010). Nodes represent individuals within the network and ties represent associations between those individuals. Visualization of the network is crucial to the understanding of network data and quantitative metrics allow further analysis of hidden behaviors (Wasserman and Faust, 1994).

Social network theory has been applied in several fields such as sociology, anthropology, economics, biology, tele-communications (Zhu et al., 2012; Aral et al., 2009), and has extended beyond social sciences. In design and construction, SNA was primarily implemented to discuss information flow among project participants and optimize communication and transparency (Alarcon et al., 2013; Hickethier et al., 2013; Chinowsky et al., 2010). It has also been used to analyze the benefits of Building Information Modeling (BIM) and lean practice on design error management (Al Hattab and Hamzeh, 2015). The success of projects is hence not only associated with optimized project management practices but also with the performance of project teams and their level of communication.

This research approaches safety through social network theory and studies the network of people involved in safety issues on construction projects. A recent study by Alsamadani et al. (2013) explores safety communication in small work crews using SNA. Safety performance of different crews is measured using communication patterns in socio-grams, and is then compared against maximum performance. However, data analysis suggests that the resulting SNA metrics other than density are not significant measures to categorize crews. This paper therefore expands on previous research to show that SNA metrics can actually be used as leading indicators for safety performance.

Hence, the objective of this research is to evaluate safety performance through mapping interactions regarding safety matters, and to reflect on the system's resilience to prevalent risks. After mapping the social network model, different network metrics are retrieved and associated with safety indicators; these include:

(1) *Node-specific metrics: Average Degree Centrality* which measures the number of links an individual has with others where a higher number indicates more connections and more influence an individual has on a network, *Betweenness* which measures the number of node pairs that an individual connects or bridges (serving as a broker or intermediary) where a higher value indicates a higher influence of this individual and his power to control flow and interactions (Hickethier et al., 2013), and *Closeness* which measures the total number of links from an individual to others where a lower value indicates that an individual is more reachable by others (Haythornthwaite, 1996; Kim, 2007).

(2) *Network-specific metrics: Density* which reflects how well-connected and cohesive a network is by measuring the number of existing links between individuals and dividing it by the number all possible links where a higher ratio value indicates a well-connected and interactive network (Alarcon et al., 2013), *Average Path Length* which measures the average number of links individuals require to reach each other where a smaller value is a better reflection of connectivity and faster interactions (Haythornthwaite, 1996), *Clustering*