Safety Science 128 (2020) 104737

Contents lists available at ScienceDirect

Safety Science

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

How can communication networks among excavator crew members in construction projects affect the relationship between safety climate and safety outcomes?

Vahid Zamani[a], Seyed Yaser Banihashemi[a,*], Alireza Abbasi[b]

[a] Ferdowsi University of Mashhad, School of Civil Engineering, Mashhad, Iran
[b] University of New South Wales (UNSW), School of Engineering and IT, Australia

ARTICLE INFO

Keywords:
Safety communication
Safety climate
Safety outcomes
Construction projects
Social network analysis

ABSTRACT

Recent research has confirmed the crucial role of safety communication in improving safety outcomes in construction sites. Safety climate is another critical factor affecting safety results; however, the interaction between safety climate and safety communication in explaining safety outcomes has remained unexplored. Assuming safety communication as an independent construct may provide opportunities to gain a better understanding of the impact of different communication modes and patterns on transforming a positive safety climate into improved safety outcomes. To address this issue, the present study investigates the intermediary role of safety communication in the relationship between safety climate and safety outcomes. The results of our analysis of communication networks among 36 excavator crews based on 259 valid questionnaires confirm that the relationship between safety climate and safety outcomes is fully mediated by safety communication. The findings of this study have theoretical and practical implications for construction safety researchers and practitioners.

1. Introduction

Given the multifaceted nature of the construction industry, numerous types of incidents occur in this field every year, which cause loss of life, injuries, and financial losses, and impede project goals. The construction industry was responsible for 19% of fatal occupational injuries across the entire industry in the US in 2016 (Bureau of Labor Statistics, 2018). Although global statistics and research findings confirm improvements in construction safety (Hallowell, 2011; Huang and Hinze, 2006), safety status is not yet satisfactory and researchers are looking for new effective ways to improve construction safety outcomes (SafOut). As Nahrgang et al. (2011) defined, SafOut refers to a holistic picture of safety status in a workplace, interpreted in terms of accidents and injuries, adverse events, and unsafe behavior.

Safety climate (SafClim), as a subset of organizational climate, is defined as employees' common perception and understanding of the importance of safety in an organization (Zohar, 1980). In other words, SafClim is concerned with creating an environment in the workplace which promotes safety perception and improves project SafOut. A positive SafClim is created when managers, supervisors, and workers create an atmosphere in which safety rules are encouraged (Cigularov et al., 2010; Griffin and Neal, 2000; Kath et al., 2010).

Safety Communication (SafCom) is defined as any formal or informal form of communication among project members regarding safety issues. Although several studies in construction safety management literature consider SafCom as a dimension of SafClim (Gao et al., 2016; Zahoor et al., 2017; Li et al., 2017; Marín and Roelofs, 2017; Mohamed, 2002), other works do not incorporate SafCom into SafClim (Chen et al., 2017; Guo et al., 2016; Hadjimanolis et al., 2015; Molenaar et al., 2009). Furthermore, other studies considered SafCom as an independent construct with an impact on project SafOut (Albert and Hallowell, 2017; Alsamadani et al., 2013; Greeff, 2017; Wehbe et al., 2016). Considering SafCom as an independent construct would help with the study of interpersonal information exchange in more detail and facilitate the examination of effect of different forms of communication on SafOut. For example, Alsamadani et al. (2013) modeled communication among project members as networks of relationships, using Social Network Analysis (SNA), to investigate the impact of different communication patterns on project SafOut.

Analyzing the impact of SafCom on the association between SafClim and SafOut is very important as it provides an opportunity to examine the role of SafCom in different modes of communication and delineates the impact of each mode on the relationship between SafClim and SafOut. However, to the best of our knowledge, no study has examined

* Corresponding author.
E-mail address: y.banihashemi@um.ac.ir (S.Y. Banihashemi).

https://doi.org/10.1016/j.ssci.2020.104737
Received 7 August 2019; Received in revised form 7 March 2020; Accepted 15 March 2020

the intermediary role of SafCom, and therefore, this research aims to address this knowledge gap. The presented mediation model considers SafCom among crews as either a weighted network or a non-weighted network replicating different communication modes.

In the following sections, we first review the literature on SafClim and SafCom and their association with SafOut. Then, we outline the role of SafCom in the relationship between SafClim and SafOut in the form of a conceptual model and develop relevant hypotheses. Next, our research method is described, results are presented, and theoretical and managerial implications are discussed. Finally, concluding remarks are highlighted and limitations of our study and suggestions for future research are presented.

2. Literature review

2.1. Safety Climate (SafClim)

SafClim is a guide for employees to adapt their behavior to workplace atmosphere (Shen et al., 2015). A positive SafClim is created when the interaction between organizations and project teams is guided in such a way that organizations ensure safe execution of projects, provide suitable and up-to-date personal protective equipment (PPE), and consider safety as their top priority (Mearns and Reader, 2008; Tam et al., 2004). Additionally, the commitment and involvement of management in workplace safety are critical factors in maintaining safety at a desirable level (Jaselskis et al., 1996). For example, Langford et al. (2000) found that workers' belief in senior executives' support for safety can lead to greater motivation and cooperation for improving safety outcomes (SafOut). Zhang et al. (2019) discussed the association between safety incidents and a lack of applicable safety regulations. Workers can create a positive SafClim by following safety regulations, including paying attention to safety signs, participating in safety training workshops, enhancing their safety knowledge, and contributing to safety activities. However, management should seek to empower workers by allowing them to actively engage in safety activities and decision making since poor training and inadequate knowledge about safety regulations lead to decreased motivation for adherence to these regulations (Williamson et al., 1997).

SafClim has been measured by evaluating different dimensions. For instance, Zohar (1980) measured SafClim through appraising eight dimensions, namely "management commitment to safety, safety training, the level of work risk, the status of safety officer, work pace, safety committee status, effects of safe conduct on promotion and effects of safe conduct on social status". Dedobbeleer and Béland (1991) measured SafClim based on nine factors, namely "management's attitude toward safety, management's attitude toward workers' safety, foreman's behavior, safety instructions, safety meetings, perceived control, perception of risk-taking, and perceived likelihood of injuries", categorized under two dimensions: management commitment, and workers' involvement.

However, in some studies, SafCom was viewed as one of SafClim dimensions. There is also a noticeable number of studies that never considered SafCom as a SafClim dimension. Alruqi et al. (2018) reviewed studies on SafClim dimensions and found a third of SafClim surveys for measuring SafClim considered SafCom as a SafClim dimension. Thus, there is no consensus on whether SafCom is one of the SafClim dimensions. Lastly, viewing SafCom as an independent construct distinct from SafClim enables us to have an in-depth investigation of SafCom properties within a safety management system.

2.2. Safety Communication (SafCom)

Communication is a vital component of any system in which humans are involved. Without effective communication, no meaningful and coherent activity can be performed successfully (Dainty et al., 2007). As long as we promote communication between team members, we can ensure fewer conflicts, which in turn leads to enhanced project delivery (Wu et al., 2016). SafCom is defined as the exchange and sharing of safety knowledge among members of a community in order to perform their tasks safely or to gain knowledge of risks. SafCom can be either formal or informal. Formal communication refers to the exchange of information carried out through predefined channels (Alsamadani et al., 2013a, 2013b; Hallowell, 2011; Jaselskis et al., 1996; Rajendran et al., 2009); it includes formal interactions with managers in the forms of safety training, work orders, written notifications, safety signs, and toolbox talks. Practical safety training is one of the essential elements for the successful implementation of safety management systems (Demirkesen and Arditi, 2015). Safety work orders including written notifications, specific policies, procedures, and instructions are to be followed by workers to keep the work environment safe. Toolbox talks are safety-focused meetings that are held regularly at pre-runtime, before the implementation of specific activities in the project to clarify safety risks (Boud et al., 2009; Huang and Hinze, 2006).

Informal communications, on the other hand, are formed among the members of a working group and may have no systematic basis (Alsamadani et al., 2013; Schein, 1990). Informal exchanges can take the form of mentorship, informal discussions, or using social media. This kind of communication has a high potential for the transfer of tacit knowledge. Mentoring is one of the oldest communication methods which has continuously been used to transfer professional knowledge from one generation to the next. In mentoring, workers acquire knowledge empirically and learn corrective/preventive techniques while assisting the mentor/master. Experienced mentors place a high priority on safety, and therefore, their assistants learn safe working conditions subconsciously and experimentally. According to previous studies, informal SafCom is one of the most effective tools of crisis management for public administrations to prevent safety incidents (Tokakis et al., 2019). Social media such as Facebook, WhatsApp and Telegram play a crucial role in working relationships as they enable team members to share audio-visual and multimedia resources. In many projects, social network applications are used to exchange information and safety experiences (e.g., graphical safety guidelines, safety-based training videos) outside of working hours (Wu et al., 2015).

Vecchio-Sadus (2007) conceived three features for effective SafCom: (1) providing transparent communications and open discussions in which people at any level can participate; (2) encouraging and supporting safe behaviors by providing feedback to the individuals; and (3) implementing educational safety programs in the field. Since most workers in the construction industry are not highly educated and might even be literate (Loosemore and Andonakis, 2007), visual educational programs can provide a deeper understanding of occupational risks (Lingard et al., 2015). In addition, safety regulations and policies can be hard to grasp for construction workers and, therefore, the existence of informal communications among workers, supervisors and project managers is essential to explain policies and procedures. Given the likelihood of language and cultural diversity among workers, traditional communication practices are insufficient (Wilkins, 2011). Therefore, it is important to communicate safety issues in visual formats to overcome communication barriers.

2.3. Safety climate and safety outcome

A project's Safety Outcome (SafOut) is measured by the number of incidents in the project. An acceptable SafOut is one with no or very few safety incidents. Donald and Canter (1994) measured employees' perception of SafClim in more than 40 construction companies in the UK and found that SafClim perception can be a valid and reliable parameter to predict SafOut. In other words, they viewed SafClim as an effective organizational factor for reducing risks and accidents. Similarly, Hofmann and Stetzer (1996) examined 21 working groups in a petrochemical plant and found that unfavorable SafClim and unsafe working behaviors are significantly associated with the occurrence of accidents, i.e., poor SafOut. Research shows that the cultural differences in different countries do not affect the relationship between SafClim and SafOut (Bahari and Clarke, 2013; Barbaranelli et al., 2015).

Zohar (2010) expressed the need to identify the antecedents, moderators, and mediators which affect the efficacy of SafClim. Although the relationship between SafClim and SafOut is evident, it is unclear whether SafClim impacts SafOut as a distal or proximal construct (Stackhouse and McDouall, 2015). For example, Nahrgang et al. (2011) claimed that SafClim is a proximal variable that has a direct effect on SafOut. In contrast, Neal and Griffin (2006) asserted that SafClim is a distal variable that affects SafOut through other constructs. Similarly, Griffin and Neal (2000) showed that SafClim impacts SafOut through safety knowledge and safety motivation. Christian et al. (2009) also acknowledged that SafClim is a contextual factor that becomes effective through tools such as communication, affecting SafOut as a distal variable. One of the main goals of this study is to address this inconsistency in the literature by investigating the relationship between SafClim and SafOut.

2.4. Safety communication and safety outcome

Many researchers argue that the exchange of safety information (i.e., SafCom) is essential for effective safety management systems (Cheng et al., 2012; Fernández-Muñiz et al., 2009; Zhou et al., 2015), and improving SafOut (El-Saboni et al., 2009; Nuntasunti and Bernold, 2006). The impact of SafCom on SafOut in construction projects has been studied extensively (Allison and Kaminsky, 2017; Alsamadani et al., 2013a, 2013b; Sawacha et al., 1999; Zou et al., 2017). Alsamadani et al. (2013a) found that SafCom among all project partners is essential to achieve optimal SafOut. They used social network analysis (SNA) to examine communications among workers and found that the type and frequency of communications affect safety outcomes. Further, signifying the importance of the quantity and quality of SafCom among the team members, they listed four main attributes for safe working environments: (1) formal communications with managers at least once a week; (2) weekly informal SafCom among workers; (3) formal safety training; and (4) use of different communication practices during a month, such as training workshops, on-site meetings, and social media. Zou et al. (2017) found that using systems that could continuously facilitate communication, decision-making, and action could improve SafOut. Allison and Kaminsky (2017) also used SNA to examine SafCom among mixed-gender construction workers and found that women, compared to men, had fewer communications and tacit knowledge of work, and therefore, the SafOut of mixed groups might be different. Also, they found that mixed groups had lower-density formal communication networks and higher-density informal communication networks compared to single-sex groups.

Open and frequent SafCom among workers and supervisors has been highli as a distinguishing feature of organizations with high SafOut, i.e., low incident rates (Alsamadani et al., 2013a, 2013b). Some researchers posit that the most successful supervisors are those who are willing to launch open discussions about safety issues among workers with different professions and to advise on safety issues when needed (Mattila et al., 1994; Niskanen, 1994; Simard and Marchand, 1994; Smith et al., 1978). Therefore, the impact of high-quality and frequent SafCom on improving the safety of a project is undeniable. In projects with effective SafCom, people carefully manage their behaviors to achieve greater SafOut, which is a preventative factor against accidents (Loosemore and Andonakis, 2007). Similarly, researchers found that strong SafCom is a crucial factor in successful management and error reduction (Cigularov et al., 2010; Parker et al., 2001; Van Dyck et al., 2005).

2.5. The relationship between safety communication, safety climate, and safety outcome

In the construction industry, SafClim has mostly been measured irrespective of SafCom. A positive SafClim is an environment in which employees feel free to discuss safety issues (Edmondson, 1996), and therefore, create and promote open exchange about safety issues. On the other hand, in a negative SafClim, workers cautiously comment on safety-related issues because they are afraid of blame, punishment, or reprimand by managers and supervisors. This type of communication is well known as defensive communication in the literature (Hofmann and Stetzer, 1998). Hofmann and Stetzer (1998) considered SafCom and SafClim as separate major organizational factors to investigate the causes of construction accidents (i.e., SafOut) and as a basis for creating a learning system to learn from past negative experiences. Hofmann and Stetzer's study was conducted assuming that through SafCom, SafClim can help apply lesson from past events to future events. Neal et al. (2000) pointed out that many of the studies conducted until then showed a positive relationship between SafClim and SafOut. Neal and Griffin (2004) demonstrated that SafClim and SafOut are interconnected through safety behaviors. Other studies (Beus et al., 2010; Christian et al., 2009; Clarke, 2006) showed that factors such as safety knowledge and safety motivation have a mediator role in that relationship. Kath et al. (2010) demonstrated that SafClim dimensions, as well as employee-supervisor interactions, could predict improved SafCom patterns among project members. Besides, Liao et al. (2014) indicated that a positive SafClim leads to denser crew communication patterns with fewer isolated members. These studies justify the presence of an association between SafClim and SafCom as well as independence of SafCom from SafClim. In another study, Albert and Hallowell (2014) showed that accurately identifying hazards, and establishing SafCom to share known hazards are necessary to prevent future accidents and injuries. They stated that ineffective communication channels, language barriers, and poor SafClim were among the issues which impeded effective SafCom at construction sites. Using SNA, they examined the relationship between SafCom and hazard identification and found that when SafCom network is denser, more risks can be identified by the groups, which in turn leads to better SafOut. Hence, they indicate the existence of a relationship between SafCom and SafOut.

In accordance with previous research, we propose that SafCom plays a mediator role in the relationship between overall SafClim and SafOut. Accordingly, this research aims to test this hypothesis (See Fig. 1).

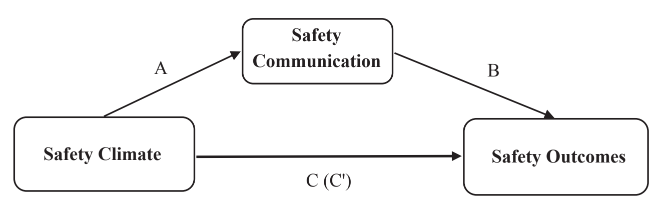


Fig. 1. Conceptual model of the study.[1]

3. Methodology

A questionnaire was used to measure perception and understanding of workers regarding the importance of safety in workplace (SafClim). The questionnaire also included questions about the people with whom each worker communicates during the course of the project. These questions enabled us to form a network of interactions among all workers in each project. Then, the communication structure among workers (SafCom) was analyzed using SNA. After collecting the SafClim

[1] A represents the significance of the relationship between the independent variable (IV) and the mediator variable (MV), B represents the significance of the relationship between MV and the dependent variable (DV), and C and C' represent the significance of the relationship between IV and DV, with and without considering the presence of MV, respectively.

and SafCom questionnaires, we interviewed project managers to collect information about the number of workers at each project site during the excavation stage, the number of accidents (SafOut), and the time span of excavation.

Finally, the mediator role of Safety Communication (SafCom) in the relationship between Safety Climate (SafClim) and Safety Outcome (SafOut) were examined using correlation and regression tests within each group of variables.

3.1. Data

Statistics released by the Administration of Labor Inspection (2016)) reported that occupational accidents in Iran, a developing country, is about three times higher than in developed countries. Further, more than 20% of work accidents in the construction industry take place in the excavation phase, of which more than two thirds lead to severe casualties. The number and severity of accidents during excavation call for serious attention. Therefore, we studied the safety conditions of the excavation phase in construction projects.

In the report by Administration of Labor Inspection (2016), Khorasan Razavi province ranked second in terms of the number of accidents, after Tehran. Additionally, given the authors' proximity and easier access to construction workers in Mashhad (the capital of Khorasan Razavi province), the city of Mashhad was selected for analysis.

The statistical sample of this research includes 36 deep excavation projects. All selected projects fulfilled the following conditions: (1) excavation in deep pits (deeper than 6 m), and (2) a minimum of 70% progress by the time of data collection. The first criterion was applied to ensure that crew size was large enough to allow communication with co-workers. Besides, this condition excludes shallower pits which require fewer safety considerations. The second condition ensures that the crew members could have been exposed to different types of incidents during the project.

No institution keeps records on active construction projects in Iran, regardless of their progress status. As Babbie (2015) stated, when the members of a target population are difficult to locate, a snowball sampling procedure is appropriate. In this study, an exponential discriminative snowball sampling method was employed. This method includes two main steps: First, identifying potential subject(s) (which may result in only one or two subjects initially); and second, asking selected subjects to introduce other subjects. Each subject gives the researchers a number of referrals, but only one new subject is recruited based on the aim of the study. These two steps are iterated until the required sample size is reached. Although this method may seem to be violating sample representativeness, it is the only choice when there are no resources to find subjects of interest (Babbie, 2015).

A sample size of 36 was selected based on the method of analysis (i.e., mediation analysis which includes linear regressions). According to Field (2013), required sample size is governed by two factors; first, the desirable effect size (i.e., how well prognosticator variables forecast the outcome, represented by coefficient of determination (R^2) in statistics), and second, how much statistical power is required to detect the effect (i.e., the significance level of the b-values, or the significance level of the regression model). Based on the benchmark provided by Cohen (1988), the minimum required sample size for two predictor variables (i.e., SafClim and SafCom) is 31. However, we selected 36 projects conservatively. Table 1 shows some features of the selected projects.

In total, our sample population includes 259 workers and foremen working in 36 projects. The size of the selected excavator crews varied from 5 to 11 people. Details about the demographic of the respondents are shown in Table 2. It is noteworthy that based on our interviews with other excavation contractors, the demographics of excavation crews in our study resemble those of excavation crews in other Iranian metropolises, except for unusual circumstances in which the number of crews as well as crew size are increased to meet deadlines.

Table 1
Project types and their statistics.

Demographic variables	Total number (N = 36)	
	Number	Percent (%)
Project type		
Residential	10	27.8
Commercial	7	19.4
Hotel	7	19.4
Hospital	3	8.3
Others	9	25
Project duration		
< 7 months	27	75
7 to 12 months	7	19.4
More than 12 months	2	5.6
Pit depth		
6 to 10 m	5	13.9
11 to 20 m	19	52.8
More than 20 m	12	33.3

Table 2
Respondents' demographic information.

Demographic variables	Total number (N = 259)	
	Number	Percent
Education		
Illiterate	27	10.5
Primary or incomplete secondary education	70	27
High school diploma	134	51.7
Bachelor's degree	28	10.8
Marital status		
Single	39	15.1
Married	220	84.9
Position		
Supervisor	36	14.3
Worker	223	85.7
Age		
< 20 years	1	0.4
20 to 25 years	64	24.7
26 to 30 years	158	61
31 to 35 years	31	12
More than 35 years	5	1.9
Work experience		
1 to 5 years	210	81.1
6 to 10 years	47	18.1
More than 10 years	2	0.8

To collect data on SafClim and SafCom, project managers were briefed about the aim of the research project and then, the research team was introduced to the foremen of the excavator crews. Then, foremen introduced the researchers to crew members and explained the aim of the research and the contents of the questionnaires. Only then did respondents complete the questionnaires. The mean time needed to fill the questionnaires was about 25 min. We should note, the research team read the questions for the 27 illiterate workers, provided additional explanations if necessary, and wrote their answers in the questionnaire. Overall, 259 questionnaires were distributed and all were returned.

3.2. Variables

This section discusses the variables and metrics used to measure the primary parameters of this study.

3.2.1. Safety communication

In order to quantify SafCom as a mediator variable in this study, we considered the type of interactions among workers in a project. We first used the classification of PMBOK (PMI, 2018) for types of communication in projects, i.e., formal and informal, and then extracted modes of communication from the literature (Alsamadani et al., 2013a, 2013b; Hallowell, 2011; Jaselskis et al., 1996; Tokakis, Polychroniou, and Boustras, 2019). Modes of formal communication comprised 'safety work orders', 'written communication' and 'safety training'. 'Informal discussion', 'toolbox talks', 'social network applications', and 'mentoring' constituted the informal modes of communication.

Then, we surveyed four safety experts, each with more than 27 years of experience, to measure and rank the identified modes of communications based on their relative effectiveness using pairwise comparisons. We adopted the questionnaire developed by Alsamadani et al. (2013a), in which the workers were asked to identify their modes of communication for transferring safety messages (Appendix A).

Analytic Hierarchy Process (AHP) was deployed to judge the effectiveness of each mode of communication based on expert judgment. AHP is one of the most appropriate methods for ranking a set of alternatives (Forman and Gass, 2001; Ouédraogo et al., 2011; Petruni et al., 2017). Having structured the hierarchy of a problem, AHP can be implemented in three main steps:

3.2.1.1. Pairwise comparison matrices. This step is fulfilled by human judgment. In this step, pairs of SafCom methods were compared by safety experts. The pairwise comparison matrix A is an $m \times m$ real matrix, where m stands for the number of selected criteria. Each entry a_{ij} of the matrix A indicates the preference of the i^{th} criterion to the j^{th}criterion, where a_{ij}signifies the entry in the i^{th}row and the j^{th}column of A (Saaty, 1990). This step was conducted based on Saaty's (1990) fundamental preferences scale in Table 3.

Table 3
Fundamental preferences scale according to Saaty (1990).

Intensity of importance on an absolute scale	Definition	Description
1	Equal importance	Two instances of SafCom have equal effectiveness
3	Moderate importance of one over another	Experience and judgment slightly favor one instance over another
5	Essential or Strong importance	Experience and judgment strongly favor one instance over another
7	Very strong importance	An instance is strongly favored and its effectiveness demonstrated in practice
9	Extreme importance	The evidence favoring one instance over another is of the highest possible order of affirmation
2,4,6	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If instance i has one of the above numbers assigned to it when compared with instance j, then j has the reciprocal value when compared to i.	
Rationals	Ratio arising from scale	If consistency were to be forced by obtaining n numerical values to span the matrix

3.2.1.2. Priority computation and consistency assessment. Having built matrix A, the priority vector, which is the normalized eigenvector of matrix A, can be calculated. This vector indicates relative weights among criteria or sub-criteria. Besides, AHP evaluates the consistency of comparison using consistency index (CI), random consistency index (RI), and consistency ratio (CR) based on equations (1) and (2). For a consistent matrix, CI is zero, and CR is less than 10% ($CR < 0.1$), meaning the subjective judgment can be accepted.

$$CI = \frac{(\lambda_{max} - \mathrm{n})}{(\mathrm{n} - 1)} \tag{1}$$

In equation (1), CI is the consistency index, λ_{max} is the maximum eigenvalue, and n is the size of the measured matrix.

$$CR = \frac{CI}{\mathrm{RI}} \tag{2}$$

where CR is the consistency ratio, CI represents the consistency index, and RI is the random consistency index.

3.2.1.3. Ranking of instances. Once the priority vectors of criteria are computed, priority vectors of SafCom instances are calculated based on each criterion. Finally, by multiplying the SafCom instances matrix by the weighted vector of criteria, the ranking order is established.

To perform AHP analysis, Expert Choice[2] 11.0 was used to calculate the weights for each mode of SafCom, presented in Fig. 2. The consistency ratio was 0.09, which is acceptable because it is less than 0.1 (Saaty and Vargas, 2012). As the results show, formal communication modes were assigned greater weight based on expert judgment. The obtained values were used for drawing the weighted SafCom network.

The numbers presented in Fig. 2 indicate the calculated weights that AHP process uses to rank different modes of SafCom. Based on expert judgment, safety work order was given the highest weight (0.264), whereas social network applications (such as Instagram, Facebook, WhatsApp, Telegram, etc.) obtained the smallest weight (0.036). In this regard, weights indicate the degree of effectiveness.

3.2.2. Safety climate

SafClim was measured using a questionnaire adapted from Dedobbeleer and Béland (1991). The responses were given on a seven-point Likert scale arranged from 1 (very low) to 7 (very high). As shown in Appendix B, the questionnaire consisted of 11 questions. To examine the validity of the questionnaire, it was reviewed by two experienced experts on safety management in the construction industry (each of whom had more than 25 years of work experience). Based on their feedback, some minor modifications were made to the questionnaire and then the final draft was prepared and distributed among the respondents. Cronbach's α was used to check the reliability of the questionnaire. Cronbach's α is a measure of internal consistency; that is, how closely related a set of items are as a group (Field, 2013). Cronbach's α can be obtained by equation (3) (Cronbach, 1951).

$$Cronbach's\alpha = \frac{N\bar{c}}{\bar{v} + (N-1)\bar{c}} \tag{3}$$

where N is the number of items, $\bar{c}$ is the average inter-item covariance among the items, and $\bar{v}$ is the average variance.

Based on the results, Cronbach's α was 0.79, which is within the

[2] Expert Choice is decision making software which performs AHP calculations.

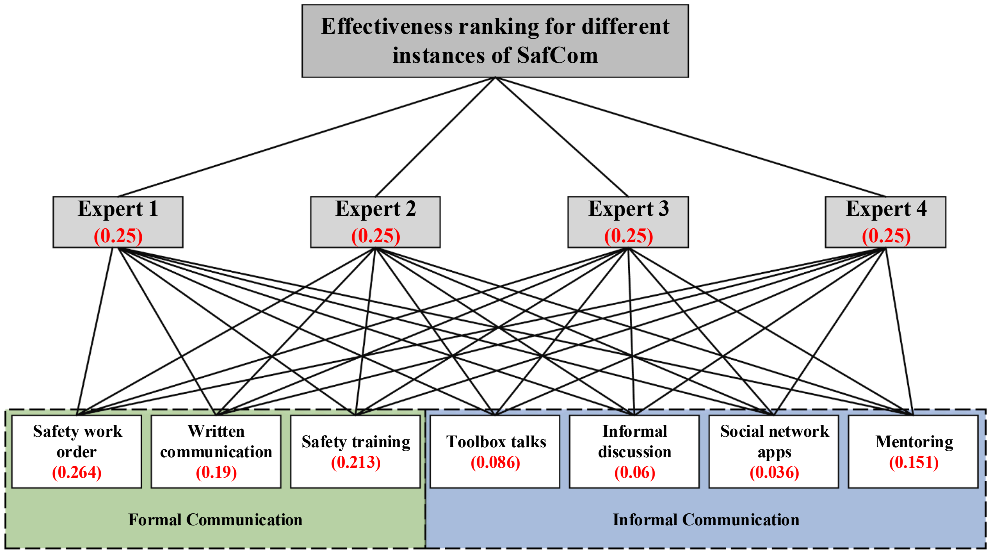


Fig. 2. AHP structure for ranking different modes of SafCom using expert judgment.

acceptable limit. To test sample adequacy, Kaiser-Meyer-Olkin index was calculated according to Hutcheson and Sofroniou (1999) (KMO = 0.82, statistically acceptable). Further, the results of Bartlett's test ($P < 0.01$) confirmed the internal consistency of the questionnaire (Field, 2013).

3.2.3. Safety outcome

SafOut can be evaluated using leading and lagging indicators. Leading indicators are those measures which do not necessarily need retrospective data and can be used as predictors of future SafOut (such as degree of safety compliance on jobsite safety inspections, earnest promotion of jobsite safety, role of safety compliance in awarding subcontracts, etc.). Lagging indicators compute SafOut after the occurrence of an incident which leads to loss (Hinze et al., 2013). Lagging indicators comprise metrics such as the Occupational Safety and Health Administration (OSHA) recordable injury rate (RIR); lost time case rate (LTC); days away, restricted work, or transfer (DART) injury rate; or the experience modification rating (EMR) for workers' compensation. To evaluate SafOut of the crews, we used RIR index since RIR is the only indicator which can be calculated using data recorded for construction projects in Iran. Eq. (4) was used to calculate RIR index for all 36 projects.

$$RIR = \frac{200,000 \times \text{Number of Recordable Cases}}{\text{Number of worked hours by employee}} \quad (4)$$

According to Bureau of Labor Statistics (2019), the 200,000 coefficient in the equation (4) is used because it represents the standard base rate of 200,000 labor hours. This number (200,000) represents the number of hours worked by 100 workers who work 40 h per week, 50 weeks per year. The number of incidents in the excavation phase was calculated by dividing the number of OSHA recordable cases by the total number of workers at the construction site during the excavation phase; the number of incidents and workers were obtained by conducting interviews with project managers.

3.3. Analyzing safety communication networks

SNA was employed in order to investigate and measure the effectiveness of communications among personnel. This technique has been used frequently in SafCom literature to visualize and analyze communication patterns (Allison and Kaminsky, 2017; Alsamadani, Hallowell, and Javernick-Will, 2013; Wehbe et al., 2016).

SNA was first developed by Moreno (1960) as a quantitative analytical method to study social interactions among different groups. Haythornthwaite (1996) used SNA as an analytical approach for studying the exchange of resources among different stakeholders in projects. SNA effectively analyzes social interactions among individuals and organizations, and is able to uncover the underlying mechanisms and dynamics that make such connections possible in complex systems (Easley and Kleinberg, 2010). Compared to other methods, SNA has the advantages of analyzing the structure of communications and generating metrics that can be studied as the indicators of a network's performance (Alsamadani et al., 2013a).

This technique has been used in the construction industry since 1997 (Loosemore, 1997). For instance, Wehbe et al. (2016) evaluated the safety performance of construction projects using networked interactions around safety issues and the system's resilience to common risks. They used metrics such as betweenness and closeness centrality, average path length, modularity, and network density as indicators of a project's SafOut and resilience to incidents. In another study, Albert and Hallowell (2017) used the network density index to measure SafCom, betweenness, and degree centrality to examine the relationship between SafCom and identification of work-related hazards by crews in the construction industry. Allison and Kaminsky (2017) also used metrics such as network density and node centrality to investigate the safety of women in construction projects in the United States.

As noted above, SNA has a variety of metrics, each offering a unique description of the communication network. In the present study, the network density metric was selected to measure SafCom among working groups.

Density is defined as ratio of the number of existing links in a network to the total number of possible links, representing the extent to which the members of a network interact with each other (Borgatti and Everett, 2006). Network density for a non-weighted network can be obtained using Eq. (5), and its value varies between zero and one.

$$Density = \frac{l}{n(n-1)} \quad (5)$$

where l and n represent the number of links and nodes in the network, respectively.

Since the standard formula for network density ignores links' weights, this study introduces a new index called 'weighted density' (see Eq. (6)) to retain the information associated with the effectiveness of communication among crews.

$$Weighted\ \ Density = \frac{\sum_{i=1}^{n(n-1)} Wi}{n(n-1)} \quad (6)$$

where Wi represents total weights available on edge i with n nodes, and the denominator represents the total number of links in the network.

To form SafCom networks of the projects and analyze them, Gephi[3] 0.9.1 was used, and the communication patterns for all the 36 excavator crews were drawn. Density and weighted density of all the networks were calculated using equations (5) and (6).

4. Results

Fig. 3 depicts the sociograms of weighted communication networks for three sample excavator teams, with statistic on the number of incidents for each team. In each network, 'w' stands for the workers, 'sup' represents the supervisor, the size of each node reflects the node's degree centrality, and a link's thickness reflects the weight

In these samples, denser networks with more communications among the members experienced fewer accidents.

4.1. Analyzing the relationship between safety Climate, safety Communication, and safety outcome

IBM SPSS[4] 24 was used to examine correlations among constructs (Table 4), conduct regression analysis, and validate research hypotheses (Tables 5 and 6).

Table 4 shows a significant negative correlation between SafClim and SafOut ($r = -0.712$, $P < 0.01$), meaning projects with better safety environments have a lower number of incidents (SafClim is significantly associated with SafOut[5]), which supports the findings of previous studies (Brondino et al., 2012; Kines et al., 2010; Li et al., 2017; Zohar, 2010). The results also reveal that there is a significant negative correlation between SafCom and SafOut (in both non-weighted or weighted networks), meaning teams with denser communications (high SafCom) have a lower number of incidents (low SafOut). That is, SafOut can be improved by increasing SafCom. This finding supports the findings from previous studies on the relationship between SafCom and SafOut (Albert and Hallowell, 2017; Allison and Kaminsky, 2017; Alsamadani et al., 2013a; Wehbe et al., 2016).

4.2. Mediation effect

According to (Hayes, 2017), when investigating how variable X exerts its effect on variable Y, one (or more) intervening variable (M) should be placed causally between X and Y to describe the mechanism of action. Such variables are referred to as mediators. Mediation analysis tells us how antecedent variable X transmits its effect on a consequent variable Y. Fig. 4 depicts a simple mediation effect model.

In order to perform a mediation analysis, the following three steps were undertaken based on (Baron and Kenny, 1986; Field, 2013; Hayes, 2017):

(1) The independent variable (X) significantly predicts the dependent variable (Y) and mediator variable (V) (C and A are significant or their associated P values in linear regression analysis have to be less than 0.05);
(2) M significantly predicts Y (B is significant or its associated P value in linear regression analysis has to be less than 0.05);
(3) When controlling M, the effect of X on Y is no longer significant (C' is non-significant, i.e., its P value should be higher than 0.05) or decreases while remaining significant (C' remains significant, but at a lower level which means P value has to be higher than 0.5 but greater than its value in step 1) which account for total or partial mediation, respectively. In other words, X must predict Y less strongly in C' than in C. If one of the conditions in steps (1) or (2) is not fulfilled, there is no mediation.

4.3. Analyzing the intermediary role of safety communication in the relationship between safety climate and safety outcome

Here, we look at whether SafCom mediates the relationship between SafClim and SafOut. A series of simple linear regression analyses were conducted based on the method by Baron and Kenny (Baron and Kenny, 1986), with SafOut as the dependent variable, SafClim as the independent variable, and SafCom as the mediating variable.

4.3.1. Non-weighted networks

Firstly, the hypothesis was tested in non-weighted networks. The results presented in Table 5, show that SafCom completely mediates the effect of SafClim on SafOut. That is, SafClim significantly predicts SafOut ($P < 0.001$, $b = -40.64$, $t = -5.91$, $R^2 = 0.51$) and SafCom ($P < 0.001$, $b = 0.11$, $t = 6.81$, $R^2 = 0.58$). The relationship between SafCom and SafOut is also significant ($P < 0.001$, $b = -310.73$, and $t = -6.36$). Additionally, the relationship between SafClim and SafOut loses its significance in the presence of SafCom ($P = 0.42$, $b = -5.88$, and $t = -0.82$), which supports our hypothesis.

4.3.2. Weighted networks

In the next step, the hypothesis was tested in weighted networks. The results presented in Table 6 show that SafCom completely mediates the effect of SafClim on SafOut. In other words, SafClim significantly predicts SafOut ($P < 0.001$, $b = -40.64$, $t = -5.91$, $R^2 = 0.51$) and SafCom ($P < 0.001$, $b = 0.027$, $t = 8.95$, $R^2 = 0.71$). Further, the relationship between SafCom and SafOut is significant ($P < 0.001$, $b = -1703.02$, and $t = -6.47$). Additionally, the relationship between SafClim and SafOut loses its significance in the presence of SafCom ($P = 0.529$, $b = -5.41$, and $t = -0.64$), which validates our hypothesis.

5. Discussion

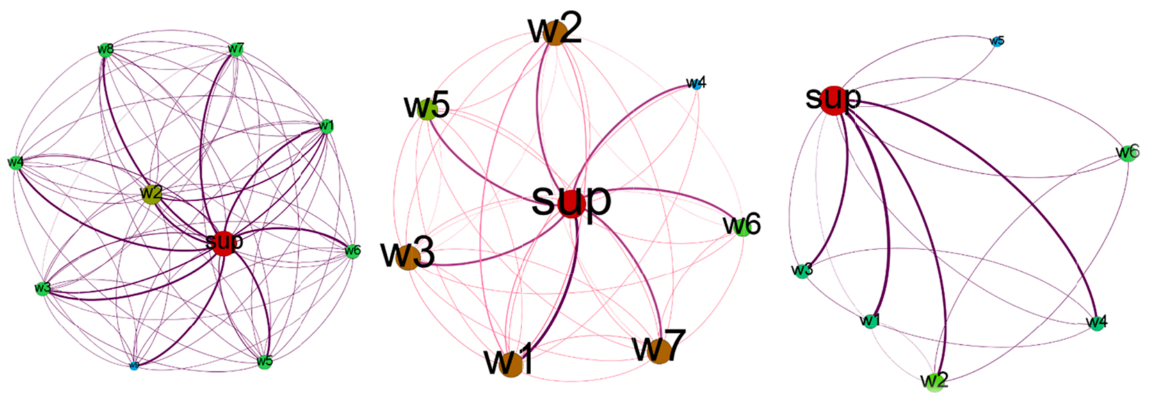
As shown by the results, SafClim can enhance SafOut when there is effective SafCom among crew members. In other words, SafClim dimensions will yield better SafOut when proper SafCom channels are established, regardless of communication modes. Managers who place a high value on safety are in touch with their employees and convince them that safety should take priority over other project objectives such as cost or schedule. Supporting this result, Bentley and Haslam (2001) suggested that communications among managers and employees may reduce the accident rate and promote safety performance in delivery companies.

Project managers are expected to use a variety of formal and informal communications to demonstrate their commitment to safety issues (Baxendale and Jones, 2000). In this regard, Simon and Piquard (1991) expressed that two-way communication channels established among managers and employees are necessary to improve the safety atmosphere. To create such an understanding among employees, training courses, regular safety meetings, encouraging safe behaviors, and punishing risk-taking behaviors can be useful. Similarly, Neal and Griffin (2004) claimed that management should communicate and interact with employees about safety issues and emphasize the high priority of safety. Making safety equipment available to the workers enables positive SafClim. Safety equipment may include personal protective equipment or safety systems at the project site. To use these

[3] Gephi is an open-source tool for social network analysis, network visualization, and pattern recognition in communication data.

[4] IBM SPSS is a statistical software which has been widely used for interactive, or batched, statistical analysis

[5] Please note, Eq. (1) has been used to measure SafOut (higher number of incidents, higher SafOut), and therefore, negative correlations mean a lower number of incidents.



a. SafCom network for a team without any incidents.
b. SafCom network for a team with 2 incidents.
c. SafCom network for a team with 6 incidents

Fig. 3. Weighted safety communication patterns of three sample crews.

Table 4
Means, standard deviations, and correlations of safety variables.

4	3	2	1	St.Dev.	M	Variable (n = 36)
			1	0.75	3.78	1. SafClim
		1	−0.712**	42.64	78.64	2. SafOut
	1	−0.88**	0.759**	0.11	0.59	3. Non-weighted SafCom
1	0.92**	−0.883**	0.838**	0.024	0.158	4. Weighted SafCom

** . P < 0.01.

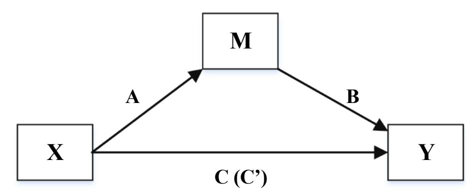


Fig. 4. Simple mediation effect.

sorts of equipment correctly and efficiently, workers need to receive training on their functionality, features, and limitations. Such training is mainly provided by the manufacturer.

Another fundamental component of SafClim is work pressure. When workload exceeds the capacity of workers, they cannot perform their duties safely (Neal and Griffin, 2004). Urban et al. (1996) showed that under work pressure, communications among crew members decrease, leading to poor performance of groups. Park (2011) simulated an emergency in the central control room of a nuclear power plant in South Korea to measure the impact of communications on the proper functioning of working groups. They found that people working in the central control room experienced considerable pressure, and that establishing reliable SafCom among the members of each working group is required to maintain safety. The probability of human error increases under pressure; thus, it is necessary to establish a prevention system through communication to identify individual mistakes using collective wisdom in order to enhance the performance of groups. Therefore, the best and inexpensive way to deal with the safety risks associated with work pressure is to develop communication channels between the members of a working group.

Safety training, as another component of SafClim, includes planned guidance and training in which knowledge about safety protocols, technical skills, and work experiences is transmitted to individuals to provide the necessary conditions for working safely. The recipients of

Table 5
Testing the hypothesis in non-weighted networks.

	Test of mediation effect	The relevant relationship	Regression coefficient (b)	T statistics (t)	Coefficient of determination (R^2)	P value	Inference
Hypothesis	Condition (1):	C	−40.64	−5.91[a]	0.51	0.000	Total mediation
		A	0.11	6.81[a]	0.58	0.000	
	Condition (2):	B	−310.73	−6.36[a]	0.78	0.000	
	Condition (3):	C'	−5.88	−0.82[b]	–	0.42	

[a] p < 0.001.
[b] p > 0.05.

Table 6
Testing the hypothesis in weighted networks.

	Conditions	The relevant relationship	Regression coefficient (b)	T statistics (t)	Coefficient of determination (R^2)	P	Inference
Hypothesis	Condition (1):	C	−40.64	−5.91[a]	0.51	0.000	Total mediation
		A	0.027	8.95[a]	0.71	0.000	
	Condition (2):	B	−1703.02	−6.47[a]	0.78	0.000	
	Condition (3):	C'	−5.41	−0.64[b]	–	0.529	

[a] p < 0.001.
[b] p > 0.05.

this information are the workers, and the instructors can be members of the company or foreign consultants (Hallowell, 2011). If there are no well-established communication channels between trainer and trainees, safety knowledge will not be passed effectively. Along the same lines, Wehbe et al. (2016) acknowledged that safety training is done through the establishment of SafCom. Alsamadani et al. (2013b) argued that the reason for Hispanic workers' high fatality rate in the US construction industry is the language and communication barriers that make safety training taught in English unhelpful.

Safety inspection is another indispensable component of SafClim, which is usually considered as an integral part of safety management systems. Safety inspection seeks to control risk through early detection of hazards and implementation of reforms (Woodcock, 2014). According to Mansdorf's study (1993), safety inspection highlights issues such as planning for safety inspections, collecting and aggregating information from previous incidents, reviewing guidelines and potential incidents, and improving workers' understanding of risks. After identifying a hazard, safety inspectors have to inform workers about the issue; otherwise, a positive outcome will be unattainable and the risks to workers will remain unknown. Also, incidents and safety inspection reports should be documented for use in future safety training to prevent reoccurrence of past mistakes. Van Dyck et al. (2005) defined Error Management Climate (EMC) as the employees' perceptions of organizational practices related to communication of errors, sharing knowledge about errors, assisting with errors, and quick detection and handling of errors.

The goal of safety inspections is the early detection of hazards. Since hazards are mainly due to human errors, the existence of communications is necessary for managing errors and safety inspections. In other words, inspection is valuable when it can ultimately lead to the transfer of results and lessons to the workforce. So, in the absence of SafCom, safety inspection is incomplete and loses its effectiveness.

Safety practices at work include rules and regulations that are drafted by official agencies such as OSHA. Safety experience implies the adequacy and extent to which safety training, toolbox talks, safe working conditions, and PPE are available at the construction sites. The research conducted by He et al. (2016) showed that safety experience and safety practices are correlated with work pressure. As previously mentioned, work pressure is observed in the context of communications among individuals and groups in the workplace. Safety practices and safety experiences play a vital role in promoting SafOut, their effectiveness depends on their transfer to the workforce, which in turn involves the establishment of SafCom. If these conditions are provided, it will be possible to promote safety; therefore, effective SafCom is integral to SafOut.

Although the creation of a positive SafClim is necessary to achieve higher performance, enhancing SafClim alone will not suffice, and performance will not improve if appropriate communication channels are not established. Even in construction projects with stringent safety rules and abundant safety resources, lack of proper communication can lead to unsatisfactory SafOut. Fig. 3a and 3b depict the communication patterns of two excavator crews with good SafOut. Fig. 3a depicts the network for the excavation project of a hospital and has a network density of 0.8. The existence of dense communications among the members of the excavator crews caused the SafClim to have a substantial impact on SafOut, and as a result, no accidents occurred in the project. Fig. 3b belongs to another excavation project with a density of 0.75, which experienced only two accidents in seven months. At the opposite end, Fig. 3c shows the communication network among an excavator crew with a network density of 0.43, which experienced six accidents in four months (one of the worst SafOut among 36 projects).

6. Conclusions

It has been extensively argued that positive SafClim is needed to enhance SafOut of construction projects. In previous studies, SafCom has mainly been considered as one of the dimensions of SafClim; however, this assumption has led to the superficial examination of this construct and its impact on SafOut. Additionally, this view of the relationship between SafCom and SafClim precludes the study of interactions between SafClim and SafCom in explaining SafOut. Therefore, the critical contributions of this research were to consider SafCom as an independent construct, investigate the relationship between SafClim and SafOut, and study the effect of different communication modes on this relationship in construction projects. For a more rigorous analysis, we examined the effect of SafCom in weighted and non-weighted communication networks. The results showed that SafCom (in both types of networks) plays a mediator role in the relationship between SafClim and SafOut; i.e., SafClim will have a significant impact on project SafOut if effective communications are established among team members.

This study contributes to safety literature by explaining the mediator role of SafCom on the relationship between SafClim and SafOut. Unlike previous studies which examined the entire construction process, this study focused on the excavation phase. Because the nature of safety risks in different stages of construction projects is different, focusing on a single phase increases the validity of the results.

This research also has implications for construction practitioners, explaining the importance of focusing on SafCom for improving SafOut at construction sites. The results showed that contractors could increase SafCom before and during the work by facilitating communications between workers and supervisors. We also found that contractors can achieve significant safety outcomes by transferring the lessons learned at the end of the work. To achieve better SafOut in projects, it is recommended that project managers inform workers about the organization's commitment to safety. To do so, managers may use different communication channels such as regular group meetings, irregular visits, and correspondence boxes. A mechanism must exist to facilitates the establishment of various types of communications between all parts of a project. It is vital that communications be inclusive since the personal characteristics of workers may isolate some and highlight others, and as a result, safety issues may become of limited concern.

Workers must be ensured that their views are taken into account so that mutual trust can be established. To this end, project managers should provide workers with regular briefings on measures taken to improve safety. Another helpful measure is to hold short informal group meetings for each project on a daily basis. It is recommended that these meetings be held for 45 min, after meals and rest periods. The meetings should be supervised by the foreman for each group, and attendance should be mandatory. Communications at these meetings should be focused on safety issues, identified hazards, and how to handle safe work while maintaining an acceptable speed. The output of such meetings usually reveals a series of new needs or conditions that should be presented at regular meetings with the project manager. Before work begins, project managers should provide training courses for the foremen on how to improve SafOut. In these courses, foremen need to learn how to promote SafCom and ensure the effectiveness of communication channels.

It is recommended to create a virtual platform in each project under the supervision of Chief HSE Officer. The platform should be accessible by all members and present safety issues in attractive ways such as short media. For example, if rain is anticipated at the construction site, graphical warnings of work hazards in rainy conditions should be shared. In this case, workers can step into the project site with a better understanding of weather conditions and its potential risks and be equipped with instructions to reduce the risk of accidents.

7. Limitations and suggestions for future research

Our research should be interpreted in light of the following limitations. The first limitation of this research is its sample size. With a larger sample size, research results can avoid potential issues of reproducibility, statistical power, and inflated effect size (Button et al., 2013). Although the chosen sample size (considering the sampling method) satisfies the statistical requirements, a larger sample size can improve generalizability, reproducibility, statistical power and effect size. Hence, future studies can examine our results using a larger sample size. Also, the focus of this study was on the excavation phase, so care must be taken in generalizing the results to other phases of construction projects.

The other limitation of this study is expert judgment bias. As experts are humans, their opinion may produce a cognitive bias (Arnott, 2006). In order to lessen the expert opinion bias, a more extensive community of experts can be employed if possible. Next, owing to the lack of official reports on active construction projects in Iran, the only possible and affordable sampling method to conduct this research was snowball sampling. Although snowball sampling was the only promising alternative for such a condition, it may not be as representative as random sampling; so it might be difficult to generalize the results beyond our sample. In order to overcome this limitation, deploying a more representative sampling method (such as random sampling) is recommended.

In the present study, the recordable incident rate was leveraged to measure project SafOut. Although it is frequently used as one of the most common indicators for representing SafOut, being a lagging indicator, it can only measure SafOut once incidents occur. Therefore, recordable incident rate cannot provide a warning for upcoming incidents (Hinze et al., 2013). It is recommended to use leading indicators such as safety participation or safety compliance for measuring SafOut in future studies (Hinze et al., 2013; Vinodkumar and Bhasi, 2010). These indicators can provide the necessary information about the safety of construction activities and have the ability to help decision-makers adopt corrective approaches (Guo and Yiu, 2015).

Furthermore, as stated in Table 2, 27 out of 259 respondents to our survey were illiterate and the research team had to transcribe their answers. Although verbal descriptions were provided when reading the questions, the transcription process may produce a marginal bias. In addition, using Analytical Hierarchy Process (AHP) to rank responses given on a Likert scale can lead to some inconsistencies. Therefore, to reduce expert judgment bias, it is recommended to implement more consistent methods such as fuzzy-based AHP to gauge the effectiveness of communication channels and their impact on SafOut.

Appendix A. Safety communication questionnaire

Age:	Construction work experience:
Education:	Position:
Number of work-related experienced incidents:	

Name of individuals who you PROVIDE safety information to		Type of communication						
First name Family name	Position	Informal communication			Formal communication			
		Mentoring	Informal discussion	Social network applications*	Toolbox talks	Formal safety training	Safety work orders	Written notifications

* Social network applications denote applications such as Instagram, Facebook, WhatsApp, Telegram, etc.

Appendix B. Safety climate indicators

1. To what extent was your team's safety important to the project manager?
2. To what extent has your supervisor emphasized safety?
3. To what extent has your supervisor complied with safety?
4. To what extent have safety regulations been implemented in this project?
5. To what extent have you had access to proper and safe equipment for work?
6. To what extent have the Work Protection Committee meetings been organized regularly and effectively?
7. To what extent have you been encouraged for following precautionary principles?
8. To what extent have signs, bulletins, and safety-related tracts been used at the construction site?
9. To what extent was safety in your control?
10. To what extent has risk-taking been part of your task?
11. To what extent do you feel that an incident will happen to you in the next year?

References

Administration of Labor Inspection, 2016. Ministry of Labour and Social Affair. Bazresikar. Available at: https://bazresikar.mcls.gov.ir/en/home [Accessed 5 Feb. 2018].

Albert, A., Hallowell, M.R. 2014. Modeling the role of social networks in situational awareness and hazard communication. In: Paper presented at the Construction Research Congress 2014: Construction in a Global Network.

Albert, A., Hallowell, M.R., 2017. Modeling the Role of social networks on hazard recognition and communication. Pract. Period. Struct. Des. Construct. 22 (4), 04017016.

Allison, L., Kaminsky, J., 2017. Safety communication networks: females in small work crews. J. Construct. Eng. Manage. 143 (8), 04017050.

Alruqi, W.M., Hallowell, M.R., Techera, U., 2018. Safety climate dimensions and their relationship to construction safety performance: a meta-analytic review. Saf. Sci. 109, 165–173.

Alsamadani, R., Hallowell, M., Javernick-Will, A.N., 2013a. Measuring and modelling safety communication in small work crews in the US using social network analysis. Construct. Manage. Econ. 31 (6), 568–579.

Alsamadani, R., Hallowell, M.R., Javernick-Will, A., Cabello, J., 2013b. Relationships among language proficiency, communication patterns, and safety performance in small work crews in the United States. J. Construct. Eng. Manage. 139 (9), 1125–1134.

Arnott, D., 2006. Cognitive biases and decision support systems development: a design science approach. Inform. Syst. J. 16 (1), 55–78.

Babbie, E.R., 2015. The Practice of Social Research. Nelson Education.

Bahari, S.F., Clarke, S., 2013. Cross-validation of an employee safety climate model in Malaysia. J. Saf. Res. 45, 1–6.

Barbaranelli, C., Petitta, L., Probst, T.M., 2015. Does safety climate predict safety performance in Italy and the USA? Cross-cultural validation of a theoretical model of safety climate. Accid. Anal. Prev. 77, 35–44.

Baron, R.M., Kenny, D.A., 1986. The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. J. Pers. Soc. Psychol. 51 (6), 1173.
Baxendale, T., Jones, O., 2000. Construction design and management safety regulations in practice—progress on implementation. Int. J. Project Manage. 18 (1), 33–40.
Bentley, T.A., Haslam, R., 2001. A comparison of safety practices used by managers of high and low accident rate postal delivery offices. Saf. Sci. 37 (1), 19–37.
Beus, J.M., Payne, S.C., Bergman, M. E., Arthur Jr, W. 2010. Safety climate and injuries: an examination of theoretical and empirical relationships. In: American Psychological Association.
Borgatti, S.P., Everett, M.G., 2006. A graph-theoretic perspective on centrality. Soc. Networks 28 (4), 466–484.
Boud, D., Rooney, D., Solomon, N., 2009. Talking up learning at work: cautionary tales in co-opting everyday learning. Int. J. Lifelong Educat. 28 (3), 323–334.
Brondino, M., Silva, S.A., Pasini, M., 2012. Multilevel approach to organizational and group safety climate and safety performance: co-workers as the missing link. Saf. Sci. 50 (9), 1847–1856.
Bureau of Labor Statistics. 2018. Census of Fatal Occupational Injuries (CFOI) - Current and Revised Data. Available at: https://www.bls.gov/iif/oshcfoi1.htm [Accessed 5 Feb. 2018].
Bureau of Labor Statistics. 2019. How To Compute Your Firm's Incidence Rate for Safety Management. (2019, March 25). Retrieved from https://www.bls.gov/iif/osheval.htm.
Button, K.S., Ioannidis, J.P., Mokrysz, C., Nosek, B.A., Flint, J., Robinson, E.S., Munafò, M.R., 2013. Power failure: why small sample size undermines the reliability of neuroscience. Nat. Rev. Neurosci. 14 (5), 365–376.
Chen, Y., McCabe, B., Hyatt, D., 2017. Impact of individual resilience and safety climate on safety performance and psychological stress of construction workers: a case study of the Ontario construction industry. J. Saf. Res. 61, 167–176.
Cheng, E.W., Ryan, N., Kelly, S., 2012. Exploring the perceived influence of safety management practices on project performance in the construction industry. Saf. Sci. 50 (2), 363–369.
Christian, M.S., Bradley, J.C., Wallace, J.C., Burke, M.J., 2009. Workplace safety: a meta-analysis of the roles of person and situation factors. J. Appl. Psychol. 94 (5), 1103.
Cigularov, K.P., Chen, P.Y., Rosecrance, J., 2010. The effects of error management climate and safety communication on safety: a multi-level study. Accid. Anal. Prev. 42 (5), 1498–1506.
Clarke, S. 2006. The relationship between safety climate and safety performance: a meta-analytic review. In: Educational Publishing Foundation.
Cohen, Jacob, 1988. Statistical Power Analysis for the Behavioral Sciences, second ed. Lawrence Erlbaum Associates Inc., Hillsdale, New Jersey, pp. 12–88.
Cronbach, L.J., 1951. Coefficient alpha and the internal structure of tests. Psychometrika 16 (3), 297–334.
Dainty, A., Moore, D., Murray, M., 2007. Communication in construction: theory and practice. Routledge.
Dedobbeleer, N., Béland, F., 1991. A safety climate measure for construction sites. J. Saf. Res. 22 (2), 97–103.
Demirkesen, S., Arditi, D., 2015. Construction safety personnel's perceptions of safety training practices. Int. J. Project Manage. 33 (5), 1160–1169.
Donald, I., Canter, D., 1994. Employee attitudes and safety in the chemical industry. J. Loss Prev. Process Ind. 7 (3), 203–208.
Easley, D., Kleinberg, J., 2010. Networks, crowds, and markets: reasoning about a highly connected world. Cambridge University Press.
Edmondson, A.C., 1996. Learning from mistakes is easier said than done: Group and organizational influences on the detection and correction of human error. J. Appl. Behav. Sci. 32 (1), 5–28.
El-Saboni, M., Aouad, G., Sabouni, A., 2009. Electronic communication systems effects on the success of construction projects in United Arab Emirates. Adv. Eng. Inf. 23 (1), 130–138.
Fernández-Muñiz, B., Montes-Peón, J.M., Vázquez-Ordás, C.J., 2009. Relation between occupational safety management and firm performance. Saf. Sci. 47 (7), 980–991.
Field, A., 2013. Discovering statistics using IBM SPSS statistics. Sage.
Forman, E.H., Gass, S.I., 2001. The analytic hierarchy process—an exposition. Oper. Res. 49 (4), 469–486.
Gao, R., Chan, A.P., Utama, W.P., Zahoor, H., 2016. Multilevel safety climate and safety performance in the construction industry: development and validation of a top-down mechanism. Int. J. Environ. Res. Public Health 13 (11), 1100.
Greeff, W.J., 2017. The role of communication in managing the safety climate of construction site environments. Communicatio 43 (1), 103–121.
Griffin, M.A., Neal, A., 2000. Perceptions of safety at work: a framework for linking safety climate to safety performance, knowledge, and motivation. J. Occup. Health Psychol. 5 (3), 347.
Guo, B.H., Yiu, T.W., 2015. Developing leading indicators to monitor the safety conditions of construction projects. J. Manage. Eng. 32 (1), 04015016.
Guo, B.H., Yiu, T.W., González, V.A., 2016. Predicting safety behavior in the construction industry: Development and test of an integrative model. Saf. Sci. 84, 1–11.
Hadjimanolis, A., Boustras, G., Economides, A., Yiannaki, A., Nicolaides, L., 2015. Work attitudes and safety performance in micro-firms–Results from a nationwide survey: (the opinion of the employees). Saf. Sci. 80, 135–143.
Hallowell, M.R., 2011. Safety-knowledge management in American construction organizations. J. Manage. Eng. 28 (2), 203–211.
Hayes, A.F., 2017. Introduction to mediation, moderation, and conditional process analysis: a regression-based approach. Guilford Publications.
Haythornthwaite, C., 1996. Social network analysis: an approach and technique for the study of information exchange. Lib. Inform. Sci. Res. 18 (4), 323–342.
He, Q., Dong, S., Rose, T., Li, H., Yin, Q., Cao, D., 2016. Systematic impact of institutional pressures on safety climate in the construction industry. Accid. Anal. Prev. 93, 230–239.
Hinze, J., Thurman, S., Wehle, A., 2013. Leading indicators of construction safety performance. Saf. Sci. 51 (1), 23–28.
Hofmann, D.A., Stetzer, A., 1996. A cross-level investigation of factors influencing unsafe behaviors and accidents. Pers. Psychol. 49 (2), 307–339.
Hofmann, D.A., Stetzer, A., 1998. The role of safety climate and communication in accident interpretation: implications for learning from negative events. Acad. Manag. J. 41 (6), 644–657.
Huang, X., Hinze, J., 2006. Owner's role in construction safety. J. Construct. Eng. Manage. 132 (2), 164–173.
Hutcheson, G.D., Sofroniou, N., 1999. The multivariate social scientist: introductory statistics using generalized linear models. Sage.
Jaselskis, E.J., Anderson, S.D., Russell, J.S., 1996. Strategies for achieving excellence in construction safety performance. J. Construct. Eng. Manage. 122 (1), 61–70.
Kath, L.M., Marks, K.M., Ranney, J., 2010. Safety climate dimensions, leader–member exchange, and organizational support as predictors of upward safety communication in a sample of rail industry workers. Saf. Sci. 48 (5), 643–650.
Kines, P., Andersen, L.P., Spangenberg, S., Mikkelsen, K.L., Dyreborg, J., Zohar, D., 2010. Improving construction site safety through leader-based verbal safety communication. J. Saf. Res. 41 (5), 399–406.
Langford, D., Rowlinson, S., Sawacha, E., 2000. Safety behaviour and safety management: its influence on the attitudes of workers in the UK construction industry. Eng. Construct. Architect. Manage. 7 (2), 133–140.
Li, Q., Ji, C., Yuan, J., Han, R., 2017. Developing dimensions and key indicators for the safety climate within China's construction teams: a questionnaire survey on construction sites in Nanjing. Saf. Sci. 93, 266–276.
Liao, P.C., Lei, G., Fang, D., Liu, W., 2014. The relationship between communication and construction safety climate in China. KSCE J. Civ. Eng. 18 (4), 887–897.
Lingard, H., Pink, S., Harley, J., Edirisinghe, R., 2015. Looking and learning: using participatory video to improve health and safety in the construction industry. Construct. Manage. Econ. 33 (9), 740–751.
Loosemore, M., 1997. Construction crises as periods of social adjustment. J. Manage. Eng. 13 (4), 30–37.
Loosemore, M., Andonakis, N., 2007. Barriers to implementing OHS reforms–The experiences of small subcontractors in the Australian Construction Industry. Int. J. Project Manage. 25 (6), 579–588.
Mansdorf, S.Z., 1993. Complete Guide to Industrial Safety in Manufacturing. Prentice Hall.
Marín, L.S., Roelofs, C., 2017. Promoting construction supervisors' safety-efficacy to improve safety climate: training intervention trial. J. Construct. Eng. Manage. 143 (8), 04017037.
Mattila, M., Hyttinen, M., Rantanen, E., 1994. Effective supervisory behaviour and safety at the building site. Int. J. Ind. Ergon. 13 (2), 85–93.
Mearns, K.J., Reader, T., 2008. Organizational support and safety outcomes: an un-investigated relationship? Saf. Sci. 46 (3), 388–397.
Mohamed, Sherif, 2002. Safety climate in construction site environments. J. Construct. Eng. Manage. 128 (5), 375–384. https://doi.org/10.1061/(ASCE)0733-9364(2002)128:5(375).
Molenaar, K.R., Park, J.I., Washington, S., 2009. Framework for measuring corporate safety culture and its impact on construction safety performance. J. Construct. Eng. Manage. 135 (6), 488–496.
Moreno, J.L. 1960. The sociometry reader.
Nahrgang, J.D., Morgeson, F.P., Hofmann, D.A., 2011. Safety at work: a meta-analytic investigation of the link between job demands, job resources, burnout, engagement, and safety outcomes. J. Appl. Psychol. 96 (1), 71.
Neal, A., Griffin, M.A., 2004. Safety climate and safety at work. Psychol. Workplace Saf. 15–34.
Neal, A., Griffin, M.A., 2006. A study of the lagged relationships among safety climate, safety motivation, safety behavior, and accidents at the individual and group levels. J. Appl. Psychol. 91 (4), 946.
Neal, A., Griffin, M.A., Hart, P.M., 2000. The impact of organizational climate on safety climate and individual behavior. Saf. Sci. 34 (1), 99–109.
Niskanen, T., 1994. Safety climate in the road administration. Saf. Sci. 17 (4), 237–255.
Nuntasunti, S., Bernold, L.E., 2006. Experimental assessment of wireless construction technologies. J. Construct. Eng. Manage. 132 (9), 1009–1018.
Ouédraogo, A., Groso, A., Meyer, T., 2011. Risk analysis in research environment–part II: weighting lab criticity index using the analytic hierarchy process. Saf. Sci. 49 (6), 785–793.
Park, J., 2011. The use of a social network analysis technique to investigate the characteristics of crew communications in nuclear power plants—a feasibility study. Reliab. Eng. Syst. Saf. 96 (10), 1275–1291.
Parker, S.K., Axtell, C.M., Turner, N., 2001. Designing a safer workplace: importance of job autonomy, communication quality, and supportive supervisors. J. Occup. Health Psychol. 6 (3), 211.
Petruni, A., Giagloglou, E., Douglas, E., Geng, J., Leva, M.C., Demichela, M., 2017. Applying Analytic Hierarchy Process (AHP) to choose a human factors technique: Choosing the suitable Human Reliability Analysis technique for the automotive industry. Saf. Sci.
PMI, 2018. A Guide to the Project Management Body of Knowledge (PMBOK® Guide). Project Management Institute.
Rajendran, S., Gambatese, J.A., Behm, M.G., 2009. Impact of green building design and construction on worker safety and health. J. Construct. Eng. Manage. 135 (10), 1058–1066.
Saaty, T.L., 1990. Decision making for leaders: the analytic hierarchy process for decisions in a complex world. RWS publications.

Saaty, T.L., Vargas, L.G., 2012. Models, methods, concepts & applications of the analytic hierarchy process Vol. 175 Springer Science & Business Media.
Sawacha, E., Naoum, S., Fong, D., 1999. Factors affecting safety performance on construction sites. Int. J. Project Manage. 17 (5), 309–315.
Schein, E.H., 1990. Organizational culture Vol. 45 American Psychological Association.
Shen, Y., Tuuli, M.M., Xia, B., Koh, T.Y., Rowlinson, S., 2015. Toward a model for forming psychological safety climate in construction project management. Int. J. Project Manage. 33 (1), 223–235.
Simard, M., Marchand, A., 1994. The behaviour of first-line supervisors in accident prevention and effectiveness in occupational safety. Saf. Sci. 17 (3), 169–185.
Simon, J., Piquard, P. 1991. Contractor safety performance significantly improves. In: Paper presented at the SPE Health, Safety and Environment in Oil and Gas Exploration and Production Conference.
Smith, M.J., Cohen, H.H., Cohen, A., Cleveland, R.J., 1978. Characteristics of successful safety programs. J. Saf. Res.
Stackhouse, M.R.D., McDouall, J.M., 2015. Safety Climate on Safety: The Mediating Role of Management Commitment. Paper presented at the Academy of Management Proceedings.
Tam, C., Zeng, S., Deng, Z., 2004. Identifying elements of poor construction safety management in China. Saf. Sci. 42 (7), 569–586.
Tokakis, V., Polychroniou, P., Boustras, G., 2019. Crisis management in public administration: the three phases model for safety incidents. Saf. Sci. 113, 37–43.
Urban, J.M., Weaver, J.L., Bowers, C.A., Rhodenizer, L., 1996. Effects of workload and structure on team processes and performance: Implications for complex team decision making. Hum. Fact.: J. Hum. Factors Ergon. Soc. 38 (2), 300–310.
Van Dyck, C., Frese, M., Baer, M., Sonnentag, S., 2005. Organizational error management culture and its impact on performance: a two-study replication. J. Appl. Psychol. 90 (6), 1228.
Vecchio-Sadus, A.M., 2007. Enhancing safety culture through effective communication. Saf. Sci. Monitor 11 (3), 1–10.
Vinodkumar, M., Bhasi, M., 2010. Safety management practices and safety behaviour: Assessing the mediating role of safety knowledge and motivation. Accid. Anal. Prev. 42 (6), 2082–2093.
Wehbe, F., Al Hattab, M., Hamzeh, F., 2016. Exploring associations between resilience and construction safety performance in safety networks. Saf. Sci. 82, 338–351.
Wilkins, J.R., 2011. Construction workers' perceptions of health and safety training programmes. Construct. Manage. Econ. 29 (10), 1017–1026.
Williamson, A.M., Feyer, A.-M., Cairns, D., Biancotti, D., 1997. The development of a measure of safety climate: the role of safety perceptions and attitudes. Saf. Sci. 25 (1), 15–27.
Woodcock, K., 2014. Model of safety inspection. Saf. Sci. 62, 145–156.
Wu, C., Wang, F., Zou, P.X.W., Fang, D., 2016. How safety leadership works among owners, contractors and subcontractors in construction projects. Int. J. Project Manage. 34 (5), 789–805.
Wu, C., Song, X., Wang, T., Fang, D., 2015. Core dimensions of the construction safety climate for a standardized safety-climate measurement. J. Construct. Eng. Manage. 141 (8), 04015018.
Zahoor, H., Chan, A.P., Utama, W.P., Gao, R., Memon, S.A., 2017. Determinants of safety climate for building projects: SEM-based cross-validation study. J. Construct. Eng. Manage. 143 (6), 05017005.
Zhang, B., Chu, Z., Cheng, L., Zou, N., 2019. A quantitative safety regulation compliance level evaluation method. Saf. Sci. 112, 81–89.
Zhou, Z., Goh, Y.M., Li, Q., 2015. Overview and analysis of safety management studies in the construction industry. Saf. Sci. 72, 337–350.
Zohar, D., 1980. Safety climate in industrial organizations: theoretical and applied implications. J. Appl. Psychol. 65 (1), 96–102.
Zohar, D., 2010. Thirty years of safety climate research: reflections and future directions. Accid. Anal. Prev. 42 (5), 1517–1522.
Zou, P.X., Lun, P., Cipolla, D., Mohamed, S., 2017. Cloud-based safety information and communication system in infrastructure construction. Saf. Sci. 98, 50–69.