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A Comprehensive Analysis of Safety Predictors in Construction Sites: A DEMATEL-Based Model

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Abstract: The construction industry, vital for economic growth and human capital development, faces significant safety challenges, particularly in the Malaysian context. Despite technological advancements, addressing safety concerns necessitates a deeper understanding of behavioural interventions. This study explores the critical factors influencing safety compliance intention and safety participation in the Malaysian construction industry, utilising the Theory of Planned Behaviour (TPB) as its theoretical framework. TPB posits that actual behaviour can be predicted by intention, while the formation of intention is mainly determined by attitude, subjective norms and perceived behavioural control. Despite the posited framework considering TPB, there is no evidence to prove the correlation between safety predictors, safety compliance intention and safety participation. This study examines the influence of safety predictors on safety compliance intention and safety participation by using the decision-making trial and evaluation laboratory (DEMATEL) technique. Based on the DEMATEL technique, 25 experts were invited to provide pairwise ranking on the predictors influencing safety compliance intention and safety participation. The predictors examined in the study include "Attitude", "Subjective norm", "Perceived behavioural control", "Types of leadership styles", "Safety knowledge", "Safety climate", "Safety motivation", "Risk perception" and "Communication". Among these predictors, the study revealed significant relationships between all safety predictors, with "Attitude" emerging as the most impactful predictor. Organisations should prioritise this to enhance safety performance. Safety performance in construction projects can be improved and intervened in when the interrelationships between safety predictors, safety compliance intention and safety participation are fully understood.

Keywords: Safety predictors, Safety compliance intention, Safety participation, DEMATEL, Theory of Planned Behaviour

INTRODUCTION

Despite employing only about 7% of the labour population, the construction industry remains one of the most dangerous industries, accountings for between 30% and 40% of all work-related injuries and fatalities (Khahro et al., 2020; Lee et al., 2019).

Construction project management is hampered by a complicated interplay between elements affecting safety and the dynamic environment. These challenges demand careful and efficient handling as they add a level of uncertainty to construction operations (Mohammadi, Tavakolan and Khosravi, 2018).

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Construction projects are dynamic and frequently prone to change, which carries inherent risks (Newaz et al., 2016). Both researchers and practitioners have given considerable attention to the issue of workplace safety. The potential effects of poor workplace safety procedures can be severe. Project stakeholders are currently facing significant losses due to tragic accidents resulting from a lack of attention to safety rules and involvement in construction site safety. Workplace fatalities and injuries cause serious setbacks, affecting not only individuals but also entire communities (Xu et al., 2021). Therefore, prioritising workers' safety is crucial to preventing negative effects on organisational costs and the subsequent reduction in productivity (Singh and Misra, 2020).

Improving site safety requires a thorough understanding of construction site compliance behaviours. The cornerstone of successful safety performance is understanding safety compliance behaviour (Hu, Yeo and Griffin, 2020). Almost no research has investigated the role of planned behaviour in intervening in safety compliance on construction sites. This study will examine the critical factors influencing safety behaviour and compliance using the Theory of Planned Behaviour (TPB). TPB posits that actual behaviour can be predicted by intention, with the formation of intention mainly determined by attitude, subjective norms and perceived behavioural control.

Additionally, safety participation has emerged as an important aspect of construction employees' safety practices (Choi and Lee, 2022). Although there have been previous attempts to identify the factors that influence workers' intention to participate in safety, it is still unclear how these variables affect different individuals (Asilian-Mahabadi et al., 2020). Additionally, the linked among micro-level safety predictors, goals for safety compliance and safety involvement within the context of construction project sites have not been effectively addressed by these studies.

Major construction projects in Malaysia are vulnerable to risky situations that could lead to accidents and jeopardise project safety outcomes. However, research on the factors impacting safety performance in the Malaysian construction industry is noticeably lacking (Albarkani and Shafii, 2021). Both safety participation and compliance significantly impact safety performance and deserve careful study. While previous studies have focused on technological approaches to improve safety, few have examined behavioural interventions in the workplace. The potential of planned behaviour as an intervention to increase safety compliance on construction sites remains largely unexplored. Surprisingly, no research has yet mapped the complex relationships between safety predictors, intentions for safety compliance and safety involvement on construction project sites using the decision-making trial and evaluation laboratory (DEMATEL) technique.

As a result of these gaps, the goal of this study is to model safety predictors that influence both safety compliance intention and safety participation among construction employees. A novel DEMATEL-based model will be developed to examine the interrelationships between safety predictors, safety compliance intention and safety participation on construction project sites.

LITERATURE REVIEW

Safety Behaviour

Safety behaviour is defined as work performance that prioritise safety and is a key factor in preventing accidents (Sampson, DeArmond and Chen, 2014). Safety behaviours include all individual actions taken for one's own protection, such as following safety rules to avoid injury to oneself or others and wearing safety gear (Seo et al., 2015). Since safety behaviour has been shown to reduce the likelihood of injuries, hazardous occurrences, mishaps and other crucial safety outcomes (Aryee and Hsiung, 2016), it plays a vital role as an indicator of safety performance (Hinze, Thurman and Wehle, 2013). As a result, safety behaviour becomes crucial in determining how to improve and regulate safety on construction sites (Fang, Wu and Wu, 2015). According to work performance theory, safety compliance and safety participation are two distinct characteristics of safety behaviour (performance) (Borman and Motowidlo, 1993).

Safety Compliance

Safety participation makes up one element of the broader concept of "safety behaviour", which is commonly discussed in the context of safety performance frameworks. Safety compliance is first component. The phrase "safety compliance" refers to "the fundamental behaviours one must exhibit to uphold workplace safety" (Griffin and Neal, 2000). For example, "I consistently use all required protective gear during my tasks" could be a sample statement for evaluating safety compliance. Safety compliance has been characterised as workplace actions intended to meet the bare minimum standards for safety (Inness et al., 2010).

Safety Participation

To improve safety practices, employees must make additional contributions. This includes fully participating in safety meetings, providing enthusiastic help to co-workers on safety-related projects and making thoughtful safety suggestions and improvements (Liu, Ye and Guo, 2019). Participation in safety has grown in importance among construction workers as a critical component of safety practices (Choi and Lee, 2022). Safety participation involves "behaviours that may not directly impact personal safety but contribute to the cultivation of a safety-promoting environment". It is closely related to situational performance and includes all voluntarily undertaken actions by employees to improve safety, such as helping co-workers, raising safety issues and suggesting safety changes (Griffin and Neal, 2000). An example of a measurable indicator for safety participation is the statement "I consistently work to improve workplace safety" is an example of a measurable indicator for safety involvement.

Theory of Planned Behaviour: Explaining Safety Compliance Behaviour

TPB was first proposed by Ajzen (1991) to explain general individual activities. This theory is based on three main beliefs: attitude toward a behaviour, subjective norms regarding the behaviour and perceived behavioural control over the behaviour.

These beliefs form a behavioural intention, which then influences the person's actual behaviour. Although TPB was initially intended as a general model, its components have been modified in this study to better fit the needs of the construction industry and explain safety compliance behaviour. The behavioural intention is composed of attitude, subjective norm and perceived behavioural control. According to the TPB framework (Swarna, Tezeswi and Siva, 2022), an individual's attitudes, subjective norms and perceived behavioural control are linked to their behavioural intention and ultimate behaviour. This approach has been widely used to forecast and explain individual behaviour.

Construction employees' attitudes toward safety compliance are reflected in whether they view safety compliance favourably or unfavourably. Employees are more likely to follow safety regulations when they have a favourable attitude toward safety compliance. Subjective norms for construction workers are influenced by significant people in their lives who believe that safety regulations should be followed. Workers are more likely to comply safety regulations when they feel that their views align with those who are important people around them. Perceived behavioural control relates to construction workers' perceptions of the ease or difficulty of adhering to safety regulations.

Intention Towards Safety Compliance

The most immediate predictor of behaviour is intention. Intentions reflect the degree of effort or level or level of difficulty a person is willing to exert when engaging in a behaviour (Lee, Yiu and Cheung, 2018a). A person's decision to act is consistent with their intention to do so. Based on an individual's intentions, actual behaviour can be predicted (Fishbein and Ajzen, 2011) and the effects of these intentions can be influenced by real-world factors such as skills, talents and environmental circumstances. Intention towards safety compliance can be determined by attitudes towards safety compliance, subjective norms and perceived behavioural control (Goh et al., 2018).

Attitude Towards Safety Compliance

Attitude can be defined as one's positive or negative feelings toward a specific behaviour (Lee, Yiu and Cheung, 2018a; 2018b). An individual's attitude toward a behaviour is formed by their beliefs about that behaviour. The total of one's beliefs about the outcomes of performing a particular action, such as compliance with safety requirements, includes statements like "Compliance with safety requirements will ensure my safety" and is multiplied by the assessment of the repercussions, such as "Compliance with safety requirements and ensuring my safety is good/bad". People's attitudes are driven by their attitudinal beliefs and influenced by the perceived consequences of a behaviour as well as their assessments of these repercussions (Fishbein and Ajzen, 1980).

Subjective Norms Towards Safety Compliance

Subjective norm is identified as a person's perceived social pressure to perform or refrain from performing a specific intended act (Lee, Yiu and Cheung, 2018a). It is determined by combining the outcome of normative beliefs—representing the site personnel's perception of the importance of other people/groups (e.g., the probability that peers, important friends and family will support, agree with, or pressure their decision to comply with safety requirements)—with the intention to comply, which refers to the motivation to conform to these perceived expectations. For instance, a site employee may feel strong pressure from essential family or friends to comply with safety rules and have a strong motivation to comply. The function of this normative belief is to convey to site personnel the perceptions of other significant individuals.

Perceived Behavioural Control Towards Safety Compliance

Perceived behavioural control refers to one's belief and confidence in one's capacity to execute an action, aligning with the concept of self-efficacy. It speaks to the perceived ease or difficulty of carrying out a behaviour. Perceived behavioural control relates to beliefs based on previous behaviour, prior knowledge, secondary data and the availability of opportunities and resources, along with four self-efficacy theory sources such as performances successes, persuasive speech, emotional activation and simulated experiences. Fewer resources and a lack of opportunity reduce perceived control over behaviour. For example, a site personnel might feel a lack of availability, time and control in complying with safety requirements but believes that having control over availability and time is crucial for compliance. The more control one feels they have over an action, the stronger the intention to act on it (Lee, Yiu and Cheung, 2018b).

Safety Predictors Affecting Safety Participation

Types of leadership styles

Leadership is a complex concept that is difficult to define precisely. Northouse (2021) described leadership as "a progress by which one person influences a team of people to accomplish a shared objective". Andriessen (1978) stated that leadership and the leader's safety standards significantly impact on workers' safety behaviour and motivation. The leader's role in promoting workplace safety is often referred to as "leadership/influence tactics" (Hedlund et al., 2010). Leaders can enhance employee safety participation and performance, as well as create a safe environment, by adopting empowering attitudes (Martínez-Córcoles et al., 2012). Burns (2012) distinguishes two leadership styles that influence followers' behaviours: transactional leadership and transformational leadership. According to the Multifactor Leadership Theory (Bass and Avolio, 2004), a third style, laissez-faire leadership, which refers to passive leadership or a lack of leadership, was added (Mcfadden, Henagan and Iii, 2009).

Safety knowledge

Safety knowledge encompasses the skills and aptitude to understand, learn and apply associated guidelines or restrictions (Ajzen, 1991). An inexperienced worker may be unable to detect and recognise surrounding hazards due to a lack of safety knowledge (Jiang, Fang, and Zhang, 2015). When performing on-site operations, construction workers must anticipate and analyse hazardous situations, which requires sufficient safety knowledge and appropriate attitudes. Without adequate safety knowledge, they cannot fully understand the risks involved. Therefore, it is critical to enhance safety knowledge among construction workers regarding potential dangers and how to prevent them (Ye et al., 2020).

Safety climate

The term "safety climate" refers to the collective perception of an organisation's safety principles, rules and values (Zohar, 1980). Given that it precedes safety behaviours (Fang, Chen and Wong, 2006) and can serve as an indicator of the underlying safety culture, the current safety climate significantly impacts overall safety performance (Chan et al., 2017). This highlights potential areas for overall safety improvement. Since the 1990s, the safety climate—which includes safety compliance and participation—has consistently been emphasised as a key factor influencing workplace safety performance. The consensus among employees regarding safety procedures, practices and rules is referred to as the safety atmosphere. This concept can be considered at two distinct hierarchical levels: within a group and throughout an organisation (Brondino, Silva and Pasini, 2012).

Safety motivation

Understanding the drivers behind operational personnel's motivation to operate safely (referred to as "safety motivation") is crucial for addressing risky behaviours and improving their safety involvement (Griffin and Curcuruto, 2016). Motivation theories (Nykänen et al., 2019) can help explain why people choose to engage in different safety-related behaviours and how these behaviours are influenced by their beliefs. According to Neal, Griffin and Hart (2000), there is a relationship between safety climate and safety behaviours, particularly safety engagement and safety compliance. This relationship is supported by numerous studies (Peker, Doğru and Meşe, 2022; Barbaranelli, Petitta and Probst, 2015). Safety motivation exhibits a positive link with safety behaviours while showing a negative association with accidents (Christian et al., 2009). Therefore, there is a causal link between safety motivation and behaviour. As a result, employees are more likely to engage in safe actions when their safety motivation is higher (Chen and Chen, 2014).

Risk perception

Unsafe actions can be motivated by both internal and external reasons, with risk perception being a key internal driver (Wang, Zou and Li, 2016). One factor that has been identified as impacting risk-taking behaviours among construction workers is safety risk perception (Chan et al., 2017). Employees within a business are directly exposed to occupational dangers, incidents and fatalities as frontline personnel. When individuals believe their work is dangerous, they are more likely to put safety first in order to protect both their own and others' safety (Didla, Mearns and Flin, 2009). They have a significantly higher risk of experiencing workplace mishaps and fatalities if they do not follow safety measures (Christian et al., 2009). There is evidence from several research (Kouabenan, Ngueutsa and Mbaye, 2015; Xia et al., 2017; 2020) that safety behaviour and risk perception are related.

Communication

The value of employees' perspectives within an organisation is emphasised by a management culture that values communication. Through discussions on organisational issues and participation in decision-making processes, this method gives employees greater opportunities to produce and improve information (Neill, Men and Yue, 2019). Effective information flow inside organisation and projects is crucial in encouraging employees to take an active role in their own safety since extra-role activities go beyond the bounds of the prescribed position. Improved self-efficacy and extra-role conduct among employees are both influenced by effective communication. Employees feel more confident that their delivery are beneficial to the organisation when there is a positive communication climate in place. Workers are more likely to offer ideas for improving organisational safety performance, for instance, when management shows a greater interest in their opinion (Choi and Lee, 2022). The conceptualised safety behaviour model is displayed in Figure 1.

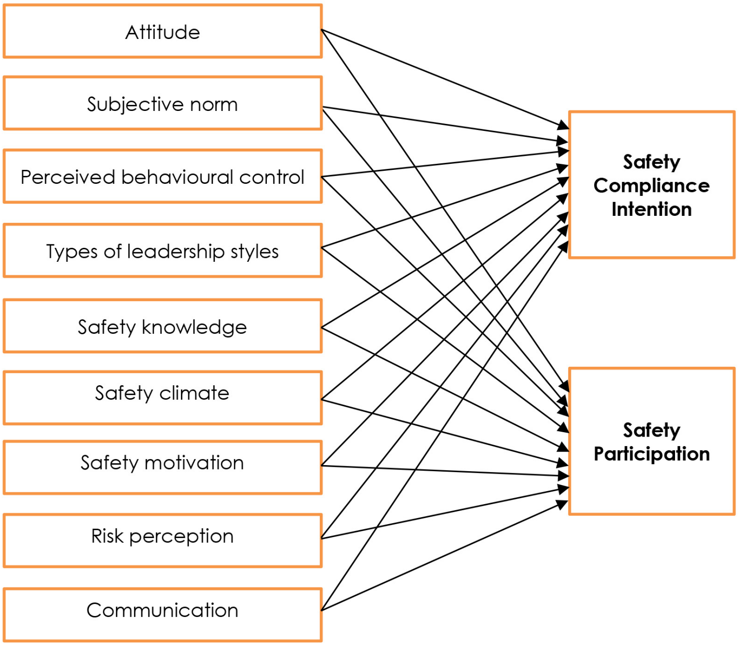

Figure 1. Conceptual safety behaviour model

METHODOLOGY

In this study, the DEMATEL technique was chosen over other possible methods for analysing interdependencies due to its ability to provide insights into causal connections and magnitudes of effects among various elements. Unlike other methods, DEMATEL employs structural modelling to generate digraphs, facilitating the identification of interdependencies within complex systems (Mohandes et al., 2022). Given the multifaceted nature of safety predictors in construction settings, DEMATEL was deemed suitable for elucidating the relationships among these predictors and their impact on safety behaviour.

A total of 25 experts were chosen after careful consideration to ensure their expertise was relevant to the study's context. Experts were selected based on their extensive experience and knowledge in the Malaysian construction industry, specifically in safety management and risk assessment. Additionally, experts were chosen from diverse backgrounds, including engineers, project managers, site managers, risk managers and construction managers, to provide a comprehensive perspective on safety predictors and behaviours in construction projects.

In total, six steps were followed in this study. Firstly, the selection of safety predictors was informed by a comprehensive literature review and consultation with industry experts. Secondly, the chosen predictors were operationalised into survey items or interview questions. Thirdly, 25 experts were invited to participate in the study, ensuring representation from various sectors within the construction industry. Fourthly, experts provided pairwise rankings of safety predictors using the DEMATEL technique. Fifthly, the data collected were analysed using DEMATEL to identify the causal connections and magnitudes of effects among safety predictors. Finally, the findings were validated through expert consultation and comparison with existing literature.

This research did not involve testing specific hypotheses as the study aimed to explore the interrelationships among safety predictors rather than test causal relationships. Instead, the focus was on mapping and analysing the connections between safety predictors and workers' safety behaviour on construction project sites, including their compliance with safety regulations and participation in safety-related activities. The findings obtained through DEMATEL analysis will provide valuable insights into the most important factors influencing safety behaviour in the Malaysian construction industry, guiding interventions and policy decisions aimed at enhancing workplace safety.

Step 1: Collect Opinion from Experts and Calculate Average Matrix Z

When using the DEMATEL technique, there is no upper or lower limit to the number of experts involved in the decision-making process. The number of professionals involved in the DEMATEL method is determined by their accessibility (Gholamnia et al., 2019). 25 experts in construction safety with a minimum of ten years of experience were contacted and interviewed. Each expert was consulted to provide feedback on the degree to which two criteria directly interact using integer scores in accordance with a pair-wise comparison. The value X_{ij} indicates how much the professional believes the criterion i has an impact on the criterion j. The four discrete categories of the numerical rating scale are 0 (No Impact), 1 (Low Impact), 2 (Moderate Impact), 3 (High Impact) and 4 (Very High Impact). The value of the integer rating has been set to zero automatically when $i = j$. As $X^k = [X_i j^k]$,a non-negative $n \times n$ matrix was created, which k is the quantity of specialists participating in this assessment process with $1 \leq k \leq m$. m specialists in a group and n causes are employed here. As a result, the matrices from m specialists are X^1, X^2, X^3 … X^m. The average matrix $Z = [Z_{ij}]$ was obtained as follows to represent all specialist opinions from m specialists as a whole:

$$Z_{ij} = \frac{1}{m}\sum_{i=1}^{m} X_{ij}^{k} \quad \text{Eq. 1}$$

A criterion with a greater numerical rating suggests that a greater enhancement in *i* is essential to enhance on *j*. The average matrix, also known as the initial direct-relation matrix *Z*, is used to show the initial direct influence each criterion has on and receives from another criterion.

Step 2: Calculate the Normalised Initial Direct-Relation Matrix *D*

The resulting matrix *D* has all its values falling between [0, 1] and is known as the normalised initial direct-relation matrix $D = [d_{ij}]$. Following is the formula:

$$D = \lambda * Z \quad \text{Eq. 2}$$

or

$$[d_{ij}]_{n\times n} = \lambda\,[Z_{ij}]_{n\times n} \quad \text{Eq. 3}$$

were

$$\lambda = Min\left[\frac{1}{max\,1 \le i \le n\sum_{j=1}^{n}|Z_{ij}|}, \frac{1}{max\,1 \le i \le n\sum_{i=1}^{n}|Z_{ij}|}\right] \quad \text{Eq. 4}$$

The entries in this normalised initial direct-relation matrix D will all only have values among zero and one.

Step 3: Develop the Total Relation Matrix *T*

The total-influence matrix T was obtained using the equation $T = D\,(I - D)^{-1}$ in which *I* is $n \times n$ identity matrices. The matrix *T* shows the overall relationship between each pair of criteria, while the element T_{ij} shows how the criterion *i* indirectly influences criterion *j*.

$$T = D\ (I - D)–1 \quad \text{Eq. 5}$$

Step 4: Determine the Sums of Columns and Rows of Matrix *T*

The row and column sums in the total-influence matrix *T* are computed using the subsequent formulas, each of which is represented by a separate vector (*r* or *c*).

$$r = [r_i]_{n\times 1} = \left(\sum_{j=1}^{n} t_{ij}\right)_{n\times 1} \quad \text{Eq. 6}$$

$$C = [C_j]'_{i\times n} = \left(\sum_{j=1}^{n} t_{ij}\right)'_{1\times n} \quad \text{Eq. 7}$$

where $[c_j]'$ is a transposition matrix expression.

Let the sum of *i*th row in matrix *T* be r_i, the sum of the direct and indirect effects that criterion *i* has on the other criteria is represented by the value of r_i.

Let c_j be the total value of the *j*th column in matrix *T*, the value of c_j is the total influence that all other criteria received both directly and indirectly, have on criterion *j*. If $j = i$, then the value of $r_i + c_j$ represents the overall impacts both provided and obtained by criterion *i*. The distinction is that the value of $r_i - c_j$ displays the criterion *i* net contribution to the system. Furthermore, when $r_i - c_j$ is positive, criterion *i* will be the net cause whereas when $r_i - c_j$ is negative, criterion *i* will be the net receiver (Sumrit and Anuntavoranich, 2013; Shieh, Wu, and Huang, 2010; Liou, Tzeng, and Chang, 2007; Lin and Tzeng, 2009).

Step 5: Determine Threshold Value

The directed graph was created by setting a threshold value. Impacts that are bigger than the threshold value is shown in matrix *T* (Lin and Tzeng, 2009). The calculation's formula is displayed as follows:

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left[t_{ij}\right]}{N} \qquad \text{Eq. 8}$$

in which *N* is the number of criteria in matrix *T* as a whole.

Step 6: Create a Causal Relationship Diagram

In order to depict the complicated interrelationship, the causal diagram will be constructed by mapping all coordinate sets of $(r_i + c_j, r_i - c_j)$, in which $r_i + c_j$ represents the horizontal axis (x-axis) and $r_i - c_j$ represents the vertical axis (y-axis) according to Shieh et al. (2010). It may additionally be employed to provide information so that decisions about the most important causes and how to influence impacted causes can be made. The causal diagram shows the elements that t_{ij} is higher than α. The plot graph that displays the outcome will clearly demonstrate how the predictors are interrelated (Lin and Tzeng, 2009).

RESULTS AND DISCUSSION

Respondent Profile

Data was collected from 25 professionals, including engineers, project managers, site managers, risk managers and construction managers, all of whom were regarded as safety experts in the construction sector with at least 10 years of experience and focus on high-rise building construction project in Selangor, Malaysia. They had a certain level of understanding and knowledge regarding safety predictors in the construction industry. According to previous research, there are no minimum participant requirements for the DEMATEL method analysis. Previous studies have typically had between three and 30 respondents. Typically, the purposive sample size is determined by theoretical data saturation (when new data no longer brings more insights to the research question, information seems redundancy for data collection).

A series of structured interview questions that complied with the standards of the DEMATEL method was developed to gather the required data. To fill out the questionnaire, the experts were interviewed virtually. They were asked to use a 0 to 4 scale to assess the accuracy of the safety predictors and safety behaviours influence each other. The respondents' backgrounds as displayed in Table 1.

Table 1. Respondents' demographic profile

Demographic Characteristics	Frequency	%
Experiences		
10 years to 15 years	11	44
16 years to 20 years	7	28
More than 20 years	7	28
Total	25	100
Position		
Safety and health manager	3	12
Project managers	7	28
Site managers	5	20
Risk managers	8	32
Construction managers	2	8
Total	25	100
Type of Company		
Main contractor	17	68
Sub-contractor	8	32
Total	25	100
Project Funding		
Government-funded	2	8
Private-funded	21	84
Both	2	8
Total	25	100
Project Contract Sum (MYR)		
Less than one million	6	24
1 million ≤ Contract sum < 10 million	1	4
10 million ≤ Contract sum < 50 million	6	24
50 million ≤ Contract sum < 100 million	7	28
More than 100 million	5	20
Total	25	100

INTERRELATIONSHIP BETWEEN PREDICTORS, SAFETY COMPLIANCE INTENTION AND SAFETY PARTICIPATION

Table 2 displays the list of safety predictors, safety compliance intention and safety participation in construction project sites.

Table 2. List of safety predictors, safety compliance intention and safety participation

Label	Safety Predictors	Label	Safety Predictors
A	Attitude	G	Safety motivation
B	Subjective norm	H	Risk perception
C	Perceived behavioural control	I	Climate
D	Types of leadership styles	J	Safety compliance intention
E	Safety knowledge	K	Safety participation
F	Safety climate		

Step 1: Collect experts' opinion and calculate average matrix Z

The experts evaluated the predictors on a 0 to 4 scale. This level indicates the impact of a particular factor on another. Equation 1 can be used to determine the average matrix Z based on these ratings, which is then given in Table 3.

Table 3. Average matrix Z

	A	B	C	D	E	F	G	H	I	J	K	Sum
A	–	2.7778	3.2778	2.8333	3.3889	3.7778	3.8333	3.6667	3.3333	3.8889	3.9444	34.722
B	3.7778	–	3.6667	2.5556	2.6667	3.1111	3.8333	3.2778	3.1667	3.6667	3.6667	33.389
C	3.7778	2.4444	–	2.2778	2.7222	3.2778	3.5000	3.5556	2.8889	3.5556	3.5000	31.500
D	3.8889	3.8889	3.8333	–	3.1111	3.6111	3.8333	3.3333	3.8333	3.8889	3.9444	37.167
E	3.7778	3.0556	3.8333	2.5556	–	3.5556	3.8333	3.8333	3.1111	3.8333	3.8333	35.222
F	3.9444	3.6111	3.6667	3.0000	3.3333	–	3.7222	3.3889	3.7222	3.8889	3.7222	36.000
G	3.8333	2.8889	3.3333	2.1667	3.2778	3.5000	–	3.6667	3.0000	3.7778	3.7778	33.222
H	3.8889	2.4444	3.6667	2.3333	2.9444	3.7222	3.8889	–	3.1111	3.8889	3.8889	33.778
I	3.1111	3.2778	3.1667	2.7778	3.0000	3.5556	3.6111	3.0556	–	3.3889	3.3333	32.278
J	–	–	–	–	–	–	–	–	–	–	–	–
K	–	–	–	–	–	–	–	–	–	–	–	–
Sum	30.000	24.389	28.444	20.500	24.444	28.111	30.056	27.778	26.167	33.778	33.611	

Step 2: Create and compute normalised initial direct-relation Matrix *D*

Equations 2, 3 and 4 were used to normalise the direct-relation matrix *D* and the results are presented in Table 4.

Table 4. Normalised direct-relation matrix D

	A	B	C	D	E	F	G	H	I	J	K
A	–	0.07474	0.08819	0.07623	0.09118	0.10164	0.10314	0.09865	0.08969	0.10463	0.10613
B	0.10164	–	0.09865	0.06876	0.07175	0.08371	0.10314	0.08819	0.0852	0.09865	0.09865
C	0.10164	0.06577	–	0.06129	0.07324	0.08819	0.09417	0.09567	0.07773	0.09567	0.09417
D	0.10463	0.10463	0.10314	–	0.08371	0.09716	0.10314	0.08969	0.10314	0.10463	0.10613
E	0.10164	0.08221	0.10314	0.06876	–	0.09567	0.10314	0.10314	0.08371	0.10314	0.10314
F	0.10613	0.09716	0.09865	0.08072	0.08969	–	0.10015	0.09118	0.10015	0.10463	0.10015
G	0.10314	0.07773	0.08969	0.0583	0.08819	0.09417	–	0.09865	0.08072	0.10164	0.10164
H	0.10463	0.06577	0.09865	0.06278	0.07922	0.10015	0.10463	–	0.08371	0.10463	0.10463
I	0.08371	0.08819	0.0852	0.07474	0.08072	0.09567	0.09716	0.08221	–	0.09118	0.08969
J	–	–	–	–	–	–	–	–	–	–	–
K	–	–	–	–	–	–	–	–	–	–	–

Step 3: Attain total relation matrix *T*

Equation 5 was used to calculate the total relation matrix *T* from the normalised matrix; the resulting matrix is displayed in Table 5.

Table 5. Total relation matrix T

	A	B	C	D	E	F	G	H	I	J	K
A	0.2329	0.2605	0.3020	0.2344	0.2771	0.3120	0.3265	0.3074	0.2870	0.3609	0.3608
B	0.3178	0.1845	0.3037	0.2228	0.2544	0.2900	0.3192	0.2918	0.2765	0.3472	0.3459
C	0.3053	0.2362	0.2020	0.2076	0.2455	0.2821	0.2992	0.2864	0.2593	0.3308	0.3281
D	0.3467	0.3018	0.3327	0.1772	0.2865	0.3261	0.3457	0.3175	0.3152	0.3818	0.3817
E	0.3300	0.2703	0.3191	0.2313	0.1975	0.3115	0.3313	0.3158	0.2859	0.3648	0.3634
F	0.3403	0.2890	0.3217	0.2465	0.2853	0.2305	0.3356	0.3118	0.3059	0.3735	0.3679
G	0.3164	0.2543	0.2937	0.2120	0.2662	0.2963	0.2230	0.2981	0.2704	0.3471	0.3457
H	0.3202	0.2464	0.3035	0.2177	0.2609	0.3038	0.3202	0.2107	0.2752	0.3526	0.3512
I	0.2994	0.2634	0.2894	0.2257	0.2592	0.2967	0.3108	0.2834	0.1953	0.3366	0.3339
J	–	–	–	–	–	–	–	–	–	–	–
K	–	–	–	–	–	–	–	–	–	–	–

Step 4: Compute the sums of rows and columns of matrix *T*

Equations 6 and 7 were used to compute the total influences acquired and given by every factor, with the results displayed in Table 6.

Table 6. Sum of influence received of predictors

	Predictors	Sum *r*	Sum c	*r* + *c*	*r* – *c*
A	Attitude	3.261552	2.808919	6.070471	0.452634
B	Subjective norm	3.153817	2.306361	5.460178	0.847456
C	Perceived behavioural control	2.982661	2.667662	5.650323	0.314999
D	Types of leadership styles	3.512821	1.975220	5.488041	1.537601
E	Safety knowledge	3.320927	2.332780	5.653707	0.988147
F	Safety climate	3.407802	2.649064	6.056866	0.758738
G	Safety motivation	3.123196	2.811581	5.934777	0.311615
H	Risk perception	3.162449	2.622885	5.785334	0.539564
I	Communication	3.093792	2.470607	5.564399	0.623185
J	Safety compliance intention	–	3.195415	3.195415	–3.195420
K	Safety participation	–	3.178522	3.178522	–3.178520

Step 5: Set a threshold value (α)

The threshold value was chosen to screen out a few inconsequential effects. Equation 8 was used to derive the threshold value, which α = 0.239827.

Step 6: Construct a cause-and-effect relationship diagram

Based on the influence of each dimension on the others, an influence diagram was created. It defined each dimension's role in relation to the others. Figure 2 depicts the diagram. The x-axis shows how much influence a dimension has and the y-axis shows how much influence one cause has on other causes. The direction of the arrows indicates the interaction of various predictors.

According to the $r_i + c_j$ values in Table 6, it shows that the most significant predictor to improve safety performance on construction project sites is "Attitude" with its highest $r_i + c_j$ value of 6.070471, while lowest $r_i + c_j$ value of 5.460178 belongs to the least important predictor which is "Subjective norm" and it is located in the farthest left corner of the diagraph. According to the ascending order of $r_i + c_j$ values displayed in Table 6, the importance of the predictors can be arranged as follows: Attitude > Safety Climate > Safety Motivation > Risk Perception > Safety Knowledge > Perceived Behavioural Control > Communication > Types of Leadership Styles > Subjective Norm.

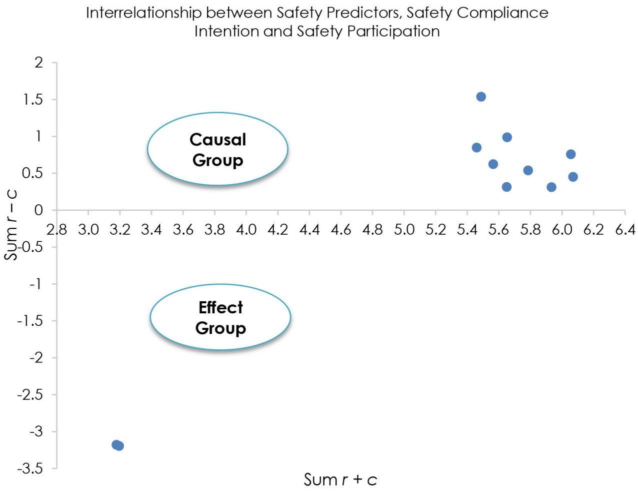

Figure 2. Impact-direction diagram among safety predictors, safety compliance intention and safety participation

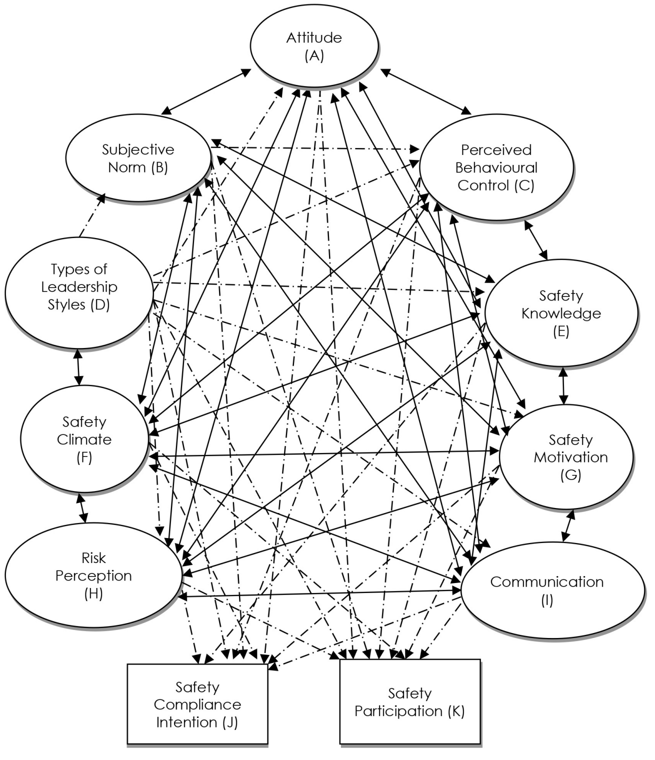

Figure 3. Relationship diagraph among safety predictors, safety compliance intention and safety participation

Based on their positive $r_i - c_j$ values, all safety predictors in this study are categorised within the causal category. It is discovered that "Types of leadership styles", which has the largest $r_i - c_j$ value of 1.537601 when compared to other predictors, has the biggest direct impact on the effect group and has the strongest correlation. Table 6 further demonstrates that, depending on their values exceeding the threshold value, α = 0.239827, every predictor in the causal group interacts with every predictor in the impact group.

The effect group consists of all the "Safety compliance intention" and "Safety participation" as they both have negative $r_i - c_j$ values of –3.19542 and –3.17852, respectively. Based on its lowest $r_i - c_j$ value of –1.259, "Safety compliance intention" is the factor that is most affected by the other components. It can be inferred that all causal group predictors influence all effect group predictors. Table 5 and Figure 2 both depict these interactions.

"Attitude" emerges as the most influential predictor, surpassing other safety predictors, due to its profound impact on shaping individual behaviour in construction settings. The significance of attitudes lies in their ability to reflect individuals' beliefs, values and perceptions regarding safety practices. Unlike subjective norms, which represent perceived social pressure to conform to safety behaviours and perceived behavioural control, which pertains to individuals' perceived ability to enact those behaviours, attitudes encapsulate a broader spectrum of cognitive and affective evaluations towards safety measures.

In construction contexts, attitudes towards safety serve as powerful determinants of behaviour. Workers with positive attitudes towards safety are more likely to voluntarily engage in safe practices, adhere to safety guidelines and proactively identify and mitigate hazards. Conversely, workers with negative attitudes may exhibit non-compliant behaviour, take unnecessary risks, or resist safety protocols, thereby increasing the likelihood of accidents or incidents on construction sites.

Several factors contribute to the superiority of attitudes as a predictor of safety behaviour. Past experiences, organisational culture, peer influences and personal beliefs all shape individuals' attitudes towards safety. Moreover, attitudes are inherently subjective and deeply ingrained, making them resistant to external influences and interventions. As such, addressing and modifying attitudes towards safety requires targeted strategies that go beyond mere provision of information or enforcement of rules.

Understanding why attitudes surpass other predictors impact provides valuable insights for designing effective interventions. By focusing on attitudinal change and fostering a positive safety culture within construction teams, organisations can promote long-term behavioural shifts and improve safety outcomes. Tailored training programmes, leadership initiatives and communication strategies can be developed to target specific attitudes and beliefs that drive safety behaviour, ultimately creating safer work environments and reducing the risk of accidents in construction settings.

CONCLUSIONS

The prior research on safety participation among construction workers has mainly focused on identifying influential variables but often overlooked personal behaviour mechanisms and interdependencies among safety predictors, compliance intention and participation. Consequently, there is a lack of conclusive insights into significant safety predictors for improving performance on construction sites. This study aims to fill these gaps by utilising the DEMATEL method to analyse relationships among safety predictors, compliance intention and participation.

The integration of the TPB and DEMATEL offers a novel perspective on safety predictors and compliance intention in construction. Unlike previous studies, this research explores the complex interactions between predictors and their impact on safety behaviour. Specifically, while previous studies have examined safety predictors in isolation, our study explores the complex interactions between these predictors and how they influence workers' intentions to comply with safety protocols. This holistic approach enhances our understanding of the underlying mechanisms driving safety behaviour in construction settings and provides valuable insights for developing targeted interventions to improve safety performance.

One notable influential safety predictor for safety performance on construction sites is "Attitude" (with the highest $r_i + c_j$ value). Organisations should therefore put more emphasis on this to improve safety performance and lower the likelihood of mishaps or incidents at building sites. The attitude of a worker toward safety determines not only do they act safely in the worksite, but also whether they comply with and accept to formal worksite guidelines and take initiatives when it is necessary to apply informal practices that accomplish the same objective. Each worker has their own beliefs about what causes occupational accidents and what factors are essential in preventing them. These beliefs shape attitudes toward workplace hazard prevention activities and their safety compliance intention and safety participation. Therefore, it is important for the organisations to improve safety communication among construction worker when they are conducting tasks in the project sites.

When $r_i - c_j$ values are positive, it indicates that the degree of influenced impact (c) is less than the degree of influencing impact (r) and it is important to pay attention. This indicates that they are drivers since they have a greater impact on other factors than other factors have on themselves. With the highest $r_i - c_j$ value, "Types of leadership styles" is the most influential predictor driving safety performance.

Depicted in Figure 2, "Types of leadership styles" can influence construction workers' "Attitude", "Subjective norm" and "Perceived behavioural control" while also improving their "Safety knowledge" and "Safety motivation". A good leadership style can influence the overall "Communication" among the teammates and then impact the organisation's "Safety climate". "Risk perception" will also be affected as the leader's safety attitudes will impact the actions of construction workers who take risks.

Construction organisations should adopt effective leadership styles, such as transformational leadership, which empowers and motivates workers to voluntarily engage in safe behaviours on every construction project, to improve safety performance. Safety compliance intention and safety participation can be increased by positively influencing workers' attitudes, leading to accident prevention and reduction. This highlights the significance of leadership styles in cultivating a strong safety culture.

Organisational culture also plays a significant role, shaping attitudes, perceptions and behaviours related to safety. Cultivating a positive safety culture through policies, practices and values alignment is essential for promoting worker safety and well-being. However, implementing safety interventions in real-world construction settings faces challenges such as project complexity and resistance to change. Strategies like comprehensive training and fostering safety awareness are crucial for overcoming these obstacles.

The causal relationship between safety predictors and safety performance offers valuable insights for the development and implementation of effective safety interventions. These findings contribute to the existing body of knowledge by offering a comprehensive understanding of the mechanisms driving safety behaviour in construction settings. However, the use of purposive sampling may introduce sample biases, limiting the generalisability of our findings. Additionally, while the integration of TPB and DEMATEL provides a comprehensive framework for analysing safety behaviour, methodological constraints may impact the accuracy of our results. Future research should consider employing larger, more diverse samples and utilising mixed method approaches to mitigate these limitations. Furthermore, our study focused primarily on individual-level predictors, overlooking potential organisational and environmental factors influencing safety behaviour. Exploring the interaction between these factors and individual attitudes could provide a more holistic understanding of safety compliance in construction settings.

Future research can also broaden the scope by exploring additional safety predictors, investigating the connections between macro and micro safety predictors and examining the impact on construction site safety performance. Identifying potential interventions and enhancing the efficacy of safety practices can be crucial outcomes of such extended research efforts.

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