Project Leadership and Society 5 (2024) 100134

Contents lists available at ScienceDirect

Project Leadership and Society

journal homepage: www.sciencedirect.com/journal/project-leadership-and-society

Empirical Research Paper

How safety value is exchanged in Chinese modern megaprojects: A stakeholder value network perspective

Shuang Dong [a,*], Yan Zhao [a], Heng Li [b], Jiayi Qu [a]

[a] School of Business, East China University of Science and Technology, Shanghai, China
[b] Faculty of Construction and Environment, Hong Kong Polytechnic University, Hung Hum, Kowloon, Hong Kong

ARTICLE INFO

Keywords:
Megaproject
Organizational safety behavior
Stakeholder value network (SVN)
Safety value exchange

ABSTRACT

To visualize and quantify these exchanges among primary stakeholders in megaprojects, this study introduces network stakeholder value network as the core methodology. Starting with a qualitative organizational safety behavior model encompassing 8 stakeholders and 61 value flows, it's built based on 3 organizational safety behavior categories. Moreover, questionnaire data from 356 experts quantifies the model, and the design structure matrix identifies 13845 safety value paths, including 4827 cycles. Analysis delves into critical cycles, stakeholders, flows, and organizational safety behavior types to refine safety strategies. The findings, based on Chinese megaprojects, suggest that contractors and governments must lead safety awareness efforts, with safety compliance paramount for all parties. The study's contributions are threefold: firstly, it broadens the scope to encompass organizational safety behavior; secondly, it introduces a novel approach to visualize and quantify safety value flows; and thirdly, it considers multiple types of value exchanges, underscores their significance in promoting safety value, and offers practical recommendations to strengthen construction safety performance.

1. Introduction

Megaprojects refer to transformative projects that involve massive investments, long durations, high level of complexity, and significant impacts on society, economy and environment (Flyvbjerg, 2014; Brookes and Locatelli, 2015). In the construction industry, megaprojects typically encompass large-scale infrastructure projects initiated by the government (Qiu et al., 2019), such as the Hong Kong-Zhuhai-Macao Bridge, Beijing Daxing International Airport, Hangzhou Bay Sea-Crossing Bridge, etc. Due to the distinctive characteristics, such as congested workspaces, working at heights and multi-level subcontracting (Ajayi et al., 2021; Manu et al., 2010), the construction sector has faced numerous accidents and been criticized for its high rates of safety incidents and casualties (He et al., 2016), resulting in adverse consequences for both individuals and organizations. Consequently, as the crucial part of project management, safety management has become a prominent concern in construction megaprojects. It has been shown that projects would perform better when organizations have a good safety management philosophy, such as implementing safety management system (SMS) and structuring a psychological safety climate (Yiu et al., 2019; Feng et al., 2014; Choudhry et al., 2008). Currently, the researches on safety management in the construction projects primarily focused on the individual worker behavior and organizational safety performance.

The unsafe behavior of construction workers is considered as the primary and immediate cause of safety incidents (Heinrich, 1941; Fang et al., 2016), and rectifying such behavior can help prevent accidents and enhance safety performance (Chen and Tian, 2012), particularly when the underlying factors have not been identified or eliminated. To obtain a comprehensive understanding of the causes of safety incidents and effectively address safety concerns, increasing attention has been devoted to examining the organizational mechanism underlying human errors, including safety climate, organizational safety behavior, prosociality, leader-member interaction, etc. (Neal and Griffin, 2006; Cui et al., 2013; Liu et al., 2020; Meng et al., 2021). Organizational safety behavior refers to safety behavior measures and practices adopted by organizations with the primary objective of enhancing the safety performance of their projects (Griffin and Neal, 2000; Burke et al., 2002; Meng et al., 2021). The interaction of organizational safety behavior among various stakeholders can be instrumental in fostering a positive safety climate within organizations, which would further enhance safety performance by promoting individual safety behaviors (Wang et al.,

* Corresponding author. School of Business, East China University of Science and Technology, No. 130 Meilong Road, Xuhui District, Shanghai, 200237, China.
E-mail address: rosine.dong@connect.polyu.hk (S. Dong).

https://doi.org/10.1016/j.plas.2024.100134
Received 27 December 2023; Received in revised form 22 May 2024; Accepted 2 June 2024
Available online 4 June 2024

2018).

China leads the world in large-scale infrastructure investment (Zhou et al., 2021). With the implementation of the "Belt and Road" project initiated by the Chinese government, a large number of transportation infrastructure projects have been proposed, planned and constructed in China (Luo et al., 2022). Compared with general projects, megaprojects have a greater social and economic impact, the characteristics of large scale, complex technology and far-reaching significance. This has led to a more complex network of Chinese megaprojects with more participants. The safety management experience of Chinese megaprojects will have universal reference significance for more general projects. Moreover, megaprojects are characterized by intricate challenges (Daniel and Daniel, 2019) and given the constraints on resources and the limitations of individual stakeholders, achieving a safe production goal demands collective efforts from all stakeholders involved in the project (Son and Rojas, 2011). Therefore, under the background of rapid urbanization in China, it is necessary to deeply study the organizational safety behaviors of different stakeholders in megaprojects and the safety value generated by their collaborative efforts.

Previous research has primarily focused on studying the safety behavior of one specific stakeholder, such as owners (Wu et al., 2015; Ma et al., 2020), or examining the role of a single type of organizational safety behavior in safety management, for instance, safety compliance behavior (Weichbrodt, 2015). However, these studies have ignored the interactions between different types of organizational safety behaviors involving multiple stakeholders in megaprojects. Owing to the complicated stakeholders' relationship and interactive process in megaprojects (Wang et al., 2021), it's crucial to explore the intricate interactions of different stakeholders from a perspective of network. Despite an increasing number of research utilizing social network analysis (SNA) to study interactions and value transition among multiple stakeholders, extending from a single individual stakeholder to a comprehensive network comprising various stakeholders in megaprojects (Zheng et al., 2016), current research can only take a particular sort of behavior into account within a network (Wang et al., 2020), making it difficult to capture an integrated view on the interaction of multiple behaviors and the generated value exchanges among different stakeholders. Moreover, contemporary studies primarily highlight direct behavioral interactions between dyadic stakeholders. However, multi-lateral and indirect value exchanges among multiple stakeholders widely exist in modern megaprojects. To have a thorough comprehension of the safety value exchange mechanism, it's imperative to adopt a novel qualitative and quantitative approach to develop a comprehensive network, which consists of both direct safety value exchanges and indirect value delivery paths of multiple behaviors.

In order to address these gaps of the above existing research, we adopt a multi-disciplinary approach in this study to explore and illustrate the safety value exchange mechanism within megaprojects. This is achieved using stakeholder value network (SVN) analysis, which has been previously employed to examine, comprehend, model, and manage diverse stakeholder behaviors (Zheng et al., 2019, 2021). By considering the implementation of organizational safety behavior as the multi-relational interconnections among stakeholders within megaprojects, an organizational safety behavior SVN (OSB-SVN) is developed, with the aim of unravelling the intricate value flows and driving paths associated with the implementation of organizational safety behavior among stakeholders. The findings of OSB-SVN hold promise in facilitating futural implementations and advancements in organizational safety behavior, ultimately enhancing safety performance of megaprojects.

The research contains three objectives: (a) to develop a qualitative and quantitative OSB-SVN model in which the inter-organizational connections and safety value exchanges within construction megaprojects are considered; (b) to identify critical stakeholders, safety value flows and value cycles that are critical for the implementation of organizational safety behavior based on the proposed OSB-SVN model; (c) to provide practical and effective value-based strategies for stakeholders in megaprojects to improve safety performance from an organizational safety behavior perspective.

The paper is structured as follows. The next section comprises a literature review on organizational safety behavior and SVN. The research methodology and methods utilized in OSB-SVN analysis are introduced in Section 3. Section 4 is focused on the analysis results and findings of the OSB-SVN model, including both qualitative and quantitative analysis. Section 5 proposes safety value enhancement strategies for stakeholders based on the results of OSB-SVN model. Finally, the last section wraps up the study by summarizing the main findings, contributions, implications, and limitations. It also outlines future research directions.

2. Literature review

The literature reviewed in this section includes two aspects. The first section encompasses background factors, influencing mechanisms and improvement strategies of safety behavior of large project organizations, thus summarizing the deficiency of research on the safety value generated by the interaction between stakeholders in safety behavior of organizations. The second section summarizes the advantages of SVN analysis over other methods to analyze stakeholders' safety value delivery and exchange mechanisms, combining the characteristics of megaprojects.

2.1. Organizational safety behavior

The mainstream approach to construction safety management has long been based on the human error identification and prevention (Choudhry and Fang, 2008; Mohajeri et al., 2021). However, the effectiveness of this approach is far from satisfaction. Instead, research has found that organizationally interactive and collaborative behaviors are significantly more effective in improving safety performance (Koh and Rowlinson, 2012; Wu et al., 2016). Therefore, an increasing number of scholars have turned their attention to organizational safety behavior. Based on various theories, previous research has examined the contextual elements, influencing mechanisms and improvement strategies of organizational safety behavior in megaprojects from different perspectives.

Concerning the identification and classification of safety behaviors, previous studies have elaborated on their specific manifestations and characteristics from various contexts and perspectives (see Table 1). For instance, in terms of the degree of voluntary, safety behaviors were classified into safety compliance behavior and safety participation behavior. The safety compliance behavior, which was required, involves adherence to safety instructions and procedures, etc. While the safety participation behavior, which was volunteered, involves helping coworkers and participating in safety meetings, etc. (Kalteh et al., 2021). This classification standard is highly acknowledged in construction safety research (Xia et al., 2020). To emphasize the interaction between workers, Dong et al. (2015) further classified safety participation behavior into interactive safety behavior and structural safety behavior. However, the identification and classification of organizational safety behavior remain disorganized and fragmented. Compliance to safety rules was considered as the most basic organizational safety behavior in construction projects (Weichbrodt, 2015). Apart from it, other types of organizational safety behaviors have also been identified. For example, organizational safety behaviors of participants could be reflected from three dimensions, which were safety commitment and participation, feasibility of safety rules and perception of safety responsibilities, respectively (Fang and Wu, 2013; Hannevik et al., 2014; Jitwasinkul et al., 2016). As to inter-organizational safety behavior, organizational citizenship behavior was proved to be beneficial to safety performance (Liu et al., 2020; Yang et al., 2020).

Based on previous review and according to the extent of voluntary

Table 1
Identification and classification of safety behaviors.

Classification of safety behaviors	Fang and Wu (2013)	Hannevik et al. (2014)	Dong et al. (2015)	Jitwasinkul et al. (2016)	Kalteh et al. (2021)
(1)In terms of the degree of voluntary: safety compliance behavior and safety participation behavior					✔
(2)In terms of the interaction between workers: interactive safety behavior and structural safety behavior			✔		
(3)Safety commitment and participation, feasibility of safety rules and perception of safety responsibilities	✔	✔		✔	

and inter-organizational interaction, it's proposed to classify organizational safety behavior into three types: normative, interactive, and participative. Normative organizational safety behavior refers to the safety practices that are clearly defined in laws and regulations and that project stakeholders are legally required to implement unilaterally. Interactive organizational safety behavior is also guided by laws, regulations or industry standards, but it involves an interactive process in various stakeholders. Participative organizational safety behavior refers to voluntary safety actions taken spontaneously by stakeholders and have a positive impact on safety performance.

To gain a deeper understanding of construction organizational safety behavior, several scholars have explored the influencing factors and driving paths of organizational safety behavior utilizing organizational behavior theory, institutional theory and social psychology theory as frameworks. It has been established that organizational, institutional and psychological factors such as spiritual leadership, institutional pressures and psychology contracts significantly impact both organizational safety behavior and safety performance (He et al., 2016; Newaz et al., 2019; Ali et al., 2020; Ali et al., 2021). Furthermore, Lu et al. (2020) identified the relationship between management practices and organizational safety behavior, demonstrating that effective management practices could affect organizational safety behavior, which also shed lights on the improvement of safety performance.

The enhancement of construction organizational safety behavior has always been an issue of utmost importance. In general, the related research tends to focus on either the improvement of the safety behavior itself or on the modification of the external environment, corresponding to active and inactive safety management strategy, respectively.

The active safety management strategy advocates the proactive correction or elimination of unsafe behavior within the organization. It emphasizes that when negative safety factors that influence safety behavior in the long run have not been improved or eliminated, the identification and correction of unsafe behaviors itself is the optimal choice (Chen and Tian, 2012; Li et al., 2015; Zhang et al., 2017). Different from active safety management strategy, the inactive safety management strategy focuses on the contextual elements of safety behavior and emphasizes the improvement of organizational and environmental factors. It advocates taking non-mandatory measures to eliminate unsafe behavior fundamentally, for example, fostering a better safety culture (Nævestad et al., 2021), establishing a healthy safety climate (Kim et al., 2019; Cheung and Zhang, 2020) and building positive inter-organizational relationships (Kalkman and Dewaard, 2017; Wang et al., 2021). Furthermore, numerous scholars have reported that establishing and maintaining collaborative and reciprocal relationships among stakeholders is highly effective in promoting organizational safety behavior (Beringer et al., 2013; Xia et al., 2018; Ruijter et al., 2021).

Consequently, current research on organizational safety behavior primarily focuses on three dimensions: (1) analyzing and identifying the contextual elements and categories of organizational safety behavior; (2) exploring the influencing factors and driving paths of organizational safety behavior through the invocation of various theories; (3) providing the improvement strategies for organizational safety behavior from the perspective of stakeholder and relationship governance. However, there is limited research on the safety value generated from interactions among stakeholders in terms of organizational safety behavior, particularly from a perspective of the network, thus failing to enhance the systematic safety value of the entire megaproject.

2.2. Stakeholder value network

The SVN analysis approach, firstly proposed by Cameron in 2007, is a multidisciplinary network analysis method designed to analyze stakeholders' value delivery and transaction mechanism (Cameron, 2007). Built upon social exchange theory, SVN offers a qualitative and quantitative analysis of diverse interactions among multiple stakeholders, encompassing social, economic, tangible, and intangible aspects, as well as direct and indirect connections within a unified network framework. In SVN, various stakeholder interactions concentrating on a particular issue are represented by value flows. Stakeholders and value flows, shown as nodes and links respectively, are the two basic elements of SVN model (see Table 2). A sequence of value flows can form value paths or value cycles, which are crucial for further analysis of the network.

Compared to traditional network analysis methods which can only involve one type of behavior in a network, SVN has the advantage of integrating multiple types of value exchanges among multiple stakeholders in a unified framework through subjective utility analysis. Furthermore, SVN has overcome the limitation of SNA which solely studies the influence of network structure on stakeholders' behavior, capable of capturing the impact from both value exchanges and network structure (Feng, 2013). Moreover, by adopting a system modeling approach, specifically design structure matrix (DSM) (Zheng et al., 2021; Yang et al., 2014), and the propagation rule, SVN allows researchers to identify the critical stakeholders, value flows and value paths, which are crucial for understanding on how value is created, delivered and exchanged within the substantial and complicated

Table 2
Elements of SVN model.

Element	Legend	Definition
Stakeholder/ Node	$a, b, \cdots, n$	Organizations that are involved in safety value exchange process directly or indirectly (including internal stakeholders and external stakeholders).
Value	$\Delta_1, \Delta_2, \cdots, \Delta_i$	Organizational safety behavior that is conducted by one stakeholder and meet needs of other stakeholders.
Value flow/ Link	$a \overset{\Delta_1}{\to} b$	The interactions between two stakeholders, through which the specific safety value Δ_1 is delivered from stakeholder (a) to stakeholder (b).
Value path	$a \overset{\Delta_1}{\to} b \to \cdots \overset{\Delta_i}{\to} n$	A string of value flows connecting a group of stakeholders via safety value delivery among them, and the stakeholder n is not stakeholder a (n ≠ a).
Value cycle	$a \overset{\Delta_1}{\to} b \to \cdots \overset{\Delta_i}{\to} a$	Special value path beginning from and ending with the same stakeholder.

stakeholder network (Feng, 2013). Due to its prominent advantages, SVN has been widely applied across diverse fields, including space exploration (Cameron et al., 2011; Sutherland et al., 2012), energy conservation (Fu et al., 2011), public transportation (Pereira et al., 2018), and construction megaprojects (Zheng et al., 2019, 2021). This allows for the identification of specific needs and objectives of stakeholders, as well as the examination of their interrelations, so as to formulate effective strategies for stakeholders to maximize the potential value of the entire network.

Megaprojects have been recognized as a process for collaborative creation of value among various organizations through their temporary cooperation and collaboration (Lehtinen et al., 2019). Thus, the organizational safety interactions among stakeholders can be viewed as the process of safety value cocreation. Therefore, SVN is well suitable for the exploration and analysis of stakeholders' safety value delivery and exchange mechanisms within the megaproject settings. Furthermore, SVN can generate value-based strategies for stakeholders to enhance safety value of the stakeholder network from a holistic perspective.

3. Material and methods

Since megaprojects in China have only flourished in recent decades, there are more modern projects for study. Meanwhile, data on earlier megaprojects are difficult to obtain due to technological limits. In this study, Chinese modern construction megaprojects are used as the research sample to unveil the complicated safety behavior interactions among multiple stakeholders. Considering its applicability and adaptability, SVN is chosen as the primary research method. To clarify the mechanisms of safety value creation and delivery in megaprojects, the proposed OSB-SVN model is introduced, comprising four critical steps (Fu et al., 2011; Feng, 2013), as depicted in Fig. 1. Details of each step are further explained on in the subsequent sub-sections.

3.1. Mapping the qualitative OSB-SVN model

The stakeholder and the safety value flow are the two fundamental components of the OSB-SVN model. Therefore, it's crucial to identify the stakeholders involved in megaprojects and safety value flows between the identified stakeholders at the onset.

The first step is the identification of stakeholders, which restricts the boundary and defines scope of the network analysis. Two types of stakeholders were considered in this study: internal stakeholders who have a direct or indirect contractual relationship with the project, and external stakeholders who are affected by the execution of megaprojects and sometimes may affect its progress (Feng, 2013; Olander, S., 2007). The final list of stakeholders was completed through literature review and semi-structure interview with seven experts possessing megaprojects safety management experiences.

The adjacent step is to identify safety value flows between each pair of the identified stakeholders. Safety value flows refer to the desirable organizational safety outcomes created by a specific stakeholder and received by another. To systematically identify these safety value flows from the massive and complex organizational safety interactions between stakeholders, the approach of stakeholder characterization template (SCT) proposed by Sutherland was adopted (Sutherland, 2009). The SCT allows us to concisely and accurately articulate the roles, objectives, specific needs of each stakeholder. Furthermore, it indicates inputs received by each stakeholder from others, which fulfill their specific needs, and all these inputs constitute exactly value flows. The adoption of SCT can not only make the value creation and delivery process traceable, but also ensure that the model captures all essential value flows indispensable to fulfill each stakeholder's needs. Content analysis was adopted to identify the detailed roles, objectives, specific needs of stakeholders. The essence of content analysis is the analysis of the amount of information contained in the content of communication and its exchanges. After collecting the data, the analysis dimension is designed, the data are preprocessed and analyzed by coding, and finally semantic analysis is carried out. The accurate meaning is inferred from the represented meaningful words and sentences. Accuracy and reliability of the identification of stakeholders and value flows were supported and supplemented by conducting semi-structure interviews.

Once the stakeholders involved in megaprojects and all the value flows between them are identified, the qualitative OSB-SVN model can be mapped.

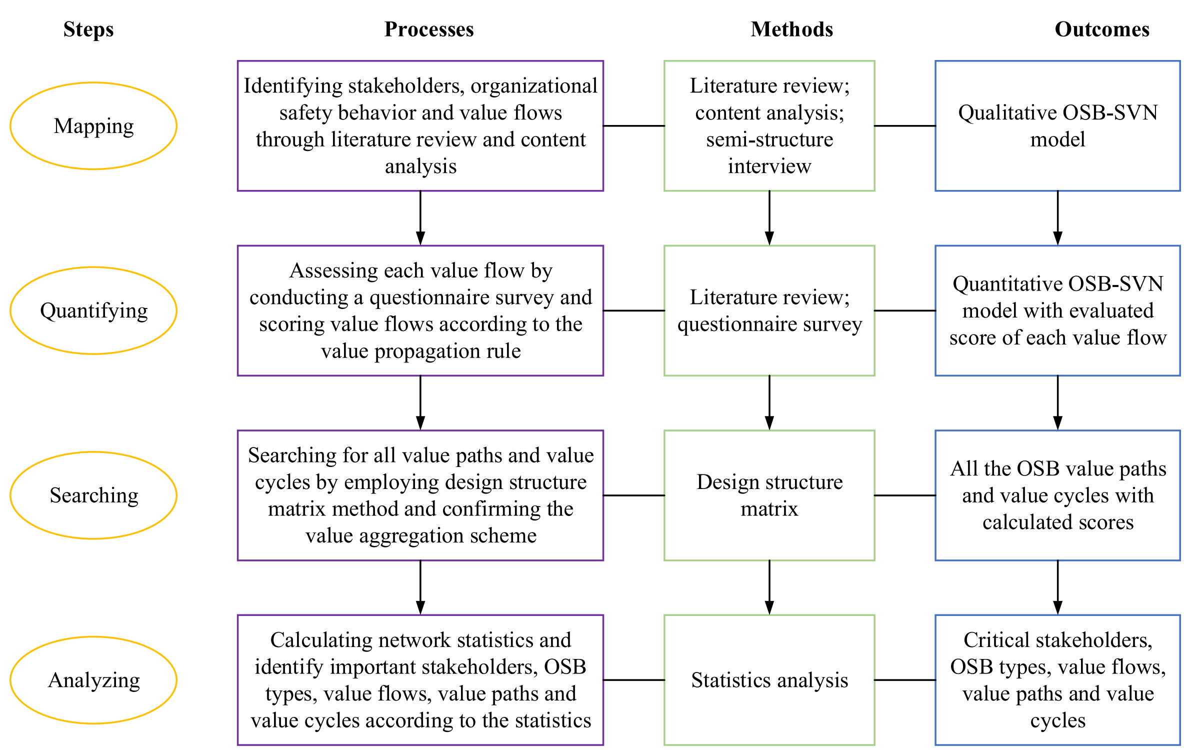

Fig. 1. The OSB-SVN modeling framework.

3.2. Quantifying the OSB-SVN model

3.2.1. Questionnaire design

The questionnaire is designed to quantify the network by assessing attributes of every value flow. According to the summarization of Sutherland (2009), there are five key attributes of value flows: "need intensity of the resource", "source importance in fulfilling a need", "competition in fulfilling a need", "urgency in fulfilling a need", and "awareness of a need". However, it's not necessary to include all the five attributes in practice. Based on previous research (Cameron 2007; Sutherland, 2009), two or three attributes are sufficient to evaluate value flows in the network.

Each value flow received by a stakeholder comprises two fundamental elements: the value delivered by the value flow and the stakeholder who creates and outputs the value. To evaluate value flows from the two dimensions, in this study, "need intensity of the resource" and "source importance in fulfilling a need" are selected as the two attributes of value flows. Specifically, "need intensity of the resource" reflects the stakeholder's satisfaction in receiving the value flow, which indicates the significance of the safety value it delivers. Conversely, "source importance in fulfilling a need" characterizes the significance of a particular stakeholder in fulfilling a specific need, namely the importance of the stakeholder that outputs the safety value.

Once the two attributes of value flows have been determined, the questionnaire can be constructed. The questionnaire contains two sections. The first section is dedicated to collecting the demographic information of participants, while the second section aims to assess the two attributes mentioned above (as detailed in Table 3). Since each stakeholder is associated with distinct value flows, 8 kinds of distinct questionnaire are designed, each for one stakeholder. Participants involved in the questionnaire survey are all managers with certain years of work experience on megaprojects. They are required to score the two attributes listed in Table 3 using Likert's five-point scale, ranging from 1 (not important) to 5 (extremely important).

Table 3
Questionnaire on the two attributes of value flow's utility.

a. need intensity of the resource (importance of the safety value delivered by the value flow)		
Q: How would you characterize the presence or absence of the safety value delivered by the value flow?		
Satisfaction scale	Description	Numerical value
a	Its presence satisfies me, but I would not regret its absence.	0.11
b	Its presence satisfies me, and I would somewhat regret its absence.	0.19
c	Its presence satisfies me, and I would regret its absence.	0.32
d	Its presence is necessary, and I would regret its absence.	0.54
e	Its presence is absolutely essential, and I would regret its absence.	0.99
b. source importance in fulfilling a need (importance of the stakeholder output the value flow)		
Q: If the safety value is essential, how important would this specific stakeholder be in delivering the value?		
Importance scale	Description	Numerical value
A	Not important – I do not need this stakeholder to provide the safety value.	0.11
B	Somewhat important – It is acceptable that this stakeholder provides the safety value.	0.33
C	Important – It is desirable that this stakeholder provides the safety value.	0.55
D	Very important – It is highly desirable that this stakeholder provides the safety value.	0.77
E	Extremely important – It is irreplaceable that this stakeholder provides the safety value.	0.99

Note: $U_s = 0.11 \times n, n = 1,3,5,7,9$.
Note: $U_v = 0.11 \times 1.7^m, m = 0,1,2,3,4$.

3.2.2. Utility calculation rule

The utility score for each safety value flow (U_f) refers to the multiplicative result of two attributes: the importance of the safety value the value flow delivers (U_v) and the importance of the stakeholder that outputs the value flow (U_s). Using the multiplicative combination rule, which is consistent with the traditional settings in the utility theory, all value flow scores are confined within the range of [0,1]. The detailed calculation rules are shown as follows.

$$U_v = 0.11 \times 1.7^m, m = 0,1,2,3,4 \tag{1}$$

$$U_s = 0.11 \times n, n = 1,3,5,7,9 \tag{2}$$

$$U_f = U_v \times U_s \tag{3}$$

The U_v is exponentially discounted, while the U_s is linearly calculated, which ensures that the critical value flows score significantly higher than those that are important but not essential. According to the research of Sutherland (2009), the score of value path is the multiplicative result of the score of each value flow in the path, and that is the reason why the maximal score of each attribute is set as 0.99 rather than 1.0. Assuming that the maximal score of the two attributes is 1.0, then value paths containing different numbers of stakeholders and value flows, each value flow with a score of 1.0, will get the same score, 1.0, which contradicts the reality, because delivering safety value through a chain of five stakeholders is typically harder than delivering that through a chain of three stakeholders. Moreover, the minimal score of each attribute is set as 0.11, based on the lowest response score used by Cameron in 2007. Each successive response is a factor of approximately 1.7 higher than the next-lowest response. Ultimately, the score of each attribute is kept within the range of [0.11, 0.99]. Table 4 presents the determination of value flow scores based on the two attributes.

3.3. Searching for value paths

Value path refers to a sequence of value flows connecting various stakeholders. These flows can be categorized as either value cycles, which originate and terminate with the same stakeholder, or value chains, which originate and terminate with different stakeholders. In this study, Design Structure Matrix (DSM) is adopted to identify these value paths. Following the scoring of value flows and the identification of value paths, the next step in quantifying the OSB-SVN model involves calculating scores of all value paths. As mentioned before, the value path score equals the pro duct of all value flow scores along the path (see Eqs. (4) and (5) below).

$$\text{Value chain}: U_p = \prod_{n=1}^{x} U_{f(n)}, 2 \le x \le m-1, x \in Z \tag{4}$$

Table 4
Determination of value flow scores based on the two attributes.

			Uv				
			$m = 0$	$m = 1$	$m = 2$	$m = 3$	$m = 4$
			0.11	0.19	0.32	0.54	0.99
U_s	$n = 1$	0.11	0.01	0.02	0.04	0.06	0.11
	$n = 3$	0.33	0.04	0.06	0.11	0.18	0.33
	$n = 5$	0.55	0.06	0.10	0.18	0.30	0.54
	$n = 7$	0.77	0.08	0.15	0.25	0.42	0.76
	$n = 9$	0.99	0.11	0.19	0.32	0.53	0.98

$$\text{Value cycle}: U_p = \prod_{n=1}^{x} U_{f(n)}, 2 \le x \le m, x \in Z \tag{5}$$

where p represents a certain value path, U_p represents the score of the value path p, $U_{f(n)}$ denotes the score of the nth value flow in the value path, x denotes the number of stakeholders in the value path and m represents the number of all stakeholders involved in the SVN model.

There are several advantages of using the multiplicative propagation rule for calculating value path scores Firstly, similar to the calculation of value flow scores, the multiplicative rule ensures that value path scores remain confined within the range of [0,1], which conforms to the utility theory. Secondly, under the multiplicative function, the score of the value path is inversely correlated to its length, reflecting the fact that as the path length increases, it becomes more challenging to engage and manage stakeholders and exchange safety value between them. Finally, the multiplicative rule aids in simplifying the calculation of value path scores.

3.4. Analyzing the OSB-SVN model

3.4.1. Analysis method of value paths

After all the value paths have been identified and their scores have been calculated, the relative importance of each path can be ranked, and high-scoring value paths will be obtained. The analysis of the formation of high-scoring value paths and their commonalities will give enlightenments to the value enhancement of the entire network.

3.4.2. Analysis method of stakeholders

The Weighted Stakeholder Occurrence (WSO) is utilized to measure the importance of each stakeholder by calculating the weighted occurrence of the stakeholder in all the value paths for the focal organization (see Eq. (6)). It can identify the most critical stakeholder in the value network. The higher the WSO, the more important the stakeholder are, and the greater value they contribute to the network.

$$WSO_s = \frac{\sum U_{ps}}{\sum U_p} \tag{6}$$

where s represents a specific stakeholder, $\sum U_{ps}$ denotes score sum of value paths containing a specific stakeholder, and $\sum U_p$ refers to score sum of all the value paths for the focal organization.

3.4.3. Analysis method of value flows

The Weighted Value Flow Occurrence (WVFO) is employed to measure relative importance of value flow through counting the weighted occurrence of the value flow in all value paths for the focal organization (see Eq. (7)). A value flow with a higher WVFO score will have more resource significance and structural edges in the network.

$$WVFO_f = \frac{\sum U_{pf}}{\sum\left(\sum U_{pf}\right)} \tag{7}$$

where f represents a specific value flow and $\sum U_{pf}$ denotes score sum of value paths containing a specific value flow.

3.4.4. Analysis method of stakeholder's value flows

The Weighted Output Occurrence (WOO) is used to measure the importance of a specific value flow output generated by a specific stakeholder. This is achieved by calculating the weighted occurrence of the specific stakeholder's output in all the value paths for the focal organization (see Eq. (8)). A higher WOO score indicates a more effective and valuable input to the value network. Therefore, WOO scores can serve as a foundation for determining the allocation order of resources when additional resources become available to the project's value network.

$$WOO_o = \frac{\sum U_{po}}{\sum U_p} \tag{8}$$

where o represents a specific output, $\sum U_{po}$ denotes score sum of value paths which contain a specific output, and $\sum U_p$ denotes score sum of all the value paths for the focal organization.

4. Results

4.1. Qualitative OSB-SVN model

Totally, 8 stakeholders are identified through interviews in this study, which are the government (G), the owner (O), the contractor (C), the investigator (I), the designer (D), the project supervisor (PS), the supplier (S), and the public (P). Their roles they play in megaproject are depicted in Table 5. The core of the megaproject is the owner, which is usually a special purpose vehicle organized by the government (Hu et al., 2015). The owner has contractual relationships with other internal organizations engaged in the megaproject, including the contractor, the investigator, the designer, the project supervisor, and suppliers. The public does not participate actively in the megaproject but will be affected by its implementation and is a key external stakeholder.

Subsequently, safety value flows were identified utilizing SCT approach. Taking the owner as an example, its stakeholder characterization template is shown in Fig. 2. Overall, 61 value flows in the whole value network have been presented and can be classified into three categories, namely normative safety behavior, interactive safety behavior and participative safety behavior.

Once the stakeholders and their corresponding value flows in megaprojects have been identified, the qualitative OSB-SVN model can be obtained. As depicted in Fig. 3, a total of 8 stakeholders and 61 value flows were ultimately determined.

4.2. Quantitative analysis of the OSB-SVN model

Research data were collected through questionnaire. The questionnaire obtained 356 valid responses, both online and field, covering all types of stakeholders, all from megaprojects. Table 6 shows value flow scores calculated from the questionnaire statistics. Based on the data collected, the OSB-SVN model can be quantified.

4.2.1. Analysis of value paths

In the OSB-SVN model, value paths serve as the foundation and focus of quantitative analysis. Table 7 details the count of value paths between

Table 5
Roles of stakeholders.

Stakeholder	Role
Government	The government is responsible for the decision-making and the supervision during the megaproject's entire life cycle construction process.
Owner	The owner is fully responsible for the construction management and the organization of stakeholders in megaprojects.
Contractor	The contractor has overall control over the schedule, quality, cost and safety of megaprojects.
Investigator	The investigator is responsible for providing detailed field data.
Designer	The designer shall provide construction drawings and the corresponding specifications and instructions based on the investigation data.
Project Supervisor	The project supervisor conducts on-site supervision of construction activities on behalf of the owner to help promote the project performance.
Supplier	The supplier is responsible for providing qualified construction materials and equipment to the contractor.
Public	The public has the right to report construction activities that infringe on their own rights and interests during the construction of the project.

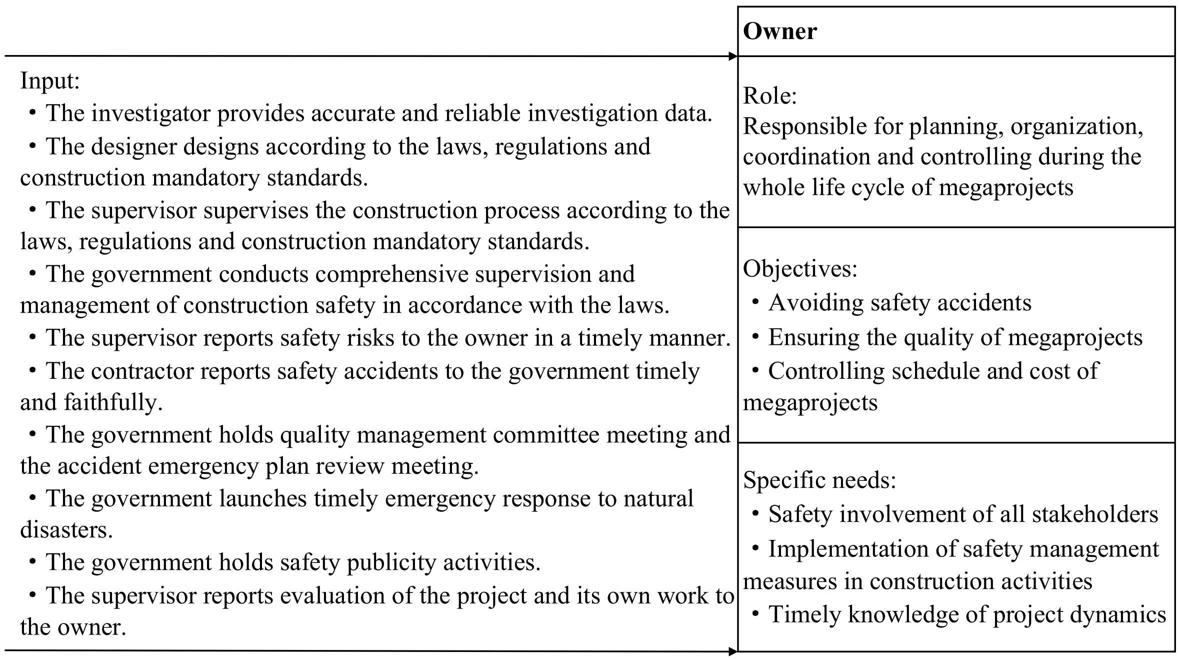

Fig. 2. The stakeholder characterization template of the owner.

stakeholders. The numbers on the diagonal of the matrix represents the numbers of value cycles. In the whole network, a total of 13845 value paths have been identified, in which there are 4827 value cycles, accounting for 34.9%, while others are value chains, accounting for 65.1%. Due to the unidirectional delivery mechanism of value chains, stakeholders in the downstream of value chains have no reverse restraint on their upstream stakeholders, making it difficult to enhance the value of value chains. Therefore, enhancing the safety value of value cycles is the focus of this study.

Among all the eight stakeholders, the government holds the highest number of value cycles at 1128. The following is the contractor, with 1110 value cycles. The owner takes the third spot, with 1062 value cycles. The ranking indicates that the government, contractor and owner are all core stakeholders in the study of organizational safety behaviors in megaprojects.

Table 8 presents the top-scoring value cycles of each focal stakeholder (listed in the row) while also involving certain other stakeholder (listed in the column). The highest-scoring value cycle for each focal stakeholder is highlighted in bold and underlined in each row. During the ranking process, only the 774 value cycles scoring greater than 0.1 were taken into consideration.

As being derived from the calculation rule of value path scores, generally, the less stakeholders the value path contains, the higher score it will get. Among the value cycles of the contractor, C→C, the highest scoring cycle is the one containing the owner, C→O06→O→C01→C, with a score of 0.72, which can also be written as O→C01→C→O06→O. It denotes that the contractor reports safety accidents to the owner timely and faithfully (O06), while the owner doesn't raise requirements violating laws and regulations to the contractor (C01). To achieve this, the two organizations are required to fully trust each other and provide timely feedback to each other.

4.2.2. Analysis of stakeholders

The importance of stakeholders in the OSB-SVN model is measured by WSO. When the contractor is taken as the focal organization, according to the definition of WSO, the WSO score of the contractor itself is 1, while other stakeholders will get different WSO scores.

As is demonstrated in Fig. 4, apart from the contractor itself, the government get the highest WSO score (0.941), followed by the owner (0.868). The rank of WSO scores of stakeholders further confirms that the government, owner and contractor are core organizations in megaprojects. The safety attitude and behavior of the contractor have the most direct impact on the construction safety performance. From the perspective of organization, the contractor's attitude towards safety management, the safety behavior it adopts, and the safety climate it creates will fundamentally influence construction safety. From the perspective of individual, the safety behavior of construction workers will directly contribute to preventing safety accidents. Furthermore, the ranking shows that the government has a high level of involvement in megaprojects, even higher than that of the owner. This suggests that the construction safety management in China mainly relies on the coercive measures taken by the government, while the autonomous safety awareness of the owner and the contractor still needs to be improved.

4.2.3. Analysis of value flows

The key value flows have a significant impact on the value delivery in the stakeholder value network. WVFO scores are used to measure the importance of value flows. Fig. 5 shows the top 20 most significant value flows. As can be seen from Fig. 5, there are 6 value flows scoring higher than 0.03, which are the public reporting construction behaviors destroying the environment to the government (G07, with a utility score of 0.751 and WVFO score of 0.071), the contractor reporting safety accidents to the government timely and faithfully (G04, with a utility score of 0.840 and WVFO score of 0.064), the contractor registering with the government within 30 days from the date of acceptance of the construction hoisting machinery, integral lifting scaffolding and formwork and other jack-up erection facilities (G05, with a utility score of 0.811 and WVFO score of 0.062), the contractor reporting safety accidents to the owner timely and faithfully (O06, with a utility score of 0.850 and WVFO score of 0.046), the supervisor participating in quality management conferences organized by the government (PS02, with a utility score of 0.715 and WVFO score of 0.042), and the designer designing according to the laws, regulations and construction mandatory standards (O02, with a utility score of 0.901 and WVFO score of 0.035). In addition to the utility of value flows, which represents their own the importance, another common reason why these value flows get high WVFO scores is that they occupy critical structural positions in the network and are indispensable to form value cycles. For example,

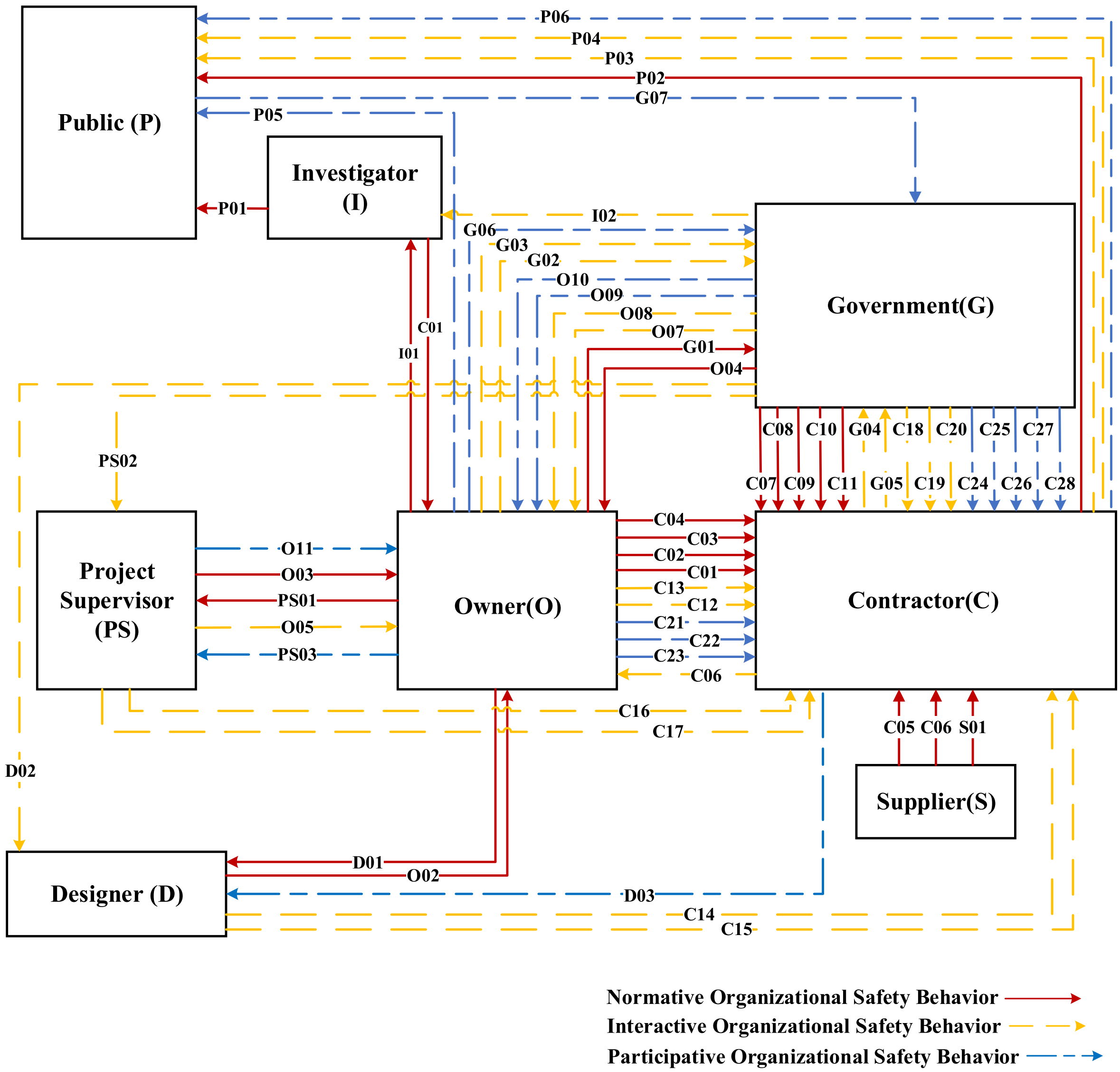

Fig. 3. The qualitative OSB-SVN model containing 8 stakeholders and 61 value flows.

though the utility score of G07 is the second lowest among value flows mentioned above, it is the only value flow output by the public, earning it the highest WVFO score. Hence, to augment the whole value of OSB-SVN, it's necessary to identify organizational safety behaviors constantly, improve the structure of the network, and achieve a more balanced distribution of WVFO scores.

4.2.4. Analysis of stakeholder's value flows

The most significant value flows output by key stakeholders hold the greatest potential for creating safety value within the stakeholder network. WOO is used to measure the importance of value flows output by certain stakeholders. Fig. 6 displays the WOO scores of the contractor outputs. As can be seen in Fig. 6, among all the 9 value flows output by the contractor, three of them score higher than 0.1, which are the contractor reporting safety accidents to the government timely and faithfully (G04), the contractor registering with the government within 30 days from the date of acceptance of the construction hoisting machinery, integral lifting scaffolding and formwork and other jack-up erection facilities (G05) and the contractor reporting safety accidents to the owner timely and faithfully (O06), respectively. Although G04 and O06 are the only two safety behaviors taking place after the occurrence of safety accident, they are both high-scoring contractor outputs, which reveals that safety management in China mainly relies on the passive handling of safety accidents rather than active prevention measures. Like key value flows with high WVFO scores, occupying critical structural positions in the network is also one of the reasons why the contractor outputs mentioned above can obtain high WOO scores.

4.2.5. Analysis of three categories of organizational safety behavior

The WSO score of the government is 0.941, with the contractor as the focal organization. This indicates that the government play a critical role in the network, which to some extent ensures the effectiveness of normative organizational safety behavior. As shown in Table 8, in all the top-scoring value cycles, there are a total of 32 value flows of normative organizational safety behavior, with only 2 value cycles not containing them. It can be inferred that value flows of normative organizational safety behavior are crucial for high-scoring value cycles, and the mandatory constraints from the government can ensure the implementation of these value cycles. However, among the top 20 most significant value flows shown in Fig. 5, only 5 are normative organizational safety behaviors. Furthermore, compared with the other two categories of organizational safety behaviors, the average WVFO score of normative organizational safety behaviors is lower. Therefore, the guidance and inspections of the implementation of normative organizational

Table 6
Questionnaire statistics.

No.	Value Flow	Receiver	Creator	Mean	SD
1	O01	Owner	Investigator	0.908	0.033
2	O02	Owner	Designer	0.901	0.035
3	O03	Owner	Supervisor	0.881	0.043
4	O04	Owner	Government	0.808	0.058
5	O05	Owner	Supervisor	0.860	0.047
6	O06	Owner	Contractor	0.850	0.048
7	O07	Owner	Government	0.715	0.080
8	O08	Owner	Government	0.758	0.070
9	O09	Owner	Government	0.785	0.061
10	O10	Owner	Government	0.615	0.103
11	O11	Owner	Supervisor	0.723	0.072
12	C01	Contractor	Owner	0.869	0.052
13	C02	Contractor	Owner	0.719	0.093
14	C03	Contractor	Owner	0.831	0.054
15	C04	Contractor	Owner	0.839	0.058
16	C05	Contractor	Supplier	0.855	0.049
17	C06	Contractor	Supplier	0.870	0.045
18	C07	Contractor	Government	0.829	0.057
19	C08	Contractor	Government	0.853	0.050
20	C09	Contractor	Government	0.854	0.048
21	C10	Contractor	Government	0.853	0.047
22	C11	Contractor	Government	0.865	0.046
23	C12	Contractor	Owner	0.870	0.043
24	C13	Contractor	Owner	0.827	0.054
25	C14	Contractor	Designer	0.814	0.057
26	C15	Contractor	Designer	0.809	0.058
27	C16	Contractor	Supervisor	0.833	0.053
28	C17	Contractor	Supervisor	0.860	0.047
29	C18	Contractor	Government	0.743	0.071
30	C19	Contractor	Government	0.715	0.080
31	C20	Contractor	Government	0.758	0.070
32	C21	Contractor	Owner	0.699	0.086
33	C22	Contractor	Owner	0.806	0.056
34	C23	Contractor	Owner	0.749	0.065
35	C24	Contractor	Government	0.703	0.073
36	C25	Contractor	Government	0.834	0.055
37	C26	Contractor	Government	0.701	0.086
38	C27	Contractor	Government	0.615	0.103
39	C28	Contractor	Government	0.729	0.074
40	G01	Government	Owner	0.822	0.057
41	G02	Government	Owner	0.782	0.070
42	G03	Government	Owner	0.768	0.069
43	G04	Government	Contractor	0.840	0.051
44	G05	Government	Contractor	0.811	0.064
45	G06	Government	Owner	0.709	0.078
46	G07	Government	Public	0.751	0.074
47	I01	Investigator	Owner	0.849	0.058
48	I02	Investigator	Government	0.743	0.071
49	D01	Designer	Owner	0.845	0.059
50	D02	Designer	Government	0.743	0.071
51	D03	Designer	Contractor	0.749	0.072
52	PS01	Supervisor	Owner	0.845	0.056
53	PS02	Supervisor	Government	0.715	0.080
54	PS03	Supervisor	Owner	0.749	0.065
55	S01	Supplier	Contractor	0.858	0.048
56	P01	Public	Investigator	0.875	0.045
57	P02	Public	Contractor	0.813	0.061
58	P03	Public	Contractor	0.854	0.046
59	P04	Public	Contractor	0.861	0.047
60	P05	Public	Owner	0.709	0.078
61	P06	Public	Contractor	0.833	0.055

safety behavior require further enhancement.

In the top-scoring value cycles listed in Table 8, there are a total of 31 value flows of interactive organizational safety behavior, and 4 value cycles without them. This indicates that as coerciveness decreases, the implementation effect of interactive organizational safety behavior is slightly weaker than that of normative organizational safety behavior. However, as shown in Fig. 5, among the top 20 high scoring value flows, there are 11 value flows of interactive organizational safety behavior, accounting for 55%. Therefore, it's undeniable that interactive organizational safety behavior still plays a significant role in the value network. In addition, 8 of the top 11 value flows of interactive organizational safety behavior occurring between the three core organizations, namely, the government, owner and contractor, accounting for 73%. It indicates that the occurrence of interactive organizational safety behavior between core organizations is more frequent. The frequent cooperation between core organizations fosters greater familiarity and a tendency towards greater trust, which will enhance their communication effectiveness and promote the implementation of interactive organizational safety behavior.

Table 7
Numbers of value paths between stakeholders.

Stakeholder	C	D	G	I	O	P	PS	S
C	1110	67	16	72	62	26	104	1
D	90	306	105	204	111	339	231	90
G	153	145	1128	42	42	654	71	153
I	238	303	96	138	42	334	142	238
O	100	172	95	96	1062	333	73	100
P	153	145	1	42	42	654	71	153
PS	260	500	245	324	91	895	427	260
S	2	134	32	144	124	52	208	2

There are only 6 value flows of participative organizational safety behavior in all the top-scoring value cycles listed in Table 8. Furthermore, as can be seen in Fig. 5, only four of the top 20 most significant value flows are linked to participative organizational safety behavior. Besides, one of the 4 value flows has got a high WVFO score only due to its critical position within the value network, without which the value cycle cannot be established. The results indicate that the implementation of participative organizational safety behaviors is far from satisfaction. Organizations have not yet devoted enough attention to participative organizational safety behaviors and are not active in implementing them.

5. Discussion

Based on the three categories of organizational safety behavior and stakeholders involved in construction megaprojects, an OSB-SVN has been created, which provides a visual tool for stakeholders to develop intuitive strategies to enhance the holistic safety value of the entire project. According to the qualitative and quantitative analysis of OSB-SVN model, several strategies are proposed for stakeholders to promote safety value from a network perspective.

To prevent safety accidents, general compliance, which entails adhering to safety policies, laws, regulations and contract rules, is the most fundamental requirements for all stakeholders. Results show that government coercion serve as an effective deterrent against unsafe behavior, but there is still room for improvement. Given the complexity and extended duration of megaprojects, the government should not only continuously revise and clarify safety laws and regulations, but also strengthen supervision and inspection of organizational safety behavior to further promote the implementation effectiveness of normative organizational safety behavior. Apart from safety laws and regulations, contract rules are also vital constraints of organizational safety behavior. Especially in the early stage of megaprojects, for stakeholders without prior working relationship and not familiar with each other, they are inclined to rely on contractual specificity to constraint other stakeholders' safety behavior and improve safety performance of megaprojects (Luo, 2002; Lee and Chong, 2021). Formal contracts specify responsibilities and obligations of stakeholders, which can minimize opportunism and reduce safety risks (Yan and Zhang, 2020). Given high level of uncertainty in megaprojects, in addition to the specificity of contractual terms, contractual contingency adaptability should also be considered when developing contracts (Lee et al., 2020), which allows for change and tolerance when safety needs evolve, or unanticipated safety accidents occur. However, if the contract is not followed rigorously by parties, it will be just a dead letter. Therefore,

Table 8
Top-scoring value cycles of each focal stakeholder (in the row) while containing certain other stakeholder (in the column).

Value cycle	Stakeholder C	D	G	I	O	P	PS	S
C→C	–	C→O06→O→D01→D→C14→C (0.44)	C→G04→G→C11→C (0.71)	C→G04→G→I02→I→O01→O→C01→C (0.37)	C→O06→O→C01→C (0.72)	C→P03→P→G07→G→C11→C (0.18)	C→O06→O→PS01→PS→C17→C (0.47)	C→S01→S→C06→C (0.41)
D→D	(0.44)	–	D→O02→O→G01→G→D02→D (0.41)	D→C14→C→G04→G→I02→I→O01→O→D01→D (0.23)	D→O02→O→D01→D (0.58)	D→C14→C→P03→P→G07→G→D02→D (0.10)	D→O02→O→PS01→PS→C17→C→G04→G→D02→D (0.23)	–
G→G	(0.71)	(0.41)	–	G→I02→I→O01→O→G01→G (0.42)	G→O04→O→G01→G (0.65)	G→C11→C→P03→P→G07→G (0.18)	G→PS02→PS→O03→O→G01→G (0.39)	–
I→I	(0.37)	(0.23)	(0.42)	–	I→O01→O→I01→I (0.59)	I→P01→P→G07→G→I02→I (0.12)	I→O01→O→PS01→PS→C17→C→G04→G→I02→I (0.24)	–
O→O	(0.72)	(0.58)	(0.65)	(0.59)	–	O→C01→C→P03→P→G07→G→O04→O (0.15)	O→PS01→PS→O03→O (0.57)	–
P→P	(0.18)	(0.10)	(0.18)	(0.12)	(0.15)	–	P→G07→G→PS02→PS→C17→C→P03→P (0.10)	–
PS→PS	(0.47)	(0.23)	(0.39)	(0.24)	(0.57)	(0.10)	–	–
S→S	(0.41)	–	–	–	–	–	–	–

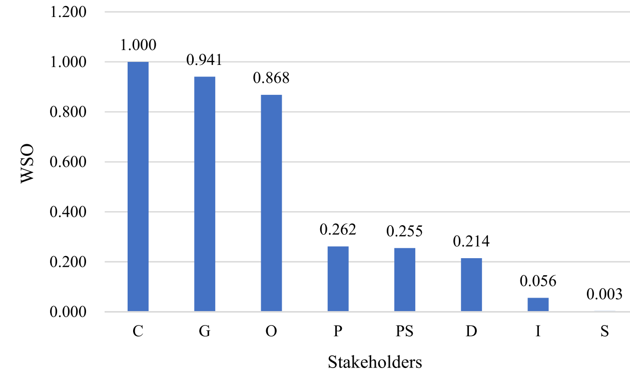

Fig. 4. WSO scores of each stakeholder with the contractor as the focal organizations.

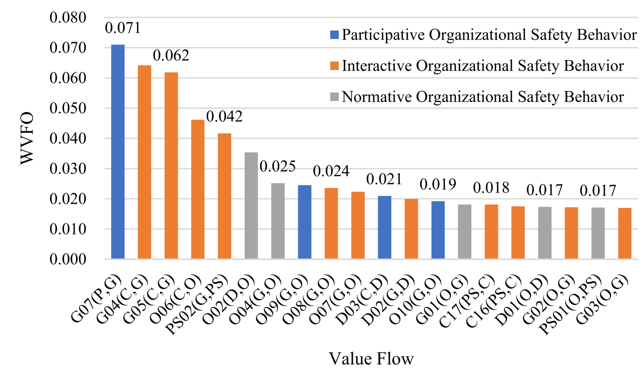

Fig. 5. Top 20 most significant value flows.

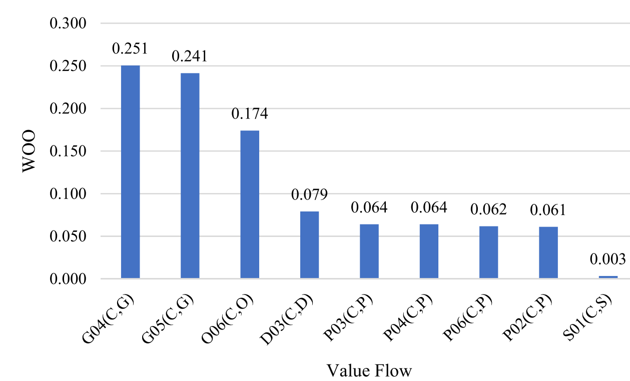

Fig. 6. WOO scores of value flows output by the contractor.

obedience to safety laws, regulations and contract rules is of utmost importance in safety management of megaprojects.

Inter-organizational communication, trust and cooperation are essential to establishing high-scoring safety value cycles. The length of value cycles determinates the extent to which safety value can exchange. A long path of communication can lead to the distortion of safety information, resulting in delayed value deliver and response. This indicates that the close communication and rapid feedback between stakeholders are critical to the effectiveness of effective safety management. Therefore, to enhance the value of low-scoring value paths, it is necessary to streamline the value chain by reducing the number of links and promoting more direct and closer communication between stakeholders. Furthermore, frequent communication is instrumental in fostering trust between stakeholders. In constraining opportunism and achieving project safety goals, trust is proved to be complementary to or even substitute for contracts, which can help overcome some of the inadequacies and limitations of contracts (Cao and Lumineau, 2015). Trust, in turn, facilitates communication, which forms a virtuous circle. Safety information exchange based on trust and communication reduces information asymmetry between stakeholders, thus decreasing the likelihood of opportunism (Galvin et al., 2021). Besides, even when the safety accident occurs, the confidence and reliance on their partners will make the stakeholder willing to report the accidents timely and faithfully, rather than conceal the truth and shirk responsibility, just like what G→C11→C→G04→G demonstrates. Furthermore, trust also strengthens solidarity and cooperation among stakeholders and facilitate the achievement of mutual beneficial agreements (Ruijter et al., 2021), avoiding conflicts and disputes concentrated on safety issues. Due to high level of complexity and innovation and lack of experience of similar projects (Chen et al., 2022), there's a tendency for megaprojects to have unusual potential risks and encounter unpredictable safety accidents. It calls for the joint planning and problem-solving of stakeholders to reduce the chance of accidents. Through effective inter-organizational cooperation, the implementation effectiveness of interactive organizational safety behavior will be enhanced, thus promoting the realization of safety goals of megaprojects.

It's necessary for stakeholders to develop their safety consciousness, especially for the contractor, since it is one of the core and critical stakeholders in megaprojects and participates in the construction process in the most direct way. The analysis of critical stakeholders shows that the government plays a dominant role in the safety network. It reflects the status quo that in China, the implementation of organizational safety behavior has a strong dependency on safety laws, regulations and the supervision of the government, whereas other stakeholders lack the motivation to take spontaneous measures to promote safety performance of megaprojects. Moreover, the analysis of the contractor's important value flows exposes a problem that the current safety management mainly depends on the passive treatment of safety accidents rather than the active prevention of the occurrence, putting the cart before the horse. In addition, the analysis of three categories of organizational safety behavior demonstrates that the implementation effectiveness of participative organizational safety behavior is unsatisfactory, because stakeholders are in lack of recognition of this category of safety behavior and reluctant to implement such behavior spontaneously, which is beneficial to the whole project, but beyond their obligations. The creation and promotion of safety climate has been emphasized as an effective way of improving organizational safety perceptions, consciousness and motivations (He et al., 2020; Maneechaeye and Potipiroon, 2022). To enhance safety climate, safety weeks are suggested to be organized regularly, which include construction site visits, safety promotional campaigns, safety seminars, safety skill training and competitions, etc. (Bronkhorst et al., 2018). Through a series of safety activities, both organizational and individual perception and familiarity of safety knowledge and skills will be enhanced, thus promoting safety consciousness (Wang et al., 2018; Renecle et al., 2021). These safety activities will further strengthen the safety connection and cooperation among stakeholders, promoting safety climate at a project level. Apart from safety weeks, to stimulate the motivation of stakeholders to conduct spontaneous safety behavior, it's recommended to construct a safety incentive system (Meng et al., 2021). For example, the government can give payment and rewards to contractors making prominent contribution to project safety performance. Under the incentive system, safety consciousness will be enhanced remarkably, and contractors are inclined to take initiative and proactive safety behavior even without supervision. When there's a positive safety climate and stakeholders have an in-depth understanding of the meaning and significance of construction safety of megaprojects, they are likely to pay more attention to the achievement of safety goals at the project level and have a stronger sense of responsibility to safety issues, and willing to investing extra efforts engaging in voluntary safety behavior, demonstrating altruism (Wang et al., 2018; Yang et al., 2020). Under the guidance of altruism, stakeholders tend to show more concern for the safety performance of their partners, provide safety suggestions and offer timely assistance to each other in pursuit of collective welfare of the whole project, thus improving the implementation effectiveness of participative organizational safety behavior and enhancing the safety performance of megaprojects ultimately.

6. Conclusions

In megaprojects, the interdependence collaboration of multiple stakeholders in terms of organizational safety behavior is a complicated process, forming an intricate stakeholder value network with numerous safety value flows. To better understand these complex safety value exchange processes and clarify the value delivery mechanism, this study presents a qualitative and quantitative OSB-SVN model based on stakeholder value network (SVN). This model includes 8 stakeholders and 61 value flows. A questionnaire survey was conducted to assign numerical scores to each value flow. Through data-driven stakeholder mapping (DDSM), a total of 13845 value paths, including 4827 value cycles were identified. Key stakeholders, value flows and value paths, as well as organizational safety behavior categories, have been identified to help formulate specific safety value enhancement strategies.

The key findings of this study can be summarized as follows. Firstly, the government, the owner and the contractor are the three critical organizations in the network, respectively fulfilling the roles of inspecting, planning and coordination, and execution. Key value flows in the network have two characteristics: (1) the behavior itself is important; (2) the value flow occupies a critical structural position in the network, which is essential for the formation of the value path. High-scoring value paths originate from strong constraints between stakeholders. Furthermore, they are highly associated with measures taken after the occurrence of accidents, indicating that safety management in China still relies on reactions after safety accidents rather than active prevention beforehand. Secondly, depending on mandatory constraints, normative organizational safety behavior plays the most critical role in the network. The influence of interactive organizational safety behavior is mainly reflected in the interactions between core organizations. However, the implementation of participative organizational safety behavior in the network is not satisfying due to the passive participation of stakeholders in the related activities. Thirdly, to improve the efficiency of organizational safety behavior and enhance the safety value of the whole project, it is crucial to foster general safety compliance, inter-organizational trust, altruism and cooperation and the promotion of stakeholders' safety consciousness.

This study has three main contributions. First and foremost, compared to previous construction safety management research which mainly focused on individual safety behavior, this study concentrated on organizational safety behavior. Specifically, this study further clarified the definition and classification of organizational safety behavior and highlighted the importance of organizational safety behavior to promote overall safety performance of a megaproject, not only contributing to the enrichment of organizational safety behavior field, but also providing a novel research perspective in safety management area. Secondly, the applicability of SVN based on the social exchange theory has been further extended and validated in the context of organizational safety behavior. By applying SVN, this study proposed a new way to visualize and quantify safety value flows existing in the complicated stakeholder network, allowing them to be characterized and compared and helping both researchers and project stakeholders to explore the key value paths in delivering safety value. Furthermore, compared to previous research which rarely considered multi-type (both tangible and intangible, economic and social) value exchanges in the project network, this study took multi-type safety value exchanges into account and emphasized their significance in safety value promotion. Thirdly, based on the identification and analysis of critical stakeholders, safety value flows and value cycles, practical and effective suggestions for megaproject stakeholders to enhance the overall construction safety performance at the project level were developed.

There are three policy and practice implications inferred from the findings of this study. First, this study validated that the organizational safety behavior interactions among stakeholders in megaprojects should be considered as complicated and systematic activities involving numerous safety value exchanges. To enhance safety value at the level of project, it's essential for stakeholders to coordinate their efforts and seek suitable cooperation modes. The proposed OSB-SVN model can help stakeholders have a better understanding of the safety value delivery mechanism in the projects, thus allowing them to engage in effective multilateral cooperation and allocate resources more appropriately to achieve project safety objectives. Second, the implementation effectiveness of three categories of organizational safety behavior not only depends on the coercive measures and restrict constrains among stakeholders, but also rests on the reciprocal relationship among them. Hence, to enhance the implementation effectiveness of organizational safety behavior, apart from the revision and improvement of laws and regulations, the establishment of cooperative relationship and the creation of safety climate by the joint effort of all stakeholders are vital. Third, key value flows and value cycles identified in this study will help both the researchers and project stakeholders to formulate effective value-based strategies on safety performance promotion.

Despite its enlightening results and findings, this study also has certain limitations, which need to be addressed in future research. In terms of methodology, SVN was designed to illustrate value exchanges and structural properties of multi-lateral networks, which has determined that the model is static and can only capture the value distribution at a specific stage. To overcome this limitation, further study should explore a dynamic analysis approach to demonstrate the dynamic value exchange within the complex system over time.

Moreover, this study only considers the main categories of stakeholders in megaprojects, ignoring the detailed sub-classification of each category. For instance, the contractor can be further divided into general contractor and different categories of sub-contractors. To make the OSB-SVN model more accurate and comprehensive, it is suggested that more categories of stakeholders across the lifecycle of megaprojects be included into the model.

Lastly, as this study focused on megaprojects in a Chinese context, the findings may have context-specific limitations and require appropriate adjustments before applying them to other contexts. It is recommended that future research should consider different project ownership, types, delivery methods, and more to enhance the generalizability of the findings.

CRediT authorship contribution statement

Shuang Dong: Writing – review & editing, Writing – original draft, Visualization, Funding acquisition, Conceptualization. **Yan Zhao:** Resources, Formal analysis, Data curation. **Heng Li:** Software. **Jiayi Qu:** Visualization.

Declaration of competing interest

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

Data availability

Data will be made available on request.

Acknowledgements

The authors gratefully acknowledge School of Business at East China University of Science and Technology and the Department of Building and Real Estate at Hong Kong Polytechnic University for providing supports to conduct this research.

References

Ali, M., Aziza, S., Phamb, T.N., Babalolad, M.T., Usmane, M., 2020. A positive human health perspective on how spiritual leadership weaves its influence on employee safety performance: the role of harmonious safety passion. Saf. Sci. 131, 104923.

Ajayi, S.O., Adegbenro, O.O., Alaka, H.A., Oyegoke, A.S., Manu, P.A., 2021. Addressing behavioural safety concerns on Qatari Mega projects. J. Build. Eng. 41, 102398.

Beringer, C., Jonas, D., Kock, A., 2013. Behavior of internal stakeholders in project portfolio management and its impact on success. Int. J. Proj. Manag. 31 (6), 830–846.

Bronkhorst, B., Tummers, L., Steijn, B., 2018. Improving safety climate and behavior through a multifaceted intervention: results from a field experiment. Saf. Sci. 103, 293–304.

Brookes, N.J., Locatelli, G., 2015. Power plants as megaprojects: using empirics to shape policy, planning, and construction management. Util. Pol. 36, 57–66.

Burke, M.J., Sarpy, S.A., Tesluk, P.E., Smith-crowe, K., 2002. General safety performance: a test of a grounded theoretical model. Person. Psychol. 55 (2), 429–457.

Cameron, B.G., Seher, T., Crawley, E.F., 2011. Goals for space exploration based on stakeholder value network considerations. Acta Astronaut. 68, 2088–2097.

Cao, Z., Lumineau, F., 2015. Revisiting the interplay between contractual and relational governance: a qualitative and meta-analytic investigation. J. Oper. Manag. 33, 15–42.

Chen, D., Tian, H., 2012. Behavior based safety for accidents prevention and positive study in China construction project. Procedia Eng. 43, 528–534.

Chen, X., Locatelli, G., Zhang, X., Gong, Y., He, Q., 2022. Firm and project innovation outcome measures in infrastructure megaprojects: an interpretive structural modelling approach. Technovation 109, 102349.

Cheung, C., Zhang, R.P., 2020. How organizational support can cultivate a multilevel safety climate in the construction industry. J. Manag. Eng. 36 (3).

Choudhry, R.M., Fang, D., Ahmed, S.M., 2008. Safety management in construction: best practices in Hong Kong. J. Prof. Issues Eng. Educ. Pract. 134, 20–32.

Choudhry, R.M., Fang, D., 2008. Why operatives engage in unsafe work behavior: investigating factors on construction sites. Saf. Sci. 46 (4), 566–584.

Cui, L., Fan, D., Fu, G., Zhu, C.J., 2013. An integrative model of organizational safety behavior. J. Saf. Res. 45, 37–46.

Daniel, E., Daniel, P.A., 2019. Megaprojects as complex adaptive systems: the Hinkley point C case. Int. J. Proj. Manag. 37, 1017–1033.

Dong, S., Yin, Q., Li, H., 2015. Positive safety participation and assessment by integrating sharing technology with virtual reality. Procedia Eng. 123, 125–134.

Fang, D., Wu, H., 2013. Development of a safety culture interaction (SCI) model for construction projects. Saf. Sci. 57, 139–149.

Fang, D., Zhao, C., Zhang, M., 2016. A cognitive model of construction workers' unsafe behaviors. J. Construct. Eng. Manag. 142 (9), 04016039.

Feng, W., 2013. Strategic Management for Large Engineering Projects: the Stakeholder Value Network Approach. Massachusetts Institute of Technology. PhD Thesis Cambridge, MA: Dept. of Engineering System Division.

Feng, Y., Teo, E.a.L., Ling, F.Y.Y., Low, S.P., 2014. Exploring the interactive effects of safety investments, safety culture and project hazard on safety performance: an empirical analysis. Int. J. Proj. Manag. 32, 932–943.

Flyvbjerg, B., 2014. What you should know about megaprojects and why: an overview. Proj. Manag. J. 45 (2), 6–19.

Fu, F., Feng, W., Li, Z., Crawley, E.F., Ni, W., 2011. A network-based modeling framework for stakeholder analysis of China's energy conservation campaign. Energy 36, 4996–5003.

Galvin, P., Tywoniak, S., Sutherland, J., 2021. Collaboration and opportunism in megaproject alliance contracts: the interplay between governance, trust and culture. Int. J. Proj. Manag. 39 (4), 394–405.

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.

Hannevik, M.B., Lone, J.A., Bjørklund, R., Bjørkli, C.A., Hoff, T., 2014. Organizational climate in large-scale projects in the oil and gas industry: a competing values perspective. Int. J. Proj. Manag. 32 (4), 687–697.

He, C., McCabe, B., Jia, G., Sun, J., 2020. Effects of safety climate and safety behavior on safety outcomes between supervisors and construction workers. J. Construct. Eng. Manag. 146 (1), 04019092.

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.

Heinrich, H.W., 1941. Industrial Accident Prevention. A Scientific Approach, second ed. McGraw-Hill, New York and London.

Hu, Y., Chan, A.P., Le, Y., 2015. Understanding the determinants of program organization for construction megaproject success: case study of the Shanghai Expo construction. J. Manag. Eng. 31 (5), 05014019.

Jitwasinkul, B., Hadikusumo, B.H.W., Memon, A.Q., 2016. A Bayesian Belief Network model of organizational factors for improving safe work behaviors in Thai construction industry. Saf. Sci. 82, 264–273.
Kalkman, J.P., Dewaard, E.J., 2017. Inter-organizational disaster management projects: finding the middle way between trust and control. Int. J. Proj. Manag. 35 (5), 889–899.
Kalteh, H.O., Mortazavi, S.B., Mohammadi, E., Salesi, M., 2021. The relationship between safety culture and safety climate and safety performance: a systematic review. Int. J. Occup. Saf. Ergon. 27 (1), 206–216.
Kim, N.K., Rahim, N.F.A., Iranmanesh, M., Foroughi, B., 2019. The role of the safety climate in the successful implementation of safety management systems. Saf. Sci. 118, 48–56.
Koh, T.Y., Rowlinson, S., 2012. Relational approach in managing construction project safety: a social capital perspective. Accid. Anal. Prev. 48, 134–144.
Lee, C.Y., Chong, H.Y., 2021. Influence of prior ties on trust and contract functions for BIM-enabled EPC megaproject performance. J. Construct. Eng. Manag. 147 (7), 04021057.
Lee, C.Y., Chong, H.Y.J., Li, Q., Wang, X., 2020. Joint contract-function effects on BIM-enabled EPC project performance. J. Construct. Eng. Manag. 146 (3).
Lehtinen, J., Peltokorpi, A., Artto, K., 2019. Megaprojects as organizational platforms and technology platforms for value creation. Int. J. Proj. Manag. 37 (1), 43–58.
Li, H., Lu, M., Hsu, S., Gray, M., Huang, T., 2015. Proactive behavior-based safety management for construction safety improvement. Saf. Sci. 75, 107–117.
Liu, Q., Xu, N., Jiang, H., Wang, S., Wang, W., Wang, J., 2020. Psychological driving mechanism of safety citizenship behaviors of construction workers: application of the theory of planned behavior and norm activation model. J. Construct. Eng. Manag. 146 (4), 04020027.
Liu, X., Wang, X., Zhao, Y., Xia, N., Guo, S., 2020. Solving workplace deviant behavior in construction by leader–member exchange and leader–member guanxi. J. Construct. Eng. Manag. 146 (6), 04020061.
Lu, Y., Taksa, L., Jia, H., 2020. Influence of management practices on safety performance: the case of mining sector in China. Saf. Sci. 132, 104947.
Luo, L., Yang, Y., Zheng, J., Xie, J., 2022. Measuring project governance of mega infrastructure in China: a scale development study. Sustainability 14 (2), 593.
Luo, Y., 2002. Contract, cooperation, and performance in international joint ventures. Strat. Manag. J. 23 (10), 903–919.
Ma, L., Zhang, P., Li, N., Fang, D., 2020. Owners' safety management behaviors in construction. In: Construction Research Congress 2020: Safety, Workforce, and Education. American Society of Civil Engineers, Reston, VA, pp. 258–267.
Maneechaeye, P., Potipiroon, W., 2022. The impact of fleet-level and organization-level safety climates on safety behavior among Thai civilian pilots: the role of safety motivation. Saf. Sci. 147, 105614.
Manu, P., Ankrah, N., Proverbs, D., Suresh, S., 2010. An approach for determining the extent of contribution of construction project features to accident causation. Saf. Sci. 48, 687–692.
Meng, X., Chan, A.H.S., Lui, L.K.H., Fang, Y., 2021. Effects of individual and organizational factors on safety consciousness and safety citizenship behavior of construction workers: a comparative study between Hong Kong and Mainland China. Saf. Sci. 135, 105116.
Mohajeri, M., Ardeshir, A., Malekitabar, H., Rowlinson, S., 2021. Structural model of internal factors influencing the safety behavior of construction workers. J. Construct. Eng. Manag. 147 (11), 04021156.
Nævestad, T., Hesjevoll, I.S., Elvik, R., 2021. How can regulatory authorities improve safety in organizations by influencing safety culture? A conceptual model of the relationships and a discussion of implications. Accid. Anal. Prev. 59, 106228.
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.
Newaz, M.T., Davis, P., Jefferies, M., Pillay, M., 2019. The psychological contract: a missing link between safety climate and safety behaviour on construction sites. Saf. Sci. 112, 9–17.
Olander, S., 2007. Stakeholder impact analysis in construction project management. Construct. Manag. Econ. 25 (3), 277–287.
Pereira, B.M., Senna, L.A.S., Lindau, L.A., 2018. Stakeholder value network: modeling key relationships for advancing towards high quality bus transit systems. Res. Transport. Econ. 69, 386–393.
Qiu, Y., Chen, H., Sheng, Z., Cheng, S., 2019. Governance of institutional complexity in megaproject organizations. Int. J. Proj. Manag. 37 (3), 425–443.
Renecle, M., Curcuruto, M., Lerín, F.J.G., Marco, I.T., 2021. Enhancing safety in high-risk operations: a multilevel analysis of the role of mindful organising in translating safety climate into individual safety behaviours. Saf. Sci. 138, 105197.
Ruijter, H., van Marrewijk, A., Veenswijk, M., Merkus, S., 2021. 'Filling the mattress': trust development in the governance of infrastructure megaprojects. Int. J. Proj. Manag. 39 (4), 351–364.
Son, J.W., Rojas, E.M., 2011. Evolution of collaboration in temporary project teams: an agent-based modeling and simulation approach. J. Construct. Eng. Manag. 137 (8), 619–628.
Sutherland, T.A., 2009. Stakeholder value network analysis for space-based earth observations. Master's Thesis Cambridge, MA: Dept. Of Aeronautics and Astronautics and Engineering Systems Division. Massachusetts Institute of Technology.
Sutherland, T.A., Cameron, B.G., Crawley, E.F., 2012. Program goals for the NASA/NOAA Earth Observation Program derived from a stakeholder value network analysis. Space Pol. 28, 259–269.
Wang, G., He, Q., Xia, B., Meng, X., Wu, P., 2018. Impact of institutional pressures on organizational citizenship behaviors for the environment: evidence from megaprojects. J. Manag. Eng. 34 (5), 1–11.
Wang, G., Zhou, K., Wang, D., Wu, G., Xie, J., 2021. Tensions in governing megaprojects: how different types of ties shape project relationship quality? Int. J. Proj. Manag. 39, 799–814.
Wang, M.D., Sun, J., Du, H., Wang, C., 2018. Relations between safety climate, awareness, and behavior in the Chinese construction industry: a hierarchical linear investigation. Adv. Civ. Eng. 1–8.
Wang, Y., Thangasamy, V.K., Hou, Z., Tiong, R.L.K., Zhang, L., 2020. Collaborative relationship discovery in BIM project delivery: a social network analysis approach. Autom. ConStruct. 114, 103147.
Weichbrodt, J., 2015. Safety rules as instruments for organizational control, coordination and knowledge: implications for rules management. Saf. Sci. 80, 221–232.
Wu, C., Fang, D., Li, N., 2015. Roles of owners' leadership in construction safety: the case of high-speed railway construction projects in China. Int. J. Oper. Prod. Manag. 33 (8), 1665–1679.
Wu, C., Wang, F., Zou, P.X., Fang, D., 2016. How safety leadership works among owners, contractors and subcontractors in construction projects. Int. J. Proj. Manag. 34 (5), 789–805.
Xia, N., Xie, Q., Griffin, M.A., Ye, G., Yuan, J., 2020. Antecedents of safety behavior in construction: a literature review and an integrated conceptual framework. Accid. Anal. Prev. 148, 105834.
Xia, N., Zou, P.X.W., Griffin, M.A., Wang, X., Zhong, R., 2018. Towards integrating construction risk management and stakeholder management: a systematic literature review and future research agendas. Int. J. Proj. Manag. 36 (5), 701–715.
Yang, Q., Yao, T., Lu, T., Zhang, B., 2014. An overlapping-based design structure matrix for measuring interaction strength and clustering analysis in product development project. IEEE Trans. Eng. Manag. 61, 159–170.
Yang, D., He, Q., Cui, Q., Hsu, S.C., 2020. Non-economic motivations for organizational citizenship behavior in construction megaprojects. Int. J. Proj. Manag. 38 (1), 64–74.
Yan, L., Zhang, L., 2020. Interplay of contractual governance and trust in improving construction project performance: dynamic perspective. J. Manag. Eng. 36 (4), 04020029.
Yiu, N.S.N., Chan, D.W.M., Shan, M., Sze, N.N., 2019. Implementation of safety management system in managing construction projects: benefits and obstacles. Saf. Sci. 117, 23–32.
Zhang, P., Li, N., Fang, D., Wu, H., 2017. Supervisor-focused behavior-based safety method for the construction industry: case study in Hong Kong. J. Construct. Eng. Manag. 143 (7), 05017009.
Zheng, X., Chen, J., Han, Y., Ren, L., Shi, Q., 2021. Unveiling complex relational behavior in megaprojects: a qualitative-quantitative network approach. Int. J. Proj. Manag. 39, 738–749.
Zheng, X., Le, Y., Chan, A.P.C., Hu, Y., Li, Y., 2016. Review of the application of social network analysis (SNA) in construction project management research. Int. J. Proj. Manag. 34, 1214–1225.
Zheng, X., Lu, Y., Li, Y., Le, Y., Xiao, J., 2019. Quantifying and visualizing value exchanges in building information modeling (BIM) projects. Autom. ConStruct. 99, 91–108.
Zhou, S., Zhai, G., Lu, Y., Shi, Y., 2021. The development of urban mega-projects in China: a case study of Nantong's metro project. Environ. Plan. B Urban Anal. City Sci. 48 (4), 759–774.